CN101413905B

X ray differentiation interference phase contrast imaging system

Abstract

The invention relates to an X-ray differential interference phase contrast imaging system, which is applicable to the fields such as medicine and nondestructive flaw detection, and the like. According to the transmission direction of X-ray, the system consists of an X-ray tube, a filter, a sample platform, a phase grating and an X-ray detector; the system also comprises a micro-computer and matched system management software. The key point is that (1) the X-ray tube adopted in the system is provided with a plurality of coherent high-energy X-ray emitters which are distributed linearly in parallel and have the emission angle of 30-50 degrees; (2) the adopted X-ray detector has dual functions of an analysis grating and a detector; the system basically consists of a parallel array-typed X-ray conversion screen, a relay optical system and a flat-panel detector or a parallel array-typed photoelectron-conductive X-ray detector; the structure and the dimension of the X-ray conversion screen or the photoelectron-conductive X-ray detector are correspondingly matched with the structure and the dimension of the coherent and high-energy X-ray light sources and the phase grating distributed linearly in parallel in the X-ray tube.

(19)中华人民共和国国家知识产权局

(12)发明专利

(10)授权公告号 CN 101413905 B
(45)授权公告日 2011.03.16

(21)申请号 200810216469.3

(22)申请日 2008.10.10

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(51)Int.Cl.
G01N 23/04(2006.01)
A61B 6/03(2006.01)
G03B 42/02(2006.01)

(56)对比文件
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审查员 孙苋

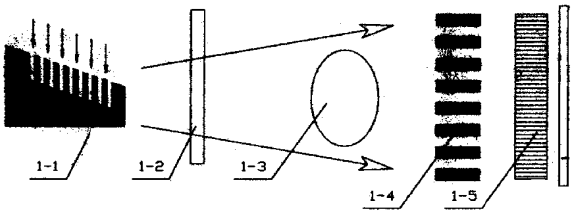
权利要求书 2 页 说明书 6 页 附图 3 页

(54)发明名称

X射线微分干涉相衬成像系统

(57)摘要

本发明涉及一种X射线微分干涉相衬成像系统。适用于医学和无损探伤等领域。系统组成中按照X射线传播方向包括X射线管、滤波器、样品台、相位光栅及X射线探测器,系统中还包括微机和配套的系统管理软件,关键在于:①系统中采用的X射线管中具有呈平行线状分布的、相干高能X射线发射体,发射角为30—50度。②所采用的X射线探测器具有分析光栅和探测器的双重功能,基本组成中包括平行线阵列式X射线转换屏、中继光学系统和面阵探测器或包括平行线阵列式光电导X射线探测器,X射线转换屏或光电导X射线探测器其结构组成和尺寸与上述X射线管中呈平行线状分布的、相干高能X光源及相位光栅对应配套。



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1. 一种 X 射线微分干涉相衬成像系统，系统组成中按照 X 射线传播方向依次排序、包括 X 射线管 (1-1)、滤波器 (1-2)、样品台 (1-3)、相位光栅 (1-4) 及 X 射线探测器 (1-5)，系统中还包括微机和配套的系统管理软件，其特征在于：

①所采用的 X 射线管中具有呈平行线状分布的、相干高能 X 射线发射体，发射角为 30-50 度；

②所采用的 X 射线探测器具有分析光栅和探测器的双重功能，基本结构中由平行线阵列式 X 射线转换屏、中继光学系统和面阵探测器构成或由光电导 X 射线探测器构成，X 射线转换屏或光电导 X 射线探测器其结构组成和尺寸与上述 X 射线管中呈平行线状分布的、相干高能 X 射线发射体及相位光栅对应配套。

2. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征在于所采用的 X 射线管是连续工作模式、或脉冲工作模式，以上工作模式通过对设置在电子源或离子源与结构阳极之间的栅极进行控制，实现对 X 射线的连续或脉冲模式 X 射线的输出。

3. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征在于 X 射线探测器的基本结构中，包括：平行线阵列式 X 射线转换屏 (6-1)、中继光学系统 (6-2) 和面阵探测器 (6-3)，其中平行线阵列式 X 射线转换屏的平行线条周期结构决定于 X 射线衍射传输参数，在每一周期内，每个周期由条带状的敏感区和非敏感区组成，非敏感区在垂直于周期结构的方向上的整个长度由对入射 X 射线不敏感的非荧光材料构成，而敏感区在垂直于周期结构的方向上整个长度被分离成一条矩形像素阵列，在每一像素区内填充对入射的 X 射线具有高灵敏度的荧光材料。

4. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征是所述的 X 射线探测器的基本结构由光电导 X 射线探测器构成，光电导 X 射线探测器具有由光电导材料制成的独立单元组合形成的平行线周期结构，该结构与上述 X 射线转换屏的结构相一致，决定于 X 射线衍射传输参数。

5. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征在于 X 射线探测器的阵列式 X 射线转换屏中独立像素区具有结构，周期节距 (P_2) 满足分析光栅的结构关系式 $P_2 = 0.5P_1(L+d_n)/L$，其中 P_1 为相位光栅周期节距，L 为 X 射线源到相位光栅的距离，d_n 为修正后的泰伯成像距离，每个独立像素区尺寸宽度 (b) 为不大于 0.5 倍的周期节距 (P_2)，长度 (a) 为 0.5-10 倍的周期节距 (P_2)。

6. 根据权利要求 3 所述的 X 射线微分干涉相衬成像系统，其特征在于所述的非荧光材料是硅、锗半导体材料或铝、不锈钢金属材料或玻璃材料，非荧光材料分割的像素区内填充的荧光材料是：CsI:Tl 或 CsI:Na 或 Gd_2O_2S:Tb，在 X 射线激发下能产生可见或近红外光的荧光物质。

7. 根据权利要求 3 所述的 X 射线微分干涉相衬成像系统，其特征在于所述的中继光学系统可由光锥、纤维面板、光锥与纤维面板的组合或光学透镜组成。

8. 根据权利要求 4 所述的 X 射线微分干涉相衬成像系统，其特征在于所述的光电导材料是非晶硒、碘化汞或碘化铅，在光电导材料上转换形成的像素信号借助聚焦点激光束或聚焦线激光束逐点或逐行读出。

9. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征在于所述的具有分析光栅和探测器双重功能的 X 射线探测器的基本结构由玻璃基底 (2-1)、介质材料 (2-2)、透

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明电极 (2-3)、光电导材料 (2-4) 和电极 (2-5) 组成，光电导材料是用非晶硒、或碘化汞、或碘化铅制取，其中透明电极 (2-3) 的宽度 T 与电极之间的介质材料 (2-2) 的宽度之和等于光栅干涉条纹周期 P，光电导材料信号输出是用聚焦点激光束或聚焦线激光束逐点或逐行读出。

10. 根据权利要求 1 所述的 X 射线微分干涉相衬成像系统，其特征在于所采用的 X 射线管发出的 X 射线光谱范围在 5-120keV，所述的相位光栅用硅或铝材料制成、通过改变光栅的厚度使其中心波长对应的光子能量可在 7-100keV 范围内调节，允许的 X 射线带宽 ±20%，所述的滤波器用铝、钨或铝材料制成，由 X 射线管发出的 X 射线通过滤波器后使 X 射线的中心波长和带宽与相位光栅允许的参数相匹配，所述的 X 射线源、滤波器、样品台、相位光栅、X 射线探测器配套有共轴和轴向相对位置精密调节机构。

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X 射线微分干涉相衬成像系统

技术领域

[0001] 本发明涉及一种 X 射线微分干涉相衬成像系统。

[0002] 技术背景

[0003] 无损伤成像探测技术在医学、生命科学、材料科学、工业应用及安检等领域有着广泛的应用，占有重要的地位。X 射线成像是其中最重要的方法之一。传统的 X 射线成像是基于物体对 X 射线的吸收特性而实现的，它利用物体内部不同部位对 X 射线的吸收不同形成衬度图像。当利用 X 射线对弱吸收物体即轻元素构成的物体成像时，由于物体各部分对输入的 X 射线吸收很少，彼此之间所表现出的吸收差异不能形成探测器可识别的吸收衬度，无法获取足够对比度的吸收图像。特别是在医学和生物学领域，如人体的血管、乳房组织、空腔器官组织、肿瘤等等由轻元素为主组成的软组织都是弱吸收物体，传统的 X 射线吸收成像方法难以获得高对比度图像。在医学领域人们只能获得由重元素组成的像骨组织的高对比度吸收图像。

[0004] X 射线相衬成像是利用 X 射线透过检测物体时，不同部位 X 射线相位发生的变化形成图像对比度来实现成像的。由于轻元素组成的物质的相移因子比吸收因子高三个数量级以上，X 射线通过物体后由于相移导致的强度变化要比吸收导致的强度变化大很多。例如，X 射线相衬技术在理论上可分辨密度变化为 0.0003—0.002g/cm^3 的不同组织 边界，空间分辨率可小于 1μm。目前被认为是软组织医用检查最好的方法—MRI，可分辨的密度变化为 0.01g/cm^3，空间分辨率仅为 1—2mm。而且 X 射线相衬成像探测到的是相位信息，可以减少样品对 X 射线的吸收，还可提高所获得的图像的对比度和分辨率，显然这对人体而言是十分有益的。

[0005] 实现 X 射线相衬成像需要相干性好、辐射通量高的 X 射线源。同步辐射源在一定程度上可满足这种要求，目前许多 X 射线相衬成像实验都是在同步辐射源上完成的。但同步辐射源体积庞大、成本昂贵，不便或无法应用于许多实际场合。尤其对人体相衬成像而言，现有的同步辐射源难以提供所必需的 40-70keV 的光子能量。

[0006] 基于 X 射线管的 X 射线相衬成像技术目前还处于研究和发展阶段。一种是基于微焦斑 X 射线管为光源的同轴相衬成像技术，另一种是基于光栅的微分干涉相衬成像技术。前者由于散热等问题，微焦斑源难以提供 X 射线相衬成像所要求的足够高的辐射通量，从而使其应用受到极大的限制，几乎无法用于普通医院或其它在线检测场合。后者是利用普通所用的低亮度 X 射线管为光源的微分干涉相衬成像技术。为了使所用的 X 射线源满足一维空间相干性，上述方法必须在所使用的低亮度 X 射线管之后引入一 X 射线吸收光栅，同时还要在 X 射线相位光栅之后使用另一吸收光栅作为分析光栅。由于工艺和其它原因，吸收光栅不可能做的太厚，使所用的 X 射线光子能量不能超过 30-40keV，也无法用于普通医院和许多其它在线检测场合。

[0007] 为了实现 X 射线微分干涉相衬成像，首先需要解决的问题是配套 的新型 X 射线管。它所发射的 X 射线应具有良好的空间相干性、高的辐射通量和宽的发射角。这种 X 射线管或者通过电子束或离子束轰击结构阳极，或者通过结构电子束或离子束轰击无结构阳

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极，形成呈平行线排列的 X 射线的线状发射体。各线状发射体发出的 X 射线束具有大的发射角，因而各射线束相互交叠共同作用于物体，满足成像光照的要求。以上所述的 X 射线管已经被深圳大学研究设计成功，可以参考文献 200610062487.1。

[0008] 为了实现 X 射线微分干涉相衬成像，需要解决的另一个问题是在不采用 X 射线分析光栅的情况下如何完成微分干涉相衬成像中的分析光栅功能？这种分析光栅的功能可由新型 X 射线探测器完成。此 X 射线探测器在一维空间上具有周期性结构，其周期结构尺寸同通常的分析光栅；探测器的每个周期由条带状的敏感区和非敏感区组成，这里的敏感是指对 X 光敏感。非敏感区在垂直于周期结构的方向上整个长度对入射的 X 射线不敏感，而敏感区在垂直于周期结构的方向上整个长度被分离成许多像素，每个像素对入射的 X 射线具有高的灵敏度。敏感区和非敏感区的宽度之和应严格等于 X 射线干涉条纹的周期。这种 X 射线探测器同时具备通常分析光栅和通常探测器的双重功能。

发明内容

[0009] 本发明的目的是在新型 X 射线管和新型 X 射线探测器的设计基础上，提供一种 X 射线微分干涉相衬成像系统的设计方案。

[0010] 现在的研究成果证明，为使低亮度的 X 射线管所产生的 X 射线满足一维空间相干性，在尽可能靠近该 X 射线源的位置放置一 X 射线吸收光 栅，使通过此光栅的 X 射线具有一维空间相干性。该系统在被检测的物体之后设置一个相位光栅，在泰伯 (Talbot) 成像距离处再放置一吸收光栅，此相位光栅和吸收光栅的走向与 X 射线源处的吸收光栅走向相一致。但是上述技术的最主要缺点是它需要使用两个吸收光栅，一个用来形成一维空间相干的 X 射线源，一个用作分析光栅，再借助具有高空间分辨率的 X 射线探测器可以获得被检物体的相衬图像。由于随着 X 射线光子能量的提高，给吸收光栅制作工艺带来了难以克服的困难，还给成像系统带来其它严重问题，如视场问题、辐射通量问题、图像失真问题等。正由于如此，尽管基于低亮度 X 射线源的微分干涉相衬成像原理已被公认多年，并获得了对小而薄的动物的高质量相衬实验图像，但在其走向实用化的过程中遇到了巨大的挑战，至今仍无法应用于医学诊断等实际领域。

[0011] 本发明所采用的方案不再利用吸收光栅形成一维空间相干的 X 射线源，也不再利用吸收光栅作为分析光栅。在本系统中，利用发明人所设计的一种 X 射线管制成 X 射线源。这种 X 射线源可同时满足一维空间相干性、大辐射通量、高光子能量和宽发射角等要求。同时，系统中还利用我们所发明的一种新型 X 射线探测器用于记录相衬图像。该探测器在一维空间上具有周期性结构，其周期结构尺寸等同于常规的分析光栅；探测器的每个周期由条带状的敏感区和非敏感区组成，这里的敏感是指对 X 光敏感。非敏感区在垂直于周期结构的方向上整个长度对入射的 X 射线不敏感，而敏感区在垂直于周期结构的方向上整个长度被分离成许多像素，每个像素对入射的 X 射线具有高的灵敏 度。敏感区和非敏感区的宽度之和应严格等于 X 射线干涉条纹的周期。该探测器同时具备通常分析光栅和通常探测器的双重功能，同样可利用莫尔效应或相移法获得物体的高空间分辨相衬图像。

[0012] 按照 X 射线在系统中的传播方向，系统组成中包括设置的 X 射线管、滤波器、样品台、相位光栅及 X 射线探测器，还包括微机和配套的系统管理软件，

[0013] ①所采用的 X 射线管中具有焦斑呈平行线状分布的、相干高能 X 射线发射体，发射

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角为 30—50 度；

[0014] ②所采用的 X 射线探测器具有分析光栅和探测器的双重功能，基本结构中包括平行线阵列式 X 射线转换屏、中继光学系统和面阵探测器或光电导 X 射线探测器，X 射线转换屏或光电导 X 射线探测器的结构组成和尺寸与上述 X 射线管及 X 射线相位光栅对应配套。

[0015] 本发明的主要创新有两点。一是本发明人所发明的 X 射线管。该 X 射线管所发射的 X 射线呈平行线状分布，不再需要外设的吸收光栅。其工作电压为 40-120kV。利用发明人所设计的滤波器与该 X 射线管相结合，所产生的 X 射线中心波长对应的光子能量可在 20-100keV 范围内变化，带宽 ±20％。所发明的 X 射线管具有一维空间相干性、大的辐射通量、高的光子能量和宽的发射角，从而为 X 射线微分干涉相衬成像系统提供一种实用化的 X 射线源。本发明的第二个主要创新点是发明人所配套设计的新型 X 射线探测器。它在一维空间上具有与 X 射线管周期参数相对应的结构，其周期同通常探测器处的分析光栅。本发明提供的探测器的每个周期由条带状的敏感区和非敏感区组成，这 里的敏感是指对 X 光敏感。非敏感区在垂直于周期结构的方向上整个长度对入射的 X 射线不敏感，而敏感区在垂直于周期结构的方向上整个长度被分离成许多像素，每个像素对入射的 X 射线具有高的灵敏度。敏感区和非敏感区的宽度之和应严格等于 X 射线干涉条纹的周期。以上结构的 X 射线探测器同时具有通常分析光栅和通常探测器的双重功能。这样就避免了制作吸收分析光栅的难度，同时也使因厚的吸收光栅和厚的分析光栅同时引入系统而导致的难以克服的弊端。

[0016] 本发明提供一种具有分析光栅功能的新型 X 射线探测器，探测器具有一维空间周期结构。成像时探测器周期方向同 X 射线相位光栅干涉条纹方向，并且其周期节距同干涉条纹的周期节距，在单个周期内，探测器的半个周期对入射的 X 射线不敏感，相当于普通探测器前加上一个 100％吸收率的分析光栅，另半个周期为 X 射线的有效探测部分，探测器结构同光栅干涉条纹形成莫尔 (Moire) 条纹。将探测器和分析光栅结合为一个光学器件，不仅减少了系统中 X 射线光学元件的个数，降低了系统复杂性，更重要的是避免了制作吸收光栅的高难度。随着 X 射线光子能量的提高，吸收光栅的制作难度越来越大，当将其用于医学等方面的成像时，分析光栅的厚度将大于 300 微米，而其线条宽度只有 1 微米左右，深宽比高达 300 以上，目前已有的工艺很难实现大面积高深宽比分析光栅的制作。

[0017] 根据上述方法和原理，本发明提供一种 X 射线管装置，它由电子或离子发射体、栅极、静电聚焦电极、结构阳极靶等组成。结构阳极由高 Z 元素如钨、钼等和低 Z 元素如铝、铍等金属带材或体材构成。 高 Z 和低 Z 带状材料或体状材料再加工成所需要的结构后作相间排列，结构件的端面倾角作反方向排布。结构阳极面向电子束或离子束的总面积取决于电子束或离子束的截面大小，一般小于 $1mm^2$。

[0018] 本发明提供的第二种 X 射线管装置由电子或离子发射体、聚焦系统、静电偏转系统和常规无结构阳极组成。电子束或离子束经聚焦后在阳极上形成微束斑电子束或离子束，该电子束或离子束经偏转系统使微束斑电子束或离子束在阳极上扫描，所形成的落点分布形成线宽为束斑直径的平行线结构。

[0019] 本发明提供的第三种 X 射线管装置由结构发射体、栅极、聚焦电极、无结构阳极组成。其中，结构发射体是指所用电子源或离子源可以产生线宽为 0.005-0.1mm 的平行线结构的电子束或离子束。

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[0020] 本发明提供的第四种 X 射线管装置由电子或离子发射体、多缝加速电极、聚焦电极、无结构阳极靶组成。电子或离子发射体产生的电子束或离子束通过多缝加速电极后形成平行线电子束或离子束，在阳极处形成有如多缝光栏结构的电子束或离子束。

[0021] 本发明提供一种栅极控制电路，对电子束或离子束连续或脉冲状态进行控制，实现对 X 射线的连续或脉冲辐射模式的控制。

[0022] 本发明提供一种 X 射线探测器装置，该探测器由转换屏和信号读出装置组成。转换屏基底材料为硅，采用各种刻蚀方法在硅材料上形成所需结构的阵列孔，氧化后或在阵列孔内蒸镀全反射膜后在阵列孔中填充 X 射线转换材料，将 X 射线转换为光信号。利用光学耦合系统和 CCD 或 CMOS 面阵探测器将光信号读出。

[0023] 本发明提供第二种 X 射线探测器装置，该探测器为光电导 X 射线探测器，其几何结构同第一种探测器转换屏结构，所不同的是用光电导材料构成，将 X 射线转换为电信号，利用电信号读出装置将图像读出。

[0024] 本发明提供一种 X 射线微分干涉相衬成像系统，系统包括 X 射线光源、X 射线滤波器、样品台、X 射线相位光栅和 X 射线探测器。X 射线源由本发明的 X 射线管构成，所产生的 X 射线经滤波器后使 X 射线满足中心波长和带宽的要求；X 射线相位光栅按照中心波长和带宽要求设计，并置于 5 维精密调节架上。成像物体位于 X 射线源和相位光栅之间，贴近相位光栅。X 射线探测器为本发明所提供的探测器。成像时 X 射线管线发射体走向、相位光栅走向和 X 射线探测器一维空间结构走向符合成像要求。

[0025] 本发明提供第二种 X 射线微分干涉相衬成像系统，采用本发明的其它结构的 X 射线管构成的 X 射线源，系统其它装置同本发明第一种成像系统。

[0026] 本发明提供第三种 X 射线微分干涉相衬成像系统，采用本发明的其它 X 射线探测器，系统其它装置同本发明第一种成像系统。

附图说明

[0027] 图 1 本发明的系统组成示意图

[0028] 图 2 光栅干涉条纹式 X 射线探测器实施例的结构示意图

[0029] 图 3X 射线探测器中转换屏局部结构俯视图

[0030] 图 4X 射线探测器中转换屏局部剖视立体图

[0031] 图 5 是图 4 填充 X 射线敏感材料后的局部剖面示意图

[0032] 图 6 采用光锥耦合的 X 射线探测器结构示意图

[0033] 附图中的图 1 给出一种微分干涉相衬成像系统的示意图，系统中包括：具有线阵列结构 X 射线源的 X 射线管 1-1、带通 X 射线滤波器 1-2、样品台 1-3、X 射线相位光栅 1-4 及一维空间周期性结构探测器 1-5。图 2 是一种光电导材料构成的 X 射线探测器实施例的结构示意图，由玻璃基底 2-1、介质材料 2-2、结构中包括透明电极 2-3、光电导材料 2-4 和电极 2-5 组成；其中的 T 代表透明电极 2-3 的宽度。图 3 是另一种 X 射线探测器实施例中转换屏的局部结构示意图，X 射线荧光材料被非荧光材料分割为阵列型多个象素单元，象素单元宽度为 b，阵列沿一维空间 X 轴向的周期为 P_2。象素单元长度为 a，阵列 Y 轴向周期为 c，长度 c 的范围为 $(0.5\text{-}10)P_2$。图 6 是采用光锥耦合的 X 射线探测器结构示意图，包括转换屏 6-1、光锥 6-2 及阵列 CCD 或 CMOS 探测器 6-3。

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[0034] 下面结合附图进一步说明本发明的目的是如何实现的。

具体实施方式

[0035] 结合全部附图可以看出，本系统组成中按照 X 射线传播方向包括 X 射线管 1-1、滤波器 1-2、样品台 1-3、相位光栅 1-4 及 X 射线探测器 1-5，系统中还包括微机和配套的系统管理软件，关键在于：

[0036] ①所采用的 X 射线管中具有焦斑呈平行线状分布的、相干高能 X 射线发射体，发射角为 30—50 度，

[0037] ②所采用的 X 射线探测器具有分析光栅和探测器的双重功能，基 本结构中包括平行线阵列式 X 射线转换屏、中继光学系统、面阵探测器或光电导 X 射线探测器，X 射线转换屏或光电导 X 射线探测器结构组成和尺寸与上述 X 射线管中呈平行线状分布的、相干高能 X 射线发射体对应配套。

[0038] 以上所采用的特别研制的 X 射线管，能产生具有良好的空间相干性、大辐射通量和宽发射角的 X 射线束。其中发明人提出了 X 射线束线发射体阵列的概念，即 X 射线束的发射体是一簇平行线阵列，每条线都是一个 X 射线束的线源，其线宽范围为 5 ～ 100 微米，最佳化数值范围是 10 ～ 20 微米；其长度范围为 0.3 ～ 2mm，优化范围是 0.6-1.2mm。线发射体阵列的占空比范围为 10％～ 50％，优化占空比为 20 ～ 25％。每条线发射体的线长与物体到源的距离相比非常小，产生的 X 射线束在其后的空间中呈锥束分布，并具有满足设计要求的相干长度，但各线发射体产生的 X 射线锥束之间没有相干性。该 X 射线管为本系统的实现奠定了基础。更加详细的内容记录在 200610062487.1 专利申请文献中。

[0039] 以上所采用的 X 射线管是连续工作模式、或脉冲工作模式，以上工作模式通过对设置在电子源或离子源与结构阳极之间的栅极进行控制，实现对 X 射线的连续或脉冲模式的输出。

[0040] 以上所采用的特别研制的 X 射线探测器，它的基本结构中包括平行线阵列式 X 射线转换屏 6-1、中继光学系统 6-2 和面阵 CCD 或 CMOS 探测器 6-3，其中平行线阵列式 X 射线转换屏的平行线条周期结构参数由衍射理论决定。每个周期由条带状的敏感区和非敏感区组成。非敏感区在垂直于周期结构的方向上整个长度由非荧光材料构成，对入射的 X 射线不敏感；而敏感区在垂直于周期结构的方向上整个长度被分离成一条矩形像素阵列，在每一像素区内填充对荧光材料，对入射的 X 射线具有高的灵敏度。敏感区和非敏感区的宽度之和应严格等于 X 射线干涉条纹的周期。

[0041] 以上所述的 X 射线探测器是光电导 X 射线探测器，以上光电导 X 射线探测器具有由光电导材料制成的独立单元组合形成的阵列结构，其周期结构参数与上述 X 射线转换屏结构参数相一致，也由衍射理论决定。

[0042] 阵列式 X 射线转换屏或阵列式光电导 X 射线探测器的周期节距 (P_2) 应满足分析光栅的结构关系式：$P_2 = 0.5P_1(L+d_n)/L$，其中 P_1 代表相位光栅周期节距，L 为 X 射线源到相位光栅的距离，d_n 为修正后的泰伯成像距离，每个独立像素区的宽度 b 不大于周期节距 (P_2) 的一半，长度 a 为 0.5-10 倍的周期节距 (P_2)。

[0043] 以上所述的非荧光材料是硅、锗等半导体材料或铝、不锈钢等金属材料或玻璃等材料，非荧光材料分割的像素区内填充的荧光材料是：CsI:Tl 或 CsI:Na 或 Gd_2O_2S:Tb 等在

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X 射线激发下能产生可见或近红外光的荧光物质。

[0044] 以上所述的中继光学系统可由光锥或光导纤维面板或由二者的组合或光学透镜组成。

[0045] 所述光电导材料是非晶硒、碘化汞或碘化铅，在光电导材料上转换形成的像素信号借助聚焦激光束或聚焦线激光束逐点或逐行读出。

[0046] 以上所说的具有分析光栅和探测器双重功能的 X 射线探测器的基本结构由玻璃基底 2-1、介质材料 2-2、透明电极 2-3、光电导材料 2-4 和电极 2-5 组成，光电导材料是用非晶硒或碘化汞或碘化铅等制成，其中透明电极 2-3 宽度为 T 与电极之间的介质材料 2-2 的宽度之和等于光栅干涉条纹周期 P，光电导材料信号输出是用聚焦点激光束或聚焦线激光束逐点或逐行读出。

[0047] 本系统所采用的 X 射线管发出的 X 射线光谱范围在 5-120keV，所述的相位光栅用硅或铝等材料制成、通过改变光栅的厚度使其中心波长对应的光子能量可在 7-100keV 范围内调节，允许的 X 射线带宽为 ±20％，所述的滤波器用钼、钨、铝等材料制成，由 X 射线管发出的 X 射线通过滤波器后使 X 射线的中心波长和带宽与相位光栅允许的参数相匹配，所述的 X 射线源、滤波器、样品台、相位光栅、X 射线探测器等配套有共轴和轴向相对位置精密调节机构。

[0048] 所述的 X 射线源、相位光栅和阵列 X 射线转换屏或光电导 X 射线探测器等配套有精密调节机构，使 X 射线源所产生的 X 射线呈现的平行线状结构走向、相位光栅结构走向与阵列 X 射线转换屏或光电导 X 射线探测器一维空间周期结构走向可精密调整，相位光栅还可以在垂直于轴的方向上相对于阵列 X 射线转换屏或光电导 X 射线探测器实现精密平移。

[0049] 本发明提供的第一种 X 射线探测器转换屏结构为阵列结构，在一维空间上具有周期性结构，在每一周期内，每个周期由条带状的敏感区和非敏感区组成，这里的敏感是指对 X 光敏感。非敏感区在垂直于 周期结构的方向上整个长度对入射的 X 射线不敏感，而敏感区在垂直于周期结构的方向上整个长度被分离成许多像素，每个像素对入射的 X 射线具有高的灵敏度。敏感区和非敏感区的宽度之和应严格等于 X 射线干涉条纹的周期。转换屏非荧光材料可以是硅、锗等半导体材料或铝、不锈钢等金属材料或玻璃等材料。用反应离子刻蚀、湿法刻蚀、光助电化学刻蚀、感应耦合等离子体反应离子刻蚀等方法在基底材料上刻蚀出阵列孔。孔的深度由 X 射线光谱范围及所用的荧光材料决定，一般在 10-500 微米范围内。阵列孔中填充 X 射线荧光材料，荧光材料在 X 射线激发下可产生可见或近红外光。当使用面积较大的转换屏时，可以利用多个光锥将转换屏图像耦合到多个分离的面阵 CCD 或 CMOS 探测器上，

[0050] 以上叙述的线阵列发射体 X 射线源、一维空间周期性结构 X 射线探测器及基于这些关键部件的微分干涉相衬成像系统仅是本发明示范性实施举例。X 射线源只涉及到与电子束有关的 X 射线管，利用离子束的 X 射线管，除离子源之外，其它结构与上述利用电子束的 X 射线管基本相同。另外，还需要说明的是，本发明中的基本思想和基本方法可以有多种变化。

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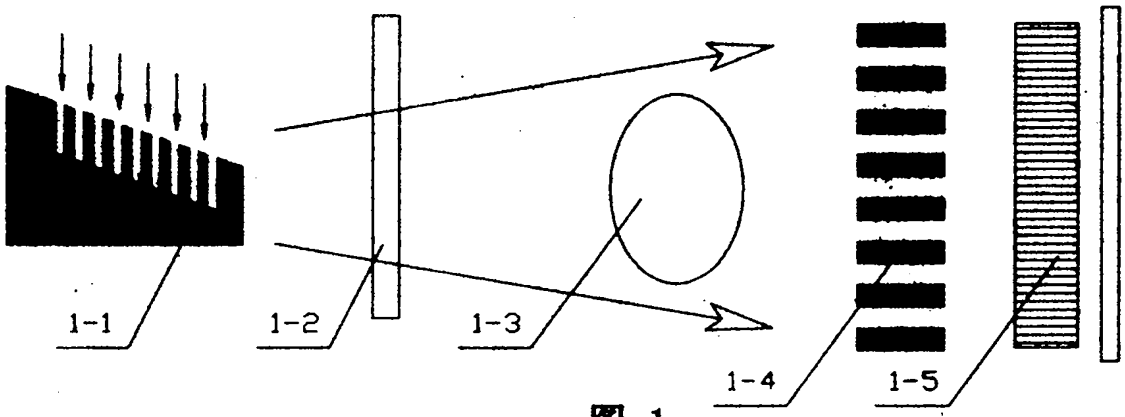


图 1

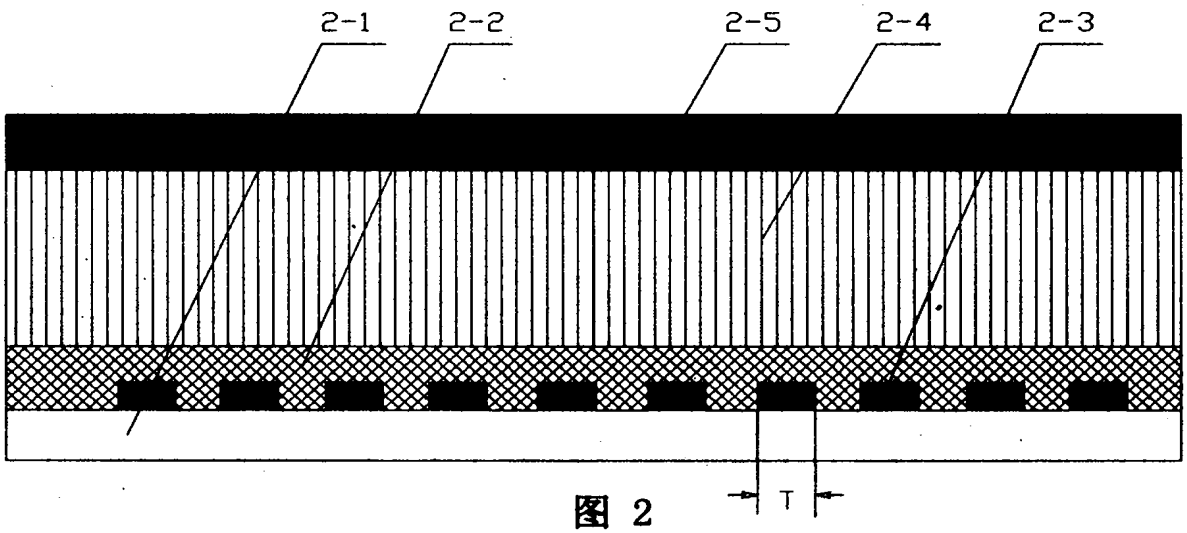


图 2

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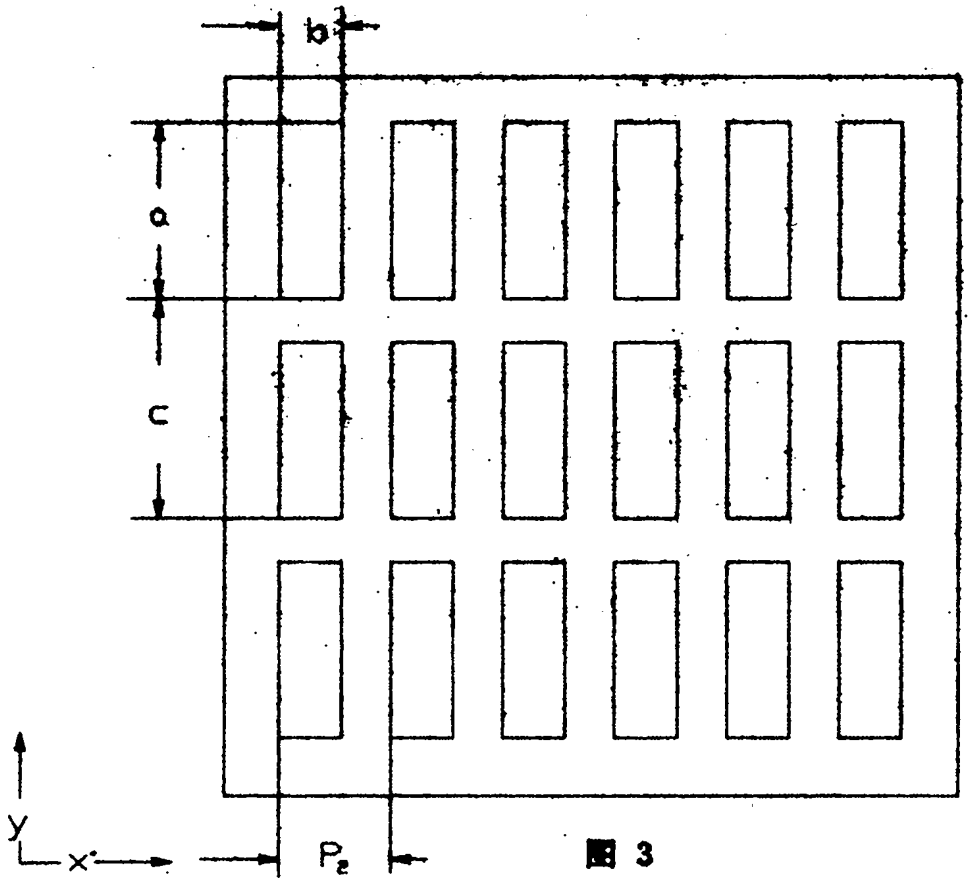


图 3

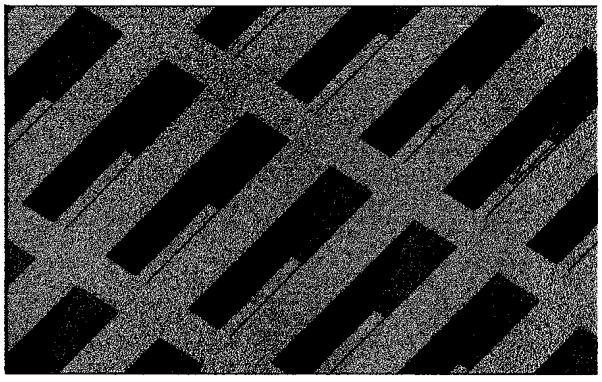


图 4

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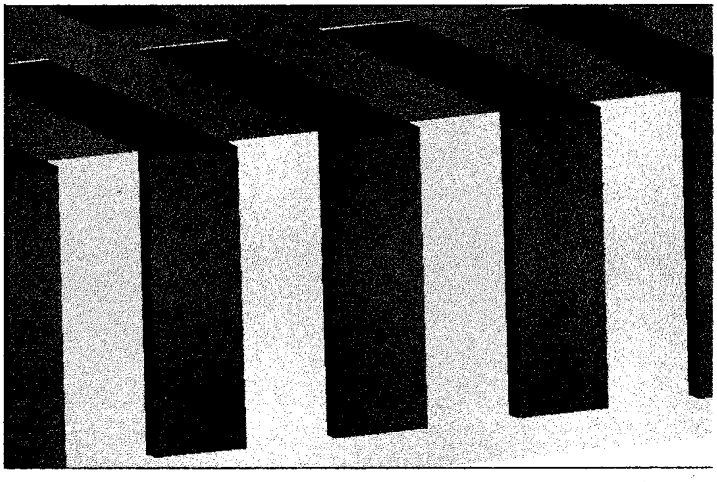


图 5

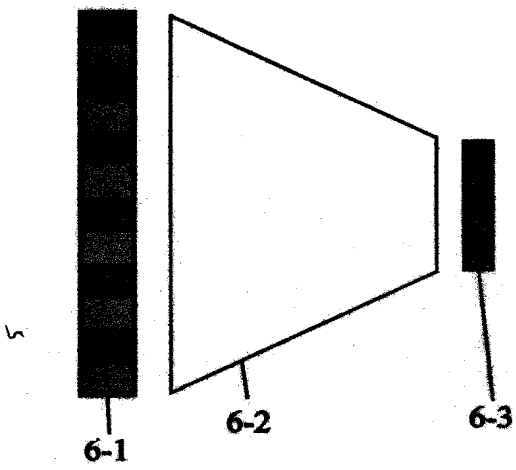


图 6

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Optical device comprising a fresnel lens

Abstract

The invention relates to an optical array for illumination purposes, especially for a Fresnel spotlight, comprising a Fresnel lens with a light-scattering element, particularly a diffusing screen. Thediffusing screen is disposed in a first zone while the Fresnel lens is located in a second zone. The aperture angle of the light that emerges from the optical array is adjustable, especially betweentwo threshold values, a lower alphaSp and an upper one alphaF1, when the form of the light impinging the optical array and/or the quantity of light illuminating the optical array change/s.

(19)中华人民共和国国家知识产权局

(12)发明专利

(10)授权公告号 CN 1918427 B
(45)授权公告日 2010.06.02

(21)申请号 200480041736.8

(22)申请日 2004.12.22

(30)优先权数据
10361121.5 2003.12.22 DE
10361122.3 2003.12.22 DE
10361117.7 2003.12.22 DE

(85)PCT申请进入国家阶段日
2006.08.15

(86)PCT申请的申请数据
PCT/EP2004/014642 2004.12.22

(87)PCT申请的公布数据
WO2005/061956 DE 2005.07.07

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(51)Int.Cl.
F21V 8/00(2006.01)
F21V 5/04(2006.01)
F21V 14/06(2006.01)
G02B 3/08(2006.01)
F21S 8/10(2006.01)
F21V 14/02(2006.01)
F21W 131/406(2006.01)

(56)对比文件
US 6654172 B2,2003.11.25, 说明书第2栏第4-15行、第30-38行及附图2和3A-3C.
US 2001/0055209 A1,2001.12.27, 说明书第[0007]-[0036]段及附图1a.
US 2853599 A,1958.09.23, 说明书第1栏第65行到第2栏第68行、第3栏第10行到第4栏第15行、说明书附图1-3.
US 2003/0063466 A1,2003.04.03, 说明书第[0006]-[0014]段和[0018]-[0019]段以及附图1-2.

审查员 崔双魁

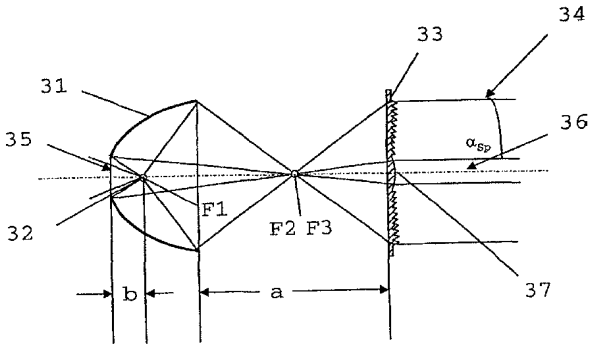
权利要求书 5 页 说明书 16 页 附图 8 页

(54)发明名称

带有阶梯形透镜的光学装置

(57)摘要

本发明包含一种照明用途的光学装置，尤其是一种阶梯形透镜点光源，其包括具有光散射器件，尤其是漫射屏的阶梯形透镜，其中漫射屏设置在第一个区域内，阶梯形透镜设置在第二个区域内，并且其中随着照射到光学装置上的光的形状和大小的变化，其能够把光学装置出射光的孔径角设置在两个极值，在较小的 α_{Sp} 和较大的 α_{F1} 间。



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1. 一种照明用途的光学装置，其包括具有漫射屏的阶梯形透镜，其中漫射屏设置在第一个区域内，阶梯形透镜设置在第二个区域内，并且其中随着照射到光学装置上的光的形状和 / 或大小的变化，其能够把光学装置出射光的孔径角设置在两个极值，较小的 α_{Sp} 和较大的 α_{Fl} 之间，其中在每种情况下第一个和第二个区域分别占据了不同直径 (2Rst1, 2RstrA) 的同心设置表面，并且其中漫射屏仅设置在阶梯形透镜的中央和 / 或中心区域，其中在具有较大的 α_{Fl} 的位置处，大部分光通过所述漫射屏，而在具有较小的 α_{Sp} 的位置处，大部分光通过所述同心设置表面。

2. 如权利要求 1 所述的光学装置，其特征在于随着投射到光学装置上的光的大小变化，其能够改变光学装置的出射光的孔径角 (α , α_{Sp}, α_{Fl})，同时不改变照亮光学装置的入射光的角度。

3. 如权利要求 2 所述的光学装置，其中所述光的大小的变化是直径的变化。

4. 如权利要求 1 或 2 所述的光学装置，其特征在于阶梯形透镜的表面尺寸相对于漫射屏的表面尺寸比率大于 2 比 1。

5. 如权利要求 4 所述的光学装置，其中所述阶梯形透镜的表面尺寸相对于漫射屏的表面尺寸比率大于 10 比 1。

6. 如权利要求 5 所述的光学装置，其中所述阶梯形透镜的表面尺寸相对于漫射屏的表面尺寸比率大于 100 比 1。

7. 如权利要求 1 所述的光学装置，其特征在于漫射屏的出射光在垂直方向上的孔径角与水平方向的孔径角不同。

8. 如权利要求 1 所述的光学装置，其特征在于漫射屏包含多个区域，其分别向不同的方向或以不同的程度散射光。

9. 如权利要求 8 所述的光学装置，其中所述多个区域是环形表面区域。

10. 如权利要求 1 所述的光学装置，其特征在于对于椭圆反射器的椭圆率为 ε 的阶梯形透镜点光源，阶梯形透镜的焦距与半径的比率 $n_{st1} = R_{st1}/F_{st1}$ 大于 0.5 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$。

11. 如权利要求 10 所述的光学装置，其中阶梯形透镜的焦距与半径的比率 $n_{st1} = R_{st1}/F_{st1}$ 大于 0.7 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$。

12. 如权利要求 11 所述的光学装置，其中阶梯形透镜的焦距与半径的比率 $n_{st1} = R_{st1}/F_{st1}$ 大于 0.9 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$。

13. 如权利要求 1 所述的光学装置，其特征在于漫射屏设置在光出射区域处。

14. 如权利要求 1 所述的光学装置，其特征在于漫射屏设置在光入射区域处。

15. 如权利要求 1 所述的光学装置，其特征在于漫射屏分别设置在光入射区域和光出射区域处。

16. 如权利要求 1 所述的光学装置，其特征在于漫射器件具有漫射程度不同的区域。

17. 如权利要求 16 所述的光学装置，其中漫射程度大的区域位于中心，而漫射程度小的区域位于边缘。

18. 如权利要求 1 所述的光学装置，其特征在于漫射屏通过闷火方式和 / 或高温成形来制造。

19. 如权利要求 18 所述的光学装置，其中漫射屏通过压印和 / 或喷射模塑法来制造。

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20. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜和 / 或漫射屏的材料包括玻璃。

21. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜和 / 或漫射屏的材料包括玻璃 - 陶瓷材料。

22. 如权利要求 1 所述的光学装置，其特征在于光学装置是单器件构造。

23. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜是一个非球面透镜。

24. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜是一个球面透镜。

25. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜的主体具有平坦的表面。

26. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜具有一个光束成形效果的主体，其表面是凹球面或非球面。

27. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜具有一个光束成形效果的主体，其表面是凸球面或非球面。

28. 如权利要求 1 所述的光学装置，其特征在于阶梯的环形、光学有效面设置成圆弧部分。

29. 如权利要求 1 所述的光学装置，其特征在于阶梯的环形、光学有效面设置成为锥包络的形状。

30. 如权利要求 1 所述的光学装置，其特征在于各个阶梯的环形、光学有效面的形状使得波阵面垂直于光轴的近似平面波在实焦点处组合或被转换成中点看起来位于虚焦点处的球面波。

31. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜和 / 或漫射屏的材料包括塑料。

32. 如权利要求 1 所述的光学装置，其特征在于带有阶梯形透镜和漫射屏的光学装置由多个器件组成。

33. 如权利要求 1 所述的光学装置，其特征在于光学装置是由玻璃和塑料制成的复合物。

34. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜包含具有第一种散射特性的材料，以及具有相反屈光力的另一个透镜。

35. 如权利要求 34 所述的光学装置，其中所述具有相反屈光力的另一个透镜是具有第二种散射特性的材料的阶梯形透镜，其能够以某种方式减小色差。

36. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜是一个压印透镜。

37. 如权利要求 36 所述的光学装置，其中所述阶梯形透镜是塑料透镜。

38. 如权利要求 36 或 37 所述的光学装置，其中所述阶梯形透镜各个阶梯的光程差小于 1000 个光波长。

39. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜设置在第一侧上，而漫射屏设置在对着第一侧的另一侧上。

40. 如权利要求 1 所述的光学装置，其特征在于围绕着阶梯形透镜的中央圆形部分的环形部分上有相同的径向程度。

41. 如权利要求 1 所述的光学装置，其特征在于至少两个相邻的环形部分的阶梯突起具有相同的高度。

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42. 如权利要求 1 所述的光学装置，其特征在于光学装置的至少一个表面面对着由玻璃制成的光源，并被预压。

43. 如权利要求 42 所述的光学装置，其中所述光学装置的至少一个表面被热预压。

44. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜和 / 或漫射屏被形成为滤光片。

45. 如权利要求 44 所述的光学装置，其中所述的滤光片是紫外、红外或全彩带通滤光片和 / 或转换滤光片。

46. 如权利要求 1 所述的光学装置，其特征在于阶梯形透镜和 / 或漫射屏涂覆了机械防划伤层和 / 或防反射层。

47. 一种如权利要求 1 所述光学装置的漫射屏，其具有被划分成小面的第一个表面，每个小面被指定了相对于弯曲的第二个表面的突起或凹陷，其中小面呈不同的几何形状并且其中漫射屏具有规定的粒度，中心区域处变得更精细，而随着离中心距离的增加变得更粗糙。

48. 如权利要求 47 所述的漫射屏，其特征在于小面具有多边形的边缘轮廓。

49. 如权利要求 47 所述的漫射屏，其特征在于小面包含了不同的面积。

50. 如权利要求 47、48 或 49 所述的漫射屏，其特征在于假设小面的形状是三角形、四边形、五边形、六边形和 / 或七边形。

51. 如权利要求 47 所述的漫射屏，其特征在于小面具有不同的取向。

52. 如权利要求 47 所述的漫射屏，其特征在于突起或凹陷构成为球帽的形状。

53. 如权利要求 47 所述的漫射屏，其特征在于突起的高度和 / 或凹陷的深度可以选择为不相同。

54. 如权利要求 47 所述的漫射屏，其特征在于突起或凹陷的各个顶点 (S) 沿着螺旋线设置。

55. 如权利要求 54 所述的漫射屏，其特征在于顶点 (S) 位于阿基米德螺旋线上。

56. 如权利要求 54 或 55 所述的漫射屏，其特征在于沿螺旋线的两个相邻顶点 (S) 之间的弧长 (L) 是等距的。

57. 如权利要求 54 或 55 所述的漫射屏，其特征在于沿螺旋线的两个相邻顶点 (S) 之间的弧长 (L) 设置成可变的。

58. 如权利要求 54 或 55 所述的漫射屏，其特征在于突起的高度和 / 或凹陷的深度可以选择为不相同。

59. 如权利要求 47 所述的漫射屏，其特征在于漫射屏具有可以相互旋转的各个小面。

60. 如权利要求 47 所述的漫射屏，其特征在于漫射屏具有通过 Monte Carlo 方法偏离其规定位置的小面。

61. 一种阶梯形透镜点光源，其出射光束的孔径角可调，具有一个椭圆反射器，一个灯和至少一个阶梯形透镜，包括如权利要求 1 所述的漫射屏的阶梯形透镜。

62. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于带有漫射屏的阶梯形透镜限定了一个光混合系统，后者改变散射光相对于几何光学成像光的比例，因此改变光混合比，其中所述改变的方式在一定程度上取决于阶梯形透镜点光源的位置。

63. 如权利要求 61 或 62 所述的阶梯形透镜点光源，其特征在于阶梯形透镜具有一个实

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焦点，其叠加到反射器的远离反射器的焦点上。

64. 如权利要求 63 所述的阶梯形透镜点光源，其中所述实焦点叠加到阶梯形透镜点光源的亮点位置上。

65. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于阶梯形透镜是一个作为阶梯形透镜的平凹会聚透镜。

66. 一种阶梯形透镜点光源，其出射光束的孔径角可调，并具有一个椭圆反射器，一个灯和至少一个如权利要求 61 所述的阶梯形透镜，其特征在于阶梯形透镜具有负焦距，因此是具有虚焦点的负透镜。

67. 如权利要求 66 所述的阶梯形透镜点光源，其特征在于阶梯形透镜的虚焦点叠加到反射器的远离反射器的焦点上。

68. 如权利要求 67 所述的阶梯形透镜点光源，其中所述虚焦点叠加到阶梯形透镜点光源的亮点位置上。

69. 如权利要求 66 或 67 所述的阶梯形透镜点光源，其特征在于阶梯形透镜是一个双凹负透镜。

70. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于阶梯形透镜点光源的出射光的孔径角在亮点位置上小于或等于 8°，在泛射位置上大于或等于 60°。

71. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于阶梯形透镜点光源的出射光的孔径角在亮点位置上小于或等于 8°，在泛射位置上大于或等于 70°。

72. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于阶梯形透镜点光源的出射光的孔径角在亮点位置上小于或等于 8°，在泛射位置上大于或等于 80°。

73. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于阶梯形透镜点光源包含一个椭圆率为 ε 的椭圆反射器，阶梯形透镜的焦距和半径的比率 $n_{St1} = R_{st1}/F_{st1}$，大于 0.5 倍的 $1/sqrt(\varepsilon^2-1)$。

74. 如权利要求 73 所述的阶梯形透镜点光源，其中阶梯形透镜的焦距和半径的比率 $n_{St1} = R_{st1}/F_{st1}$，大于 0.7 倍的 $1/sqrt(\varepsilon^2-1)$。

75. 如权利要求 74 所述的阶梯形透镜点光源，其中阶梯形透镜的焦距和半径的比率 $n_{St1} = R_{st1}/F_{st1}$，大于 0.9 倍的 $1/sqrt(\varepsilon^2-1)$。

76. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于反射器包含一个金属的或透明的玻璃和 / 或塑料。

77. 如权利要求 76 所述的阶梯形透镜点光源，其中所述玻璃和 / 和塑料是介质材料。

78. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于反射器的两个主表面至少其中之一具有光学薄层系统。

79. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于反射器的光反射面以光散射方式构成，除了漫射屏之外，阶梯形透镜的零个、一个或两个表面以光散射方式构成。

80. 如权利要求 79 所述的阶梯形透镜点光源，其中所述反射器的光反射面具有局部区域或小面。

81. 如权利要求 61 所述的阶梯形透镜点光源，其特征在于在阶梯形透镜和反射器之间设置了一个辅助反射器。

82. 如权利要求 61 所述的阶梯形透镜点光源的用途，用于医疗、建筑、电影院、舞台、演

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播室和摄影。

83. 一种包含如权利要求 61 所述的阶梯形透镜点光源的闪光灯。

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带有阶梯形透镜的光学装置

[0001] 本发明总体上涉及一种照明用途的光学装置，其带有至少一个阶梯形透镜，尤其涉及一种带有集成漫射屏的阶梯形透镜。

[0002] 阶梯形或菲涅尔透镜可以追溯到十九世纪的法国物质物理学家奥古斯丁·让·菲涅尔，他发明了这种光学元件，也称为环形透镜。与其它使用固体的光学透镜相比，阶梯形透镜或菲涅尔透镜具有同心的阶梯，这些阶梯基本上垂直于透镜的基面，其间设置了环形部分。环形部分的光学有效表面的形状大致相应于固体普通透镜的表面部分的形状，但所述表面更靠近各个透镜的相反表面。此外，阶梯的光学无效区域尽可能地设置成平行于光传输的主方向，使得反射最小或不期望的散射光较小。因此，大致上说，除了阶梯导致的光扰动，菲涅尔透镜的成像特性与普通透镜相同。但是，除了所述光扰动，菲涅尔透镜比起传统透镜具有显著的优点，使得该类型透镜显然成为许多应用中的优选或唯一选择。菲涅尔透镜的厚度较小，它需要的光学材料较少，相应也更轻，菲涅尔透镜吸收量较小，因而热升温也很小，尤其适用于发光强度很高的照明设备。

[0003] 菲涅尔透镜在用于剧院、舞台、演播室、电影院或其他建筑的照明的阶梯形点光源时是非常有利的。

[0004] 但是，菲涅尔透镜的较小厚度也意味着它们通常也很容易制造。对于压印、喷射模塑或高温成形法，比起相应的固体，能够更佳地控制较薄菲涅尔透镜的冷却和脱模。这些优点的重要性随着所述透镜的尺寸的增加而增大。由此，优选应用领域是照明技术，尤其是剧院、演播室内，尤其用于电影院、舞台上或建筑内，这些地方中高强度的照明光通常还伴有很高的热负荷，但成像特性的扰动具有较小的意义。

[0005] 轨枕 (rail-borne) 通信信号技术中已知一种具有中央设置的平行棱镜器件的阶梯形透镜，其更适宜地把光导到下半空间，这用于提供进入阶梯形透镜的用于附近范围的信号分辨的部分光。

[0006] WO 01/86341 A1 描述了一种具有阶梯形透镜的信号发射器，阶梯形透镜包括焦距相对较短的散射器件，在这种情况下短焦距散射器件延伸发射光的发光角。但是，覆盖了阶梯形透镜整个表面的散射器件不允许通过在阶梯形透镜位置处改变照亮阶梯形透镜的光强来使光通量发生变化，尤其是光的孔径角。

[0007] EP 0 391 287 具体描述了一种操作照明装置，其包括一个双曲线镜以及光出射侧的一个透镜装置，后者包括至少三个不同焦距的菲涅尔透镜。借助于阶梯形透镜的不同焦距可以实现在相对较大的景深获得均匀的光强，因此对于很深的外科创口可以得到均匀的照明。优选使用结构尺寸小于阶梯形透镜的六边多角形在照明范围内进一步均匀化。但是，该装置不能实现对出射光场的孔径角或照明范围的大小的变化，要借助其他附加手段来获得。但是为此则需要附加的器件。

[0008] EP 1 242 399 A2 中提及了一种作为阶梯形透镜点光源的光学系统，它是由本申请的发明人发明的，其中通过调整该系统的灯相对于反射器的位置来影响出射光的孔径角。但是，在这种情况下，使一个通常非常热的灯相对于反射器机械移动，为了调整，需要相当可观的机械开支。首先，必需确保对在较大范围内振动敏感的灯在高温状态下不会损坏，

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并且其次，调整器件必须同时具有很高的抗高温性和抗热循环性。

[0009] JP 61 097 602 A 涉及一种屏幕，例如反射式照相机的毛玻璃屏幕，其中边缘区域通常看起来比屏幕中心要暗，这是因为倾斜入射到边缘的像场光线在通过毛玻璃屏幕后也从屏幕中心倾斜地出射。为了增强屏幕边缘区域的亮度，同时不降低中心区域的亮度，该发明包括为屏幕的中心区域设置具有散射器件的菲涅尔透镜，由此屏幕的整个成像区域被均匀地照亮。但是，该装置不能实现对出射光场的孔径角或照明范围的大小的变化，该类型的系统也不是最佳手段。

[0010] DE 38 06 879 C1 公开了一种滤光透镜，其中为了在菲涅尔透镜的光场内对于传感器相关或度量目的实现尽可能均匀的强度分布，所述菲涅尔透镜具有径向延伸的结构，该结构旨在防止增加光场中心处的光强。在这种情况下，径向延伸结构发出的光不再在传感器上成像。但是，该类型的装置对于照明应用存在缺陷，因为存在不能成像的区域，就会产生所不期望的光损耗。此外，对于照明设备，例如演播室、剧院、电影院和类似建筑内，通常非常期望借助于较亮的中心区域对照明物体的特定区域进行所需的着重。

[0011] 本发明所基于的目的是进一步增强阶梯形透镜的可用性，尤其对于照明应用，以及尤其通过使用该类阶梯形透镜来简化照明设备的结构。

[0012] 该目标借助于权利要求 1 的特征非常容易地达到。

[0013] 在根据本发明的照明用途的光学装置的情况下，尤其是阶梯形透镜点光源，如果在第一个区域上设置了一个漫射屏，在第二个区域上设置了一个阶梯形透镜，则能够以非常简单并且极端可行的方式来改变投射到光学装置上的光的形状和 / 或照亮光学装置的光的大小。这能够改变光学装置的出射光的孔径角 α，尤其把所述角度设置在两个极值之间，较小的 α_{SP} 和较大的 α_{F1}。

[0014] 从而能够减少机械元件的数量并且显著增加了照明效率，尤其当此光学装置用于阶梯形透镜点光源时。

[0015] 通过阶梯形透镜的在几何光学上导向的光相对于通过漫射屏的光的光混合比也可以用简单的方法来改变。

[0016] 一个主要优点是当照明光锥通过光学装置时，能够只通过改变光锥相对于光学装置的位置来改变发光角度，例如从 8° 到 60°，从 8° 到 70° 或者甚至从 4° 或 8° 到 80°，使光分布均匀变化。

[0017] 此时，孔径角定义成从系统光轴上测量时，光强度下降到光轴方向上光强的十分之一时的角度。

[0018] 在这种情况下能够以非常简便的方式来连续改变孔径角，并且在改变过程中始终保持照明角范围内的均匀照明。

[0019] 适当选择光装置的散射结构和几何尺寸，阶梯形透镜的几何光学成像和漫射屏上散射光的散射瓣叠加的组合还使得此时的光照明分布不仅能够抑制光源或发光体的成像，而且甚至能够大大降低或避免照射光路的缺陷。

[0020] 在这样的情况下发现另一种特别感兴趣的应用：反射装置具有相对于其支持物较小的光源，例如出射光范围大约为几个微米数量级的高压放电灯，并且有明显大的支持物直径。这种类型的光源，中央光场会变暗，这是因为通过反射器的支持物需要在反射器内的一个明显大于光源的开孔，因此光束不会被开孔内光轴附近反射。借助于适当选择光漫射

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设备的前向散射瓣，优选是圆形的中央漫射屏，它能够令人惊讶地基本上保持阶梯形透镜的几何光学特性，然而避免中央光强的降低。

[0021] 此时，光学装置有利地构成在一个零件，以便从制造工艺上来说，阶梯形透镜和漫射屏被方便地在单个压印操作中完成。

[0022] 在最优选实施例中，在每个情况下和阶梯形透镜和漫射屏一致的第一和第二区域占据了光学装置的实际表面，优选的是具有不同直径（2RSt1，2RstrA）的同心设置的表面。

[0023] 此时，阶梯形透镜和漫射屏的表面大小比率可以确定在很宽的范围内的－具体情况具体考虑－用于照明用途的出射光的部分比，优选地大于 2 比 1（阶梯形透镜表面比漫射屏表面），阶梯形透镜和漫射屏的表面大小比率优选地大于 10 比 1，阶梯形透镜和漫射屏的表面大小比率更优选大于 100 比 1。

[0024] 本说明书中，阶梯形透镜或漫射屏的表面并不是具有全部微观和宏观升降的实际表面，而是在平行于一个平面内的光轴的照明下，此平面垂直于光轴延伸并直接位于光学装置之后，对应于阶梯形透镜或漫射屏的投影面积的区域。

[0025] 在一种极其有利的方式中，漫射屏的出射光在垂直方向上的孔径角与水平方向的孔径角不同，从而漫射屏可选地给出非圆形、椭圆形、多边形以及尤其矩形和／或正方形状的照明光场。

[0026] 矩形以及尤其正方形的光场允许多个光场排成一列，从而能够均匀照明较大的面积，例如演播室、舞台或建筑照明。

[0027] 根据漫射屏的照明面积，也可以实现把圆形的照明光场变换成非圆形、椭圆形、多边形以及尤其矩形和正方形的光场，例如漫射屏包括多个区域，尤其是向不同方向或以不同程度的散射光的环形表面区域。

[0028] 此时，如果光锥尽管仍覆盖了整个漫射屏直径 R_{strA}，不再覆盖阶梯形透镜，亮点位置的圆形光场在调整时也能变换到非圆形，例如正方形光场。进一步调整并且光锥变小时，如果光锥仅覆盖了内直径 R_{StrI} 光场会再次变换成不同的形状，例如椭圆形光场，光锥把光仅导入椭圆形光场的部分。

[0029] 照明光场的形状可以用此方式灵活调整。

[0030] 此外，漫射屏再划分为具有不同散射性质的区域也使得入射光类型成为可控的。调整过程中，如果光锥尽管仍覆盖了整个漫射屏直径 R_{strA}，不再覆盖阶梯形透镜，亮点位置的圆形光场首先变换成具有柔和边缘的正方形光场，进一步调整并且光锥变小时，如果光锥仅覆盖了内直径 R_{StrI}，光场会再次变换成不同的形状，例如椭圆形光场，光锥把光直接引导入椭圆形光场的部分，但是仅入射到非常精确的后者，光场进一步变换成强反差边缘的光场。

[0031] 在一种有利的方式中，对于具有椭圆率为 ε 的椭圆反射器的阶梯形透镜点光源，阶梯形透镜的焦距与半径的比率 $n_{St1} = R_{st1}/F_{st1}$ 大于 0.5 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$，优选大于 0.7 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$，更优选大于 0.9 倍的 $1/\mathrm{sqrt}(\varepsilon^2-1)$。

[0032] 为了补偿球面像差以及为了获得尽可能最佳的成像效果，阶梯形透镜优选是一个非球面透镜。

[0033] 如果阶梯形透镜的主体具有光束成形效果，主要是凹面，其能够应用于更复杂的光学需求，因为这使得能够限定凹－凸或双凹面透镜，例如其中阶梯形透镜和其主体都具

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有几何光学效果。

[0034] 此外，阶梯形透镜的主体也可以具有基本凸面，以便生成凸－凹或双凸面透镜。

[0035] 大致地说，主体的形状可以按照光束成形方式被独立地利用，可以用组合或叠加的方式利用阶梯形透镜的光束成形特性。

[0036] 此时，阶梯形透镜的主体被理解为，如果去除阶梯形透镜的阶梯而产生的部分；这意味着阶梯形透镜的阶梯被施加的或压入的大量材料。

[0037] 因此从制造工艺上来说，能够首先计算所需阶梯形透镜的形状，通过主体的进一步构型获得附加的光束成形特性，主体的构型优选的是平凹、平凸、双凹、双凸或凹凸形式。

[0038] 如果阶梯的基本上环形的光学有效表面被设置成圆弧表面部分，其使能够利用就制造工艺中易于实现，同时仍然具有相对较好的光学特性的几何特性。

[0039] 在一个简单、成本有效的实施例中，阶梯的基本上是环形光学有效表面被制成圆锥包络的形状。

[0040] 但是，最优光学成像性能通常是在会聚阶梯形透镜，因此透镜具有正焦距和实焦点的情况下获得的，如果各个阶梯的基本环形光学有效表面被这样成形，使得当单个实焦点产生的光进入所述透镜时，波阵面垂直于光轴的近似平面波远离透镜。在发散透镜的情况下，因而透镜具有负焦距和虚焦点，当进入阶梯形透镜的光从平面波被转换成其中点看起来似乎由单个虚焦点产生的球面波时达到最优效果。

[0041] 一个优选实施例中，漫射屏仅设置在阶梯形透镜的中心区域，优选地位于阶梯的侧面，因为此实施例已经借助于高精度的单步高温成形而制造出。

[0042] 如果漫射屏以定界方式设置在阶梯形透镜的中心区域是非常有利的，因为由此能够在照明设备中产生不寻常地可变的光强分布。因此，例如通过使用光阑或改变入射光场的聚焦，能够改变光场直径，并可调整地从散射变换到几何光学成像光。只要当光仅投射到内部漫射屏时，其特性便确定了出射和照明光场的形状。如果当光场直径加大而增加了几何光学成像特性时，能够例如获得照明光锥高度均匀的放大。

[0043] 如果光散射器件具有漫射程度不同的区域，则能够获得要被改变的光分布中更加连续和平滑的过渡，优选地漫射程度大的区域在中央，而漫射程度弱的区域在边缘。

[0044] 根据漫射屏的材料，优选通过高温成形、尤其压印和／或喷射模塑法来制造适用于不同漫射特性的漫射屏。

[0045] 阶梯形透镜和／或漫射屏的优选材料是玻璃和玻璃陶瓷材料。玻璃陶瓷的高耐温度变化是尤其有利的。

[0046] 此外，例如为了利用不同的工艺方法及其优点，带有阶梯形透镜和漫射屏的光学装置可以由多个器件组成。

[0047] 因此，一个压印塑料阶梯形透镜可以连接到玻璃制成的漫射屏，从而产生了玻璃和塑料制成的复合物。

[0048] 如果阶梯形透镜包括具有第一散射特性的一种材料以及具有相反屈光力的另一个透镜，优选地具有第二散射特性的材料的阶梯形透镜，则甚至能够生成色差校正的或消色差透镜系统。

[0049] 本说明书中的光程长度被认为是使用的各个光谱中心区域的波长。

[0050] 如果阶梯形透镜是一个压印塑料透镜，如果此透镜在各个阶梯上的光程长度差小

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于大约 1000 个波长是非常有利的，因为这样通常能够实现相对平坦的阶梯形透镜，这对于几何光学的光传播仅产生很小的扰动。

[0051] 另外，在局部高光强度的情况下，根据构造，不再使用传统的明胶滤光片，其在高光强区域内，例如实焦点附近可以快速变白或者甚至熔融和点火，而是使用镀膜或彩色玻璃，这是更为实际的。

[0052] 因此，如果阶梯形透镜和 / 或漫射屏其中一个或都被构成滤光片，尤其作为紫外、红外或全彩带通滤光片和 / 或转换滤光片，则能够非常可靠和更精确地滤光。此外，制造成套光学装置，优选地具有二向色或干涉滤光层对于特定光源在特定光温度下配置了，其适应于限定的光源的限定的温度，都处于这种结构的范围内。

[0053] 因此，例如低色温值方向上的特定色偏会使得高压放电灯具有黑体辐射器的光谱，例如白炽灯。

[0054] 另外，受激放电线的主要光谱带可以用一种限定的方式来调制，从而获得更均匀的光谱分布。

[0055] 此外，对于光源的预定光谱，使用此类型的滤光装置还能够模拟在光谱分布内的发光环境。例如晨光、夜间光、暴雨或雷暴雨的光，因此通过一个光源以及指定的根据本发明的一套光学装置就能满足演播室、剧院、电影院和建筑的大多数需求。

[0056] 因为二向色或干涉滤光片能够永久承受高光谱精度的高辐射强度，根据应用不同，这些滤光片不仅光谱效果更好，而且由于其工作寿命长，它们比起传统的彩色滤光片的价格更便宜。另外，苛刻的环景条件，例如建筑照明或户外录制情况，是使用此类型光学装置的另一个原因。

[0057] 当使用塑料透镜和 / 或漫射屏时，如果它们被涂覆了一个机械防划伤层则更为有利。

[0058] 另外，不希望的反射，尤其在阶梯区域上的反射，不仅会导致主要光通量的损失，而且会在照明平面上形成更亮的圆或点，这可以通过所述阶梯区域上的防反射层来大量减小或甚至抑制。

[0059] 通过本发明的照明用途的光学装置，尤其对于阶梯形透镜点光源，其包括一个阶梯形透镜和一个光漫射元件，其能够非常有利的产生一个阶梯形透镜点光源，后者的出射光孔径角可变，在每个孔径角都有均匀照明光场，同时具有高效率。

[0060] 本目标能够根据权利要求 51 的阶梯形透镜点光源非常简单地获得。

[0061] 发明者发现可以用漫射屏非常简便地避免阶梯形透镜点光源常见的高损耗。此时，如果阶梯形透镜具有一个漫射屏，尤其优选为圆形并设置在阶梯形透镜的中心处，则更为有利。

[0062] 本实施例中，照明场中心处的暗区域可以在阶梯形透镜点光源的各个位置处被非常有效地避免，而且同时不再出现反射器的亮点位置上的较高的光损耗。

[0063] 令人惊讶的是，很明显当所需的散射光的比例增加时，反射器的出射光的几何光路精确地照亮阶梯形透镜位置上的很小区域。

[0064] 发明者通过本发明利用了这一现象来生成一个自动或自适应光混合系统，其与阶梯形透镜点光源的调整同步，仅将该位置上所需的散射光分量和几何光学成像光混合。

[0065] 该光混合比可以最优的自适应于各种所需的光分布，下文简称为混光比。

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[0066] 通过这种自动光混合系统，对反射器的各个位置基本上生成正确的混光比，因此总具有非常均匀的照明光场，而且在过程中不会出现不必需的散射损失。

[0067] 在这种情况下，阶梯形透镜照亮整个区域的混光比可以根据选择漫射屏相对于阶梯形透镜其余部分的直径来确定，散射光的孔径角可以根据阶梯形透镜的散射特性在很宽的范围内任意确定。

[0068] 另外，散射效果可以在集成漫射屏本身上变化，由此例如散射较强的区域设置在漫射屏的中心，而散射次强的区域设置在所述屏的边缘。其结果是高聚焦的光束也能被额外地扩展，从而能够实现极宽的照明角度。

[0069] 可选的，漫射屏的边缘不仅可以设置成阶跃式终止，所述边缘还可以设置成散射效果连续降低，还可以在延伸到阶梯形透镜之下或之上。这进一步适应了取决于位置的混光比。

[0070] 同时，整个光场内保持了照度的均匀性，例如图 12 的实例对于亮点位置和泛射位置同时保持了均匀性。

[0071] 根据本发明提供了一个大孔径椭圆形反射器。黑体辐射器，尤其是卤素灯的灯丝，或放电灯的放电弧位于椭圆的反射侧焦点上，而椭圆的第二个远离反射器的焦点大致位于靠近反射器的阶梯形透镜的实焦点上，根据这一事实来设置亮点位置。

[0072] 反射器的反射光在进入阶梯形透镜之前，事实上完全聚焦到椭圆的远离反射器的焦点上。位于阶梯形透镜的反射侧焦点上的放电弧或灯丝成像到通过阶梯形透镜的无穷远处，因此它的光被转换成实际上的平行光束。

[0073] 假定适当选择反射器的孔径角和阶梯形透镜，反射器的反射光事实上完全被阶梯形透镜获得，作为很窄的点光束向前辐射。

[0074] 但是，在另一个机械上更加复杂的实施例中，一方面通过以适当的方式改变灯相对于反射器的位置，另一方面，改变阶梯形透镜和反射器之间的距离，可以按照要求增加阶梯形透镜的出射光束的孔径角。

[0075] 为了保持传统型阶梯形透镜点光源的较好的照度均匀性，这些距离调整应该通过适当选择的约束联结来实现。

[0076] 通常，反射器、阶梯形透镜和 / 或漫射屏至少一侧上被涂覆，例如这些元件由塑料制成时涂覆上一个防划伤和 / 或防反射层。

[0077] 本发明的一个优选实施例包括一个阶梯形透镜点光源，其中反射器的光反射面，优选具有局部区域或小平面，以光散射方式构成，并且阶梯形透镜的零个、一个或两个表面以光散射形式构成。这导致了散射光的一个确定的部分叠加到几何光学成像光上，这能够减少光场内的暗环。

[0078] 根据本发明，有利地提供了点光源对于建筑、医疗、电影院、舞台、演播室和摄影以及闪光灯的使用。

[0079] 下面通过优选实施例并参照附图更详细地阐释本发明。

[0080] 图中：

[0081] 图 1 给出了光学装置的第一个实施例，其中阶梯形透镜中心设置了环形漫射屏，后者具有略微相对旋转的各个小面，

[0082] 图 2 给出了光学装置的第二个实施例，其中阶梯形透镜中心设置了环形漫射屏，

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后者具有通过 Monte Carlo 方法略微偏离规定位置的各个小面，

[0083] 图 3 给出了第三个实施例，其中阶梯形透镜中心设置了环形漫射屏，后者的各个小面位于阿基米德螺线上，

[0084] 图 4 给出了平凸透镜和中心漫射屏的横截面，其主体是平行结构，阶梯形透镜是凸形，

[0085] 图 5 给出了双凹阶梯形透镜的横截面，具有几何光学光束扩展或光散射特性，主体和其几何光学效果的阶梯形透镜系统是凹形结构，

[0086] 图 6 给出了图 4 中剖面图示的上半部分的放大细节，

[0087] 图 7 给出了凸凹阶梯形透镜设备的剖面图，其主体是凹形，几何光学效果的阶梯形透镜系统是凸形结构，

[0088] 图 8 给出了一种混合透镜设备的剖面图，其包括一个压印平凹塑料阶梯形透镜，并固定到玻璃制成的漫射屏上，

[0089] 图 9 给出了一种混合消色差透镜的剖面图，其中玻璃制成的平凹透镜连接到塑料或不同色散的玻璃制成的双凹阶梯形透镜上，

[0090] 图 10 给出了阶梯形透镜点光源的一个实施例，阶梯形透镜在亮点位置上具有正的屈光力，反射器的远离反射器的焦点近似叠加到阶梯形透镜左侧的实焦点上，

[0091] 图 11 给出了图 10 所示的阶梯形点光源在第一泛射位置上的实施例，反射器的远离反射器的焦点靠近阶梯形透镜的表面，

[0092] 图 12 给出了阶梯形透镜的光强在亮点位置以及在一个泛射位置时和孔径角相关的对数表示，

[0093] 图 13 给出了阶梯形透镜点光源的一个实施例，阶梯形透镜在亮点位置上具有负的屈光力，反射器的远离反射器的焦点近似叠加到阶梯形透镜右侧的虚焦点上，

[0094] 图 14 给出了图 13 所示的阶梯形点光源在第一泛射位置上的实施例，反射器的远离反射器的焦点近似位于靠近反射器的阶梯形透镜表面上，

[0095] 图 15 给出了阶梯形透镜的光强在亮点位置以及在一个泛射位置时和孔径角相关的对数表示，

具体实施方式

[0096] 下面参照优选实施例来具体说明本发明。

[0097] 本说明书通常假定进入透镜的光在图中从左侧向右侧传播。

[0098] 此外，在各个实施例的说明中，对于光学装置 1 的作用相同或基本相同的组成部分使用了相同的附图标记。

[0099] 在先申请 DE 103 61 122 和 DE 103 61 117 的内容构成了优先权的内容，标题为“阶梯形透镜点光源，光器件的耦合距离可变”也被合并到本发明中作为参考。

[0100] 下面参看图 1，它给出了光学装置的第一个实施例，其中阶梯形透镜中心设置了环形漫射屏，后者具有略微相对旋转的单个表面。

[0101] 光学装置整体标注为 1，它包括一个阶梯形透镜 2 和设置在透镜中心区域上的漫射屏 3。

[0102] 阶梯形透镜 2 设置了同心的环形阶梯，图 1 中的光学有效面区域的附图标记为 4、

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5 和 6。

[0103] 图 1 所示以及图 2 和 3 所示的漫射屏 3 例如同一申请人在 2003 年 9 月 19 日申请，题目为“漫射屏”的德国专利申请 DE 103 43 630.8 中所述的漫射屏，其全部内容也合并在本发明的内容中作为参考。

[0104] 在这个优选实施例的情况下，光学装置 1 用平面的主体 7 通过单步高温成形制造而成，基本上在由塑料构成的实施例的情况下。

[0105] 下文中，首先仅说明图 1、2 和 3 所示的光学装置 1 的共有特征，然后再详细阐释其中的差别。

[0106] 环形漫射屏 3 设置在主体 7 的右侧出射面上，并在第一环形部分 8 内的整个区域上延伸，后者被清晰地界定，优选地无中断地连接所述屏。

[0107] 当透镜具有实的、右侧、正焦点时，主体 7 优选为凸形或者在漫射屏 3 区域内以及在环形表面 4、5、6 和 8 区域内向外弯曲，如图 4 和图 6 的剖面图所示。

[0108] 当透镜具有虚的或负的、左侧焦点时，主体 7 优选为凹形或者在漫射屏 3 区域内以及在环形表面 4、5、6 和 8 区域内向内弯曲，如图 5 的剖面图所示。

[0109] 但是，尤其当使用混合透镜时，如图 8 和 9 的剖面图所示，主体 7 由两个或更多个器件组成，包括具有阶梯形透镜 2 的主体部分 7 以及另一个主体部分 9，后者可以如图 8 所示为平面形式，或如图 9 所示为平凸形式。

[0110] 在混合透镜的情况下，主体部分 7 优选由第一种材料的玻璃制成，而主体部分 7 由色散与主体部分 9 不同的第二种材料的玻璃或者由可热成形的塑料制成。

[0111] 下面参看图 4，其给出了一个具有中心漫射屏 3 的平凸阶梯形透镜，如图 6 所示，还放大给出了图 4 中的细节。

[0112] 图 4 和图 5 所示的单器件式阶梯形透镜 2 中，各个光学有效面 11、12、13 是非球面或球面透镜的一部分，光学装置 1 的边缘区域 10 是平面平行的形式，从而安装在规定的机械容器内。

[0113] 作为非球面透镜的一部分，所述阶梯的环形光学有效面（例如 4、5、6、11、12、13）的形状使得近似平面波在实焦点上结合，其波阵面垂直于光轴。

[0114] 此时，光轴趋于延伸通过基本垂直于基平面的光学装置的中心。

[0115] 图 5 所示的双凹阶梯形透镜时，各个环形光学有效面的形状使得平面波从左侧进入透镜，产生了球面波的波阵面，其虚焦点或原点看起来位于图 5 所示的阶梯形透镜 2 左侧的光轴上。

[0116] 这种情况是：几何光学条件仅对所用光谱的中心波长范围内的一个波长精确地保真。

[0117] 为了简化制造工艺，可以用球环部分来模拟非球面透镜，从而取代复杂的非球面环形结构。

[0118] 此时，尽可能模拟球面部分的例如圆弧面部分用在环的各个表面上，从而能简化所需压印工具的制造。

[0119] 另一个简化包括例如利用阶梯形透镜的光锥包络形状的光学表面，此透镜的阶梯数量很多，相邻阶梯的边缘点之间的各个光程差很小，那么该表面的倾角仅适于非球面透镜的平均倾角。

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[0120] 此时，阶梯形透镜的各个环形部分和中心圆形部分可以设置成凹形或凸形，这根据需要光会聚或光发散特性来确定。

[0121] 为了阐释本发明的原理的最大可变可用性，图 5 给出了一个双凹阶梯形透镜，图 7 给出了一个凸凹透镜，图 8 和图 9 给出了混合透镜，其中图 9 所示的透镜具有色差校正特性。

[0122] 下面具体阐释图 9 所示的混合透镜，其中右侧有一个实焦点的平凹玻璃透镜 14 连接到一个凹凸发散阶梯形透镜 15。

[0123] 两个透镜 14 和 15 的屈光力或焦距以及折射率分别综合选择，由此仍然能产生会聚效果。这意味着整体效果是一个焦点向右移动的会聚透镜。

[0124] 但是，此时选择阶梯形透镜 15 的材料使得其色散效果在整个设备内产生与平凹透镜 14 相反的色散效果，这样整体效果是此透镜系统的色差很小。

[0125] 在另一个替换设置中，阶梯形透镜 15 也由层压到透镜 14 上的压印塑料制成。塑料透镜 15 具有一个防划伤层 21。

[0126] 如果使用了压印玻璃透镜，各个阶梯区域内的光程差优选大于 100 个光波长。

[0127] 如果使用了压印塑料阶梯形透镜，各个阶梯区域内的光程差优选小于 1000 个光波长。

[0128] 此外，围绕着阶梯形透镜的中心圆形部分的环形部分通常具有相同的径向程度 16，即相同的阶梯宽度 16，参看图 6。此时会产生不同高度的阶梯，因为各个环形光学有效面部分的倾角一般随着离中心的距离的增加而变化。

[0129] 可选的，对于难以成形的材料，为了获得制造工艺中的高精度，光学有效面部分的高度 17 可以保持固定，从而产生了不同宽度的环形，参见图 6。

[0130] 另外，阶梯形透镜 2 和 / 或漫射屏 3 可以构成为一个滤光片，尤其是紫外，红外或全彩带通滤光片和 / 或转换滤光片。

[0131] 为此，如果在一侧上施加了一个干涉滤光层 20 是尤其有利的，如图 9 的实例中平凹透镜 14 的左侧所示。

[0132] 可选的，此干涉滤光层系统也可以用于色温漂移或谱线补偿。

[0133] 另外，如果光学装置 1 的至少一个表面面对着玻璃制成的光源，并且被预压，优选热预压，因为这能导致明显增加的热稳定性。

[0134] 漫射屏 3 通常位于光学装置 1 的左侧和右侧上，即光入射面和光出射面。

[0135] 此外，如图 7 示意性所示，能够在光入射面和光出射面上都设置漫射屏 3，从而以规定的方式叠加其散射效果。

[0136] 而且，漫射屏 3 可能有漫射程度不同的区域来取代突变的径向边界，例如漫射程度大的区域位于中心，而漫射程度小的区域位于边缘，优选连续的从大到小。

[0137] 为此，参看图 8 示意性所示，漫射屏例如具有规定的粒度，包括在中心区域 22 的精细粒度结构，以及随着径向距离的增加的边缘区域 23 的粗糙粒度结构。

[0138] 下述实施例中漫射屏 3 可以被用作简单粒度或有关区域，除了常规漫射屏的面的常规设置，这种新方法和其他方法一样。

[0139] 图 1 所示的第一个实施例中，通过提供一个具有透明主体 7、9 的漫射屏 3 来实现，漫射屏 3 的光学有效面被划分成小面 24、25、26，实例中仅用附图标记来表示，并且各个小

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面 24、25、26 相对于第二个弯曲表面有规定的突起或凹陷，小面 24、25、26 的这种设置使得它们能够相对互相旋转，或假定了不同的几何形状。

[0140] 在这种情况下，小面被理解成各个几何形状的边缘轮廓所跨的面积。根据第一个表面即漫射屏 3 的主体 7 的表面的结构是平面或弯曲区域，几何形状的小面 24、25、26 所跨的形状也类似是平面或弯曲的。

[0141] 小面 24、25、26 所指定的突起或凹陷表示了漫射屏 3 的一个元素。突起或凹陷以小面 24、25、26 作为基面，并且至少位于所述基面之上或之下。突起或凹陷相当于照明时的透镜。

[0142] 这种方案导致了多个不同轮廓的光场进行叠加，因此构成了所需的圆形光场。

[0143] 根据各个小面的设置以及小面的突起或凹陷结构，其能够提供一个照明强度梯度可选的光场，或者预先设置的看起来柔和或反差大的光场。

[0144] 看起来柔和的光场是照明强度向光场边缘的梯度较小的场。反过来，光场边缘处照明强度的梯度较大会导致看起来反差很大的光场。所获得的另一个优点是当使用放电灯时，小面设置能够避免边缘色差。

[0145] 为了通过这种方法增加贡献于叠加的单个光场对的变化，以及为了获得上述优点，可以进行各种测量。

[0146] 因此，小面具有多边形的边缘轮廓。此时，多边形的角的个数是可变的。

[0147] 多边形边缘轮廓的小面应该完全覆盖了表面，因为否则就没有局部漫射效果。

[0148] 此外，还能够提供一种漫射屏，其小面 24、25、26 包含不同的区域，如图 2 的实例所示。

[0149] 多边形可以选择三角形、四边形、五边形、六边形和 / 或七边形。多边形的相邻角之间的连接部分可以是直线或曲线。

[0150] 小面的不规则性另一个结果是它具有不同的取向。

[0151] 采用的另一种方法是满足圆形光场的目标，根据光场边缘处的照明强度，看起来柔和或反差大的光场是选择适当的不同曲率的突起或凹陷的结果。曲率可以是球面的，突起或凹陷相应的构成为球帽。可选的，也可以选择非球面的曲率。此外，为了确保上述目标，可以改变凹槽的深度或凸起的高度。

[0152] 如上所述，很明显上述方法是可选的或累加的。对于上述方案的实际实现，第一种变化提供了一种漫射屏，其透明主体的第一表面被划分成小面，每个小面被指定了相对于弯曲的第二表面的突起或凹陷，其中突起或凹陷的顶点 S 沿着螺旋线设置。

[0153] 突起或凹陷的顶点 S 被定义成通过小面中点的小面法线和突起或凹陷的曲面之间的交点。

[0154] 如果对于两个相邻小面的突起或凹陷的高度、半径和 / 或深度不同，那么公共边缘通常是弯曲的，假定了平面视图上不同几何形状的边缘导致了凹陷。

[0155] 沿螺旋线设置顶点 S 产生了多个不规则设置的小面，生成了所需的圆形光场，在放电灯时，光场不会在边缘区域产生色差，并且照明强度梯度也可以预先设置。

[0156] 突起或凹陷的高度可以通过漫射屏 3 来改变，因此突起和凹陷具有不同的高度或深度。这也有助于提供一个看起来或多或少柔和或者反差大的圆形光场。

[0157] 如图 3 所示设置漫射屏 3 时，小面 24、25、26 的顶点 S 基本上位于阿基米德螺旋线

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上。

[0158] 沿着螺旋线由内向外连续去除固定的弧长 L 就得到了各个点。这些顶点等距排列。除了等距设置这些顶点，也可以使用不等的弧长 L。因此可以选择从内向外增加的弧长 L。漫射屏内的小面具有很小高度的突起或者具有很小深度的凹陷，由此获得了较小的漫射效果。朝向边缘处，小面变得较大，突起高度或凹陷深度变得较大，漫射效果也同样变得更大。那么光场在中心处有相当小的半散射角，同时有非常大的照明强度。与此相比，给定固定的弧长 L，照明强度相当平稳，柔和的从大变小。

[0159] 上述测量手段可以选择地实现，如果合适的话，也可以累积实现，其使得漫射屏 3 以不同的方式适应各种照明系统，例如各种反射器。

[0160] 因此适应各种反射器可以通过选择螺旋线的类型、弧长 L 的数值来实现，也可以选择变化的或固定的弧长。这些测量手段能够影响照明系统预设区域内的光场，以局部放大或衰减，并且因此以多种方式来优化光场。

[0161] 很明显从上述说明可以看出本方案对于本领域技术人员提供了很多参数，以便于他能够根据照明系统来设置和调节光场。关于这点，不同几何形状的小面的选择方法使得光场以更加多变和不同的方式来适应各种条件。

[0162] 通过实例，图 1 和 2 给出了其他优选实施例。图 1 阐释了光学装置的第一个实施例，其中阶梯形透镜包括近似中心设置并带有各个小面的圆形漫射屏，这些小面可以略微互相旋转，而图 2 给出了阐释了光学装置的第二个实施例，其中阶梯形透镜包括近似中心设置圆形漫射屏，漫射屏的小面通过 Monte Carlo 方法偏离其规定位置。

[0163] 此外，存在设计不同的多种可能性仍适合实现所需的光场或所需的预定漫射特性。关于这点，各种解决方案还使得漫射屏的视觉效果最优。例如，小面可以使用菱形或犬牙图案。

[0164] 另外，漫射屏使用非同轴或非同心的设置也在本发明的范围内。

[0165] 本发明的优选实施例中的光混合系统可以被很好的使用，下文将通过实例具体讨论。

[0166] 照明设备的优选实施例的具体实施方式的详细说明

[0167] 包含正屈光力的阶梯形透镜的阶梯形透镜点光源

[0168] 下面参照图 10，其给出了阶梯形透镜点光源在亮点位置上的一个实施例。

[0169] 阶梯形透镜通常包含一个椭圆反射器 31，一个灯 32，后者可以是一个白炽灯，尤其是卤素灯、发光二极管、发光二极管阵列或者气体放电灯，以及一个阶梯形透镜 33，后者是一个会聚透镜，优选是一个平凹阶梯形透镜。

[0170] 图 10 中，椭圆反射器 31 的远离反射器的焦点 F2，近似叠加到阶梯形透镜 33 左侧的实或正焦点 F3 上。

[0171] 图中，点光源发出的光束 34 仅示意性的用其外边缘的光线来表示。

[0172] 阶梯形透镜 33 和反射器 31 的前边缘之间的距离 a，以及灯 32 和反射器 31 的顶点之间的距离 b，也在图 10 中示出。

[0173] 根据灯 32 的灯丝或放电弧基本上位于椭圆反射器 31 的反射侧焦点 F1 上来设置亮点位置。

[0174] 在这个位置上，反射器 31 的反射光能够基本上完全被导入椭圆 31 的远离反射器

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的焦点F2上。那么阶梯形透镜33的左侧正或实焦点F3基本上与椭圆反射器31的焦点F2一致。

[0175] 从图31也能够看出在近场区域，反射器32内的开孔35相当于光场34的平行光路内的暗区域36。

[0176] 阶梯形透镜33内设置了一个圆形中央设置的漫射屏37，其生成了规定的散射光比率和散射光的规定孔径角。这提供了散射光相对于阶梯形透镜33的几何光学成像光的规定混光比。

[0177] 作为此实施例中漫射屏37的替换，另一个实施例中，散射效果沿着漫射屏37的半径连续变化，从而在漫射屏37的中心设置了散射更强的区域，而在所述屏的突变边缘处设置了散射较弱的散射区域。

[0178] 另一种可选的设置中，漫射屏37边缘的构成使得不仅其突变终止，而且其散射效果连续降低，所述边缘延伸到阶梯形透镜之上或之下。

[0179] 其结果是，根据系统来进一步调节与位置相关的混光比，这样本领域技术人员总是能为均匀照明光场或以规定方式产生的局部光强较大的光场提供一个最优混光比。

[0180] 从图10中还可以看出总的光通量仅有一小部分通过亮点位置上的漫射屏37。

[0181] 漫射屏37产生了非常均匀的照明，如图12中亮点位置的线38所示，其给出了阶梯形透镜的光强与孔径角相关的对数表示形式。

[0182] 图11给出了图10所示的阶梯形透镜点光源在第一个泛射位置上的实施例，其中反射器31的远离反射器的焦点F2近似位于靠近反射器的阶梯形透镜33的表面上。

[0183] 此时，相对于亮点位置的a值的变化是通过机械导引以规定的方式来实现的。

[0184] 此构造从原理上与图10所示的阶梯形透镜点光源的构造相对应。

[0185] 但是，从图11可以明显看出，出射光束34和暗区域36的孔径角都增加了。

[0186] 但是，因为在这个位置上，很高比例的光量仅投射到漫射屏37中心的一个非常小的区域上，这个区域可以精确设置，由此其前向散射瓣近似的以期望的方式补偿了远场或远区的暗区域36。还可以参看图12，其通过实例用线39表示了泛射位置上的光条件。

[0187] 通过下面的阶梯形透镜点光源的实施例可以获得更小型的阶梯形透镜点光源，其具有更高的可用照明效率。

[0188] 包含负屈光力的阶梯形透镜的阶梯形透镜点光源

[0189] 下面参照图13，其给出了阶梯形透镜点光源在亮点位置上的一个实施例。

[0190] 阶梯形透镜通常包含一个椭圆反射器41，一个灯42，后者可以是一个卤素灯或者气体放电灯，以及一个阶梯形透镜43，后者是一个会聚透镜，优选是一个双凹阶梯形透镜。

[0191] 图13中，椭圆反射器41的远离反射器的焦点F2，近似叠加到阶梯形透镜43右侧的虚或负焦点F3上。

[0192] 图中，点光源发出的光束44仅示意性的用其外边缘的光线来表示。

[0193] 阶梯形透镜43和反射器41的前边缘之间的距离a，以及灯42和反射器41的顶点之间的距离b，也在图13中示出。

[0194] 根据灯42的灯丝或放电弧基本上位于椭圆反射器41的反射侧焦点F1上来设置亮点位置。

[0195] 在这个位置上，反射器41的反射光能够基本上完全被导入椭圆41的远离反射器

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的焦点F2上。那么阶梯形透镜44的右侧负或虚焦点F3基本上与椭圆反射器41的焦点F2一致。

[0196] 从图13也能够看出在近场区域，反射器41内的开孔45相当于光场44的平行光路内的暗区域46。

[0197] 阶梯形透镜43内设置了一个圆形中央设置的漫射屏47，其生成了规定的散射光比率和散射光的规定孔径角。这提供了散射光相对于阶梯形透镜43的几何光学成像光的规定混光比。

[0198] 作为此实施例中漫射屏47的替换，另一个实施例中，散射效果沿着漫射屏47的半径连续变化，从而在漫射屏47的中心设置了散射更强的区域，而在所述屏的突变边缘处设置了散射较弱的散射区域。

[0199] 另一种可选的设置中，漫射屏47边缘的构成使得不仅其突变终止，而且其散射效果连续降低，所述边缘延伸到阶梯形透镜之上或之下。

[0200] 其结果是，根据系统来进一步调节与位置相关的混光比，这样本领域技术人员总是能为均匀照明光场或以规定方式产生的局部光强较大的光场提供一个最优混光比。

[0201] 从图13中还可以看出总的光通量仅有一小部分通过亮点位置上的漫射屏47。

[0202] 本实施例中漫射屏47也产生了非常均匀的照明，如图15中亮点位置的线48所示，其给出了阶梯形透镜的光强与孔径角相关的对数表示形式。

[0203] 图14给出了图13所示的阶梯形透镜点光源在第一个泛射位置上的实施例，其中反射器41的远离反射器的焦点F2近似位于靠近反射器的阶梯形透镜43的表面上。

[0204] 此时，相对于亮点位置的a值的变化是通过机械导引以规定的方式来实现的。

[0205] 此构造从原理上与图13所示的阶梯形透镜点光源的构造相对应。

[0206] 但是，从图14可以明显看出，出射光束44和暗区域46的孔径角都增加了。

[0207] 但是，因为在这个位置上，很高比例的光量仅投射到漫射屏47中心的一个非常小的区域上，这个区域可以精确设置，由此其前向散射瓣近似的以期望的方式补偿了远场或远区的暗区域46。还可以参看图15，其通过实例用线49表示了泛射位置上的光条件。

[0208] 上述实施例中，分别分配给阶梯形透镜以及漫射屏的第一个和第二个区域占据了光学装置的实表面，其形式是具有不同直径的同心表面(2RSt1，2RStrA)。此时，漫射屏位于半径为RstrA的圆内，并进一步被再次划分。

[0209] 半径为RstrA的漫射屏包含一个半径为RstrI的较小同心圆，后者可选的设置成具有不同的散射特性。

[0210] 阶梯形透镜相对于漫射屏的表面尺寸比率确定了可以用于照明的出射光的比例(根据具体情况确定)，并且根据本发明的实施例，此比率大于2比1(阶梯形透镜表面相对于漫射屏表面)，阶梯形透镜相对于漫射屏的表面尺寸比率优选大于10比1，并且阶梯形透镜相对于漫射屏的表面尺寸比率最优选大于100比1。

[0211] 本发明的另一种设置中，漫射屏的出射光在垂直方向上的孔径角与水平方向上的孔径角不同，从而根据实施例的漫射屏生成了非圆形、椭圆、多边形以及尤其矩形和/或正方形的照明光场。

[0212] 漫射屏划分成散射特性不同的区域，尤其是散射程度不同，还能够控制入射光的类型。亮点位置的圆形光场在调整过程中，如果光锥尽管仍覆盖了整个漫射屏直径RstrA

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但不再覆盖阶梯形透镜，首先变换成边缘柔和的正方形光场，进一步调整时，光锥逐渐变小，如果光锥仅覆盖了内部直径 RstrI，光场再变换为边缘反差大的光场，光锥把光仅导入正方形光场而且非常精确的进入后者。

[0213] 椭圆反射器的椭圆主体可以用基轴 Ha，Hb 精确的确定，见图 14，假定反射器 31、41 的后者是柱面对称并且旋转固定，这意味着通过确定两个互不相同的基轴 Ha 和 Hb 就能完全确定椭圆主体。

[0214] 例如图 14 所示，反射器 31、41 的椭圆率表示确定了椭圆形式的基轴比率 $\varepsilon = Ha/Hb$，这种情况下基本考虑相对于阶梯形透镜点光源的光轴柱面对称的反射器设备。

[0215] 此外，仅为了阐释方便以及更好的理解下述的不等性，图 14 所示的反射器近似对应了中心划分的一半椭圆，或者也相差不大。

[0216] 对于利于照明用途并且高照明效率的设置，ε 的数值应该大于 1。

[0217] 对于上述实施例中的阶梯形透镜点光源，其椭圆反射器的椭圆率为 ε，阶梯形透镜的焦距与半径的比率 $n_{st1} = R_{st1}/F_{st1}$ 优选大于 0.5 倍的 $1/sqrt(\varepsilon^2-1)$，更优选大于 0.9 倍的 $1/sqrt(\varepsilon^2-1)$，其中 $1/sqrt(\varepsilon^2-1)$ 表示 (ε^2-1) 的平方根的倒数。

[0218] 使用本发明带有漫射屏的阶梯形透镜能够将灯 32、42 发射的更高比例的光通量用于照明用途，例如灯 32、42 发射的高达超过 50％的光被导向到照明场。亮点位置上，基本上反射器 31、41 的所有光能够被导向入点照明的窄光场内，此时，入射到漫射屏 37、47 上的部分光形成了柔和的渐逝边缘，这对于很多照明用途是非常需要的。

[0219] 阶梯形透镜点光源具有负屈光力的阶梯形透镜的实施例中，尤其在亮点位置上，其也能够基本上利用灯 42 发送的所有光，直接进入阶梯形透镜和漫射屏，因为这部分光很大程度上产生了照明光的柔和渐逝边缘区域。

[0220] 对于阶梯形透镜点光源的亮点位置，首次利用了灯 42 发射的超过 80％的光，而且在泛射位置上可以利用灯 42 发射的高达超过 60％的光。

[0221] 通过选择阶梯形透镜的照明区域和漫射屏的照明区域的面积比率，例如通过选择漫射屏和阶梯形透镜的直径，能够根据需要设置亮点区域和边缘区域内光的比率。从而能够使阶梯形透镜点光源的光场在亮点位置上朝着边缘迅速下降或更柔和一些。

[0222] 上述阶梯形透镜点光源与一个供电单元或稳压器一起用于照明系列是非常有利的，其相比起现有技术显著的减小了尺寸。与现有技术相比，对于相同的可用光功率，所述供电单元可以从电气上和机械上设计的更小，因为本发明的阶梯形透镜点光源具有非常高的照明效率。因此，对于运输和保管，所需的重量更轻，并且占据的存放空间也更小。

[0223] 但是，其结果是照明人群和目标上的总热负荷也减小了，尤其当使用冷光反射器时。

[0224] 此外，本发明的阶梯形透镜点光源也可以被用于有利地增加闪光灯的照明效率以及照明光场的均匀性。

[0225] 附图标记列表

[0226] 1 装置

[0227] 2 阶梯形透镜

[0228] 3 漫射屏

[0229] 4 环形、同心设置的光学有效面部分

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[0230] 5 同上

[0231] 6 同上

[0232] 7 主体（部分）

[0233] 8 如 4 到 6

[0234] 9 多分区装置的主体部分

[0235] 10 平面平行边缘区域

[0236] 11 光学有效面

[0237] 12 同上

[0238] 13 同上

[0239] 14 固体材料制成的平凹透镜

[0240] 15 凸凹阶梯形透镜

[0241] 16 光学有效面部分的径向程度，宽度

[0242] 17 光学有效面部分的高度

[0243] 18 防反射层

[0244] 19 防划伤层

[0245] 20 干涉滤光层

[0246] 21 防划伤层

[0247] 22 漫射程度大的中央区域

[0248] 23 漫射程度小的边缘区域

[0249] 24 小面

[0250] 25 同上

[0251] 26 同上

[0252] 31 反射器

[0253] 32 灯

[0254] 33 阶梯形透镜

[0255] 34 出射光束

[0256] 35 反射器 31 内的开孔

[0257] 36 暗区域

[0258] 37 漫射屏

[0259] 38 亮点位置上的强度分布

[0260] 39 泛射位置上的强度分布

[0261] 41 反射器

[0262] 42 灯

[0263] 43 阶梯形透镜

[0264] 44 出射光束

[0265] 45 反射器 41 内的开孔

[0266] 46 暗区域

[0267] 47 漫射屏

[0268] 48 亮点位置上的强度分布

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[0269] 49 泛射位置上的强度分布

HESAI EX1002, P.526

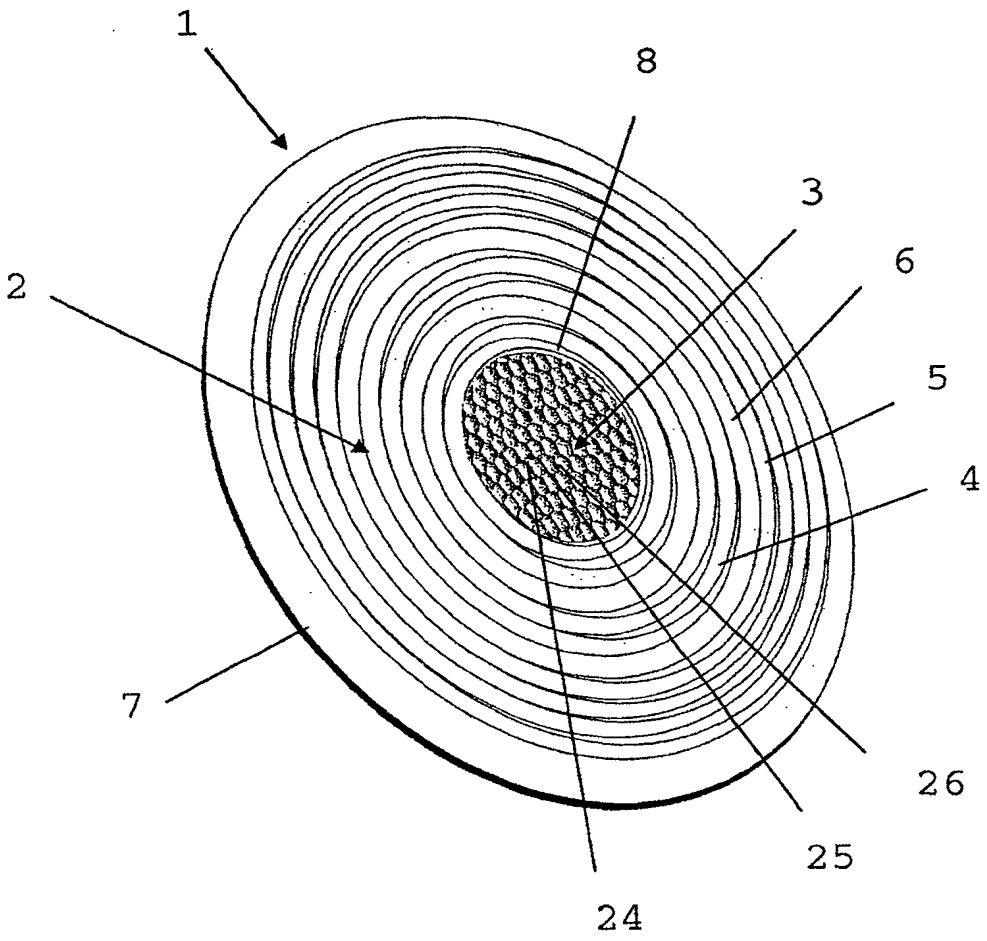


图 1

HESAI EX1002, P.527

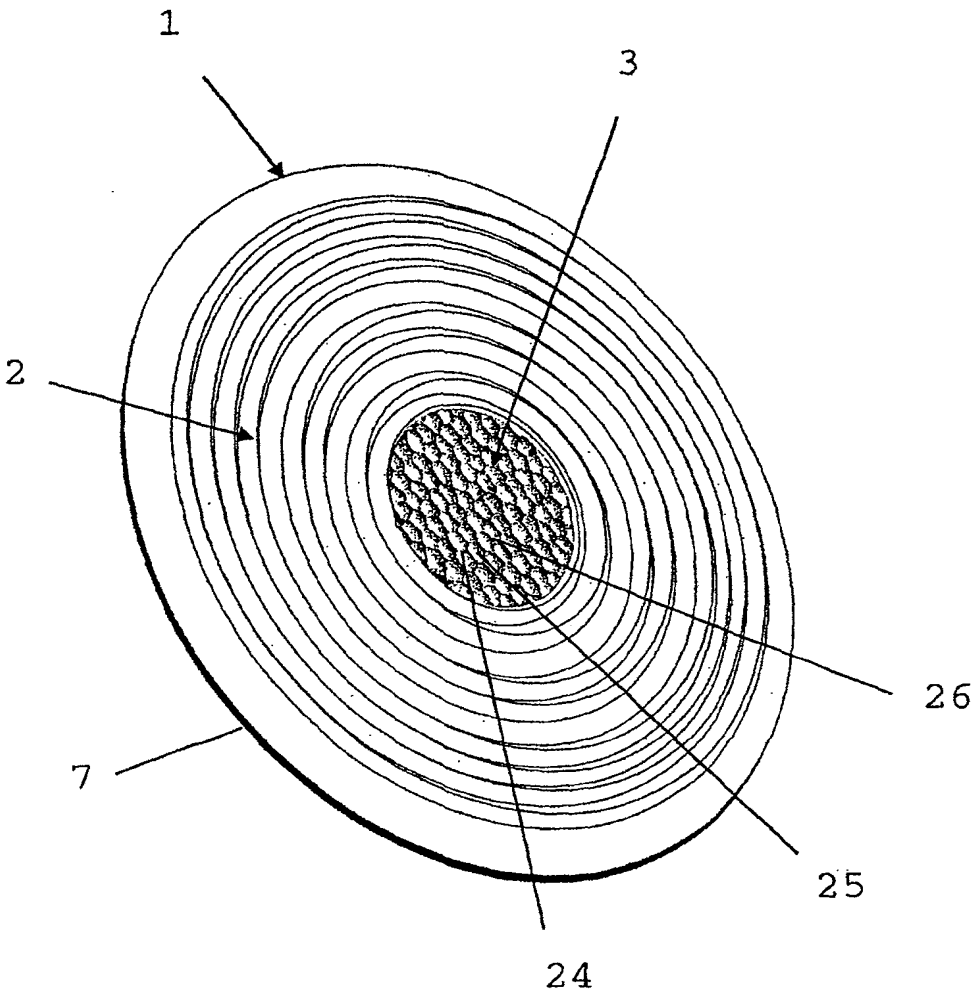


图 2

HESAI EX1002, P.528

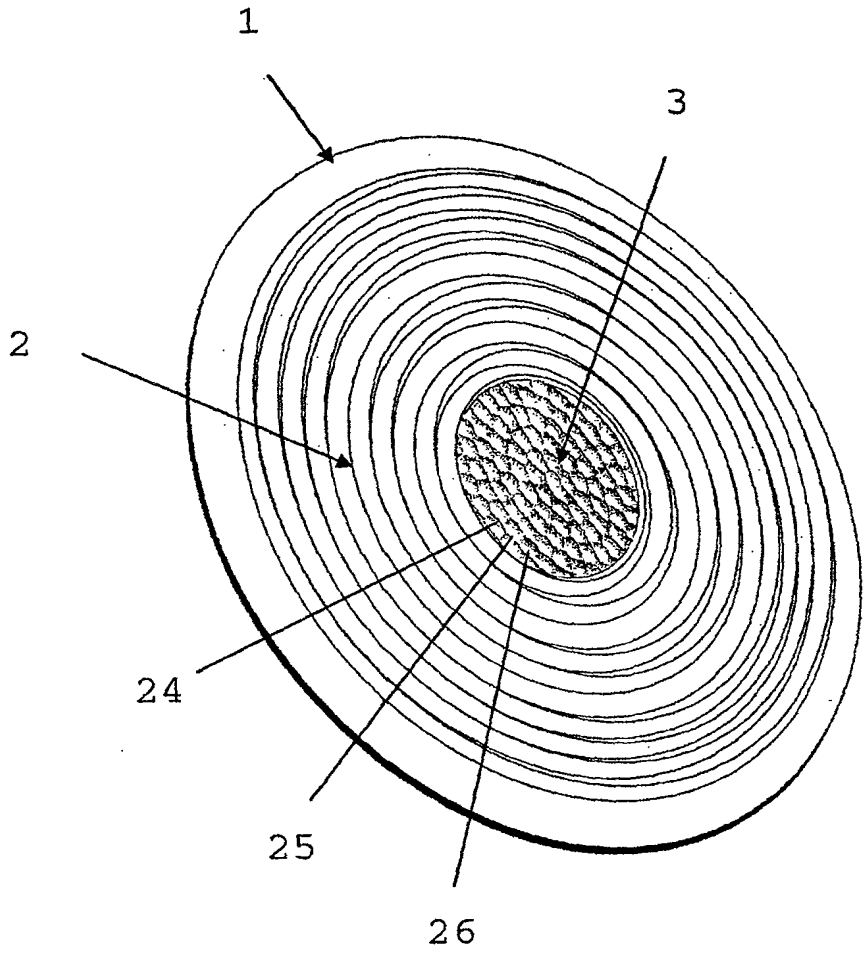


图 3

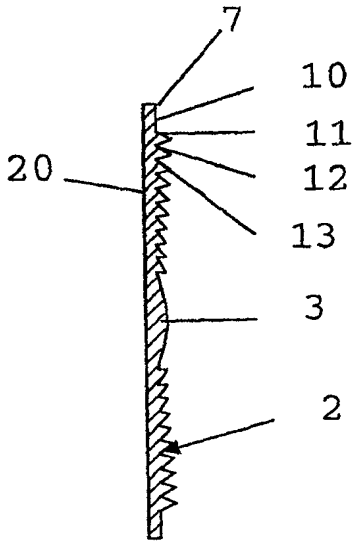


图 4

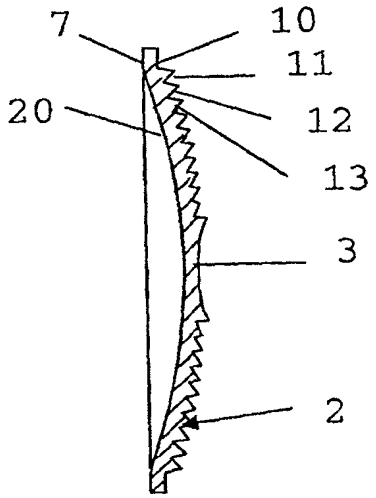


图 5

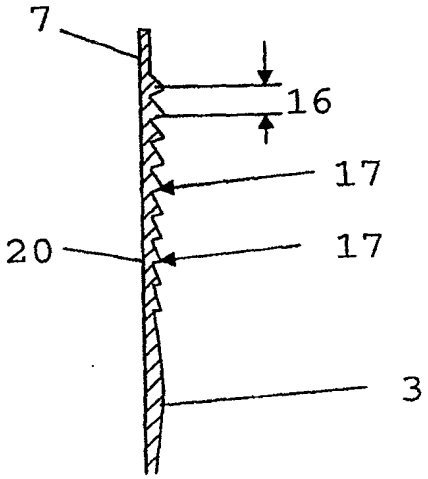


图 6

HESAI EX1002, P.529

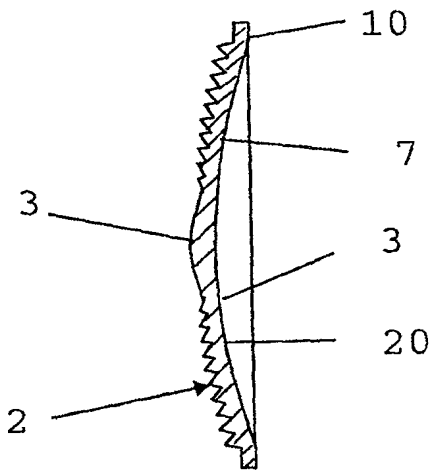


图 7

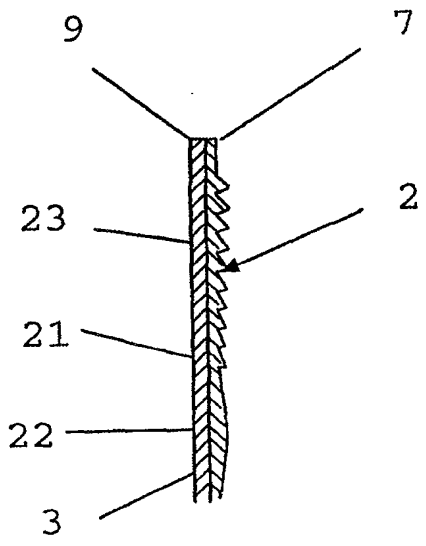


图 8

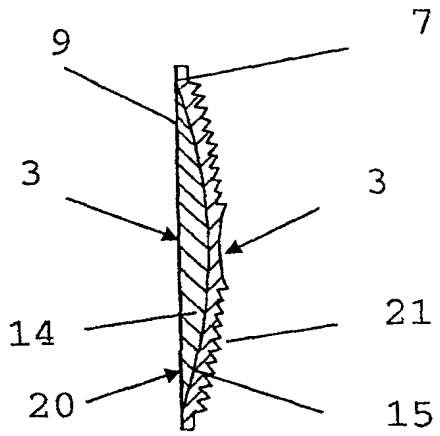


图 9

HESAI EX1002, P.530

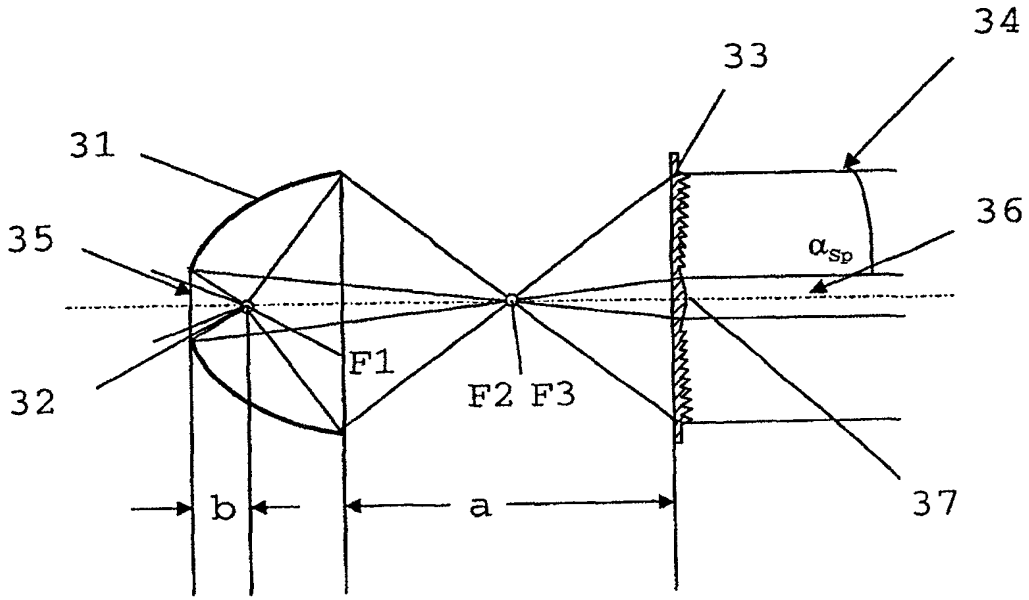


图 10

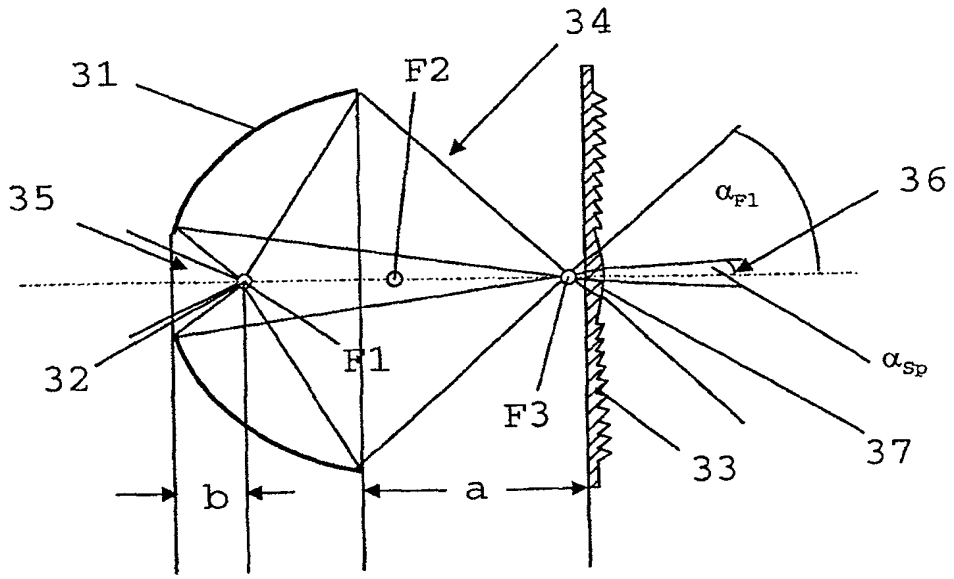


图 11

HESAI EX1002, P.531

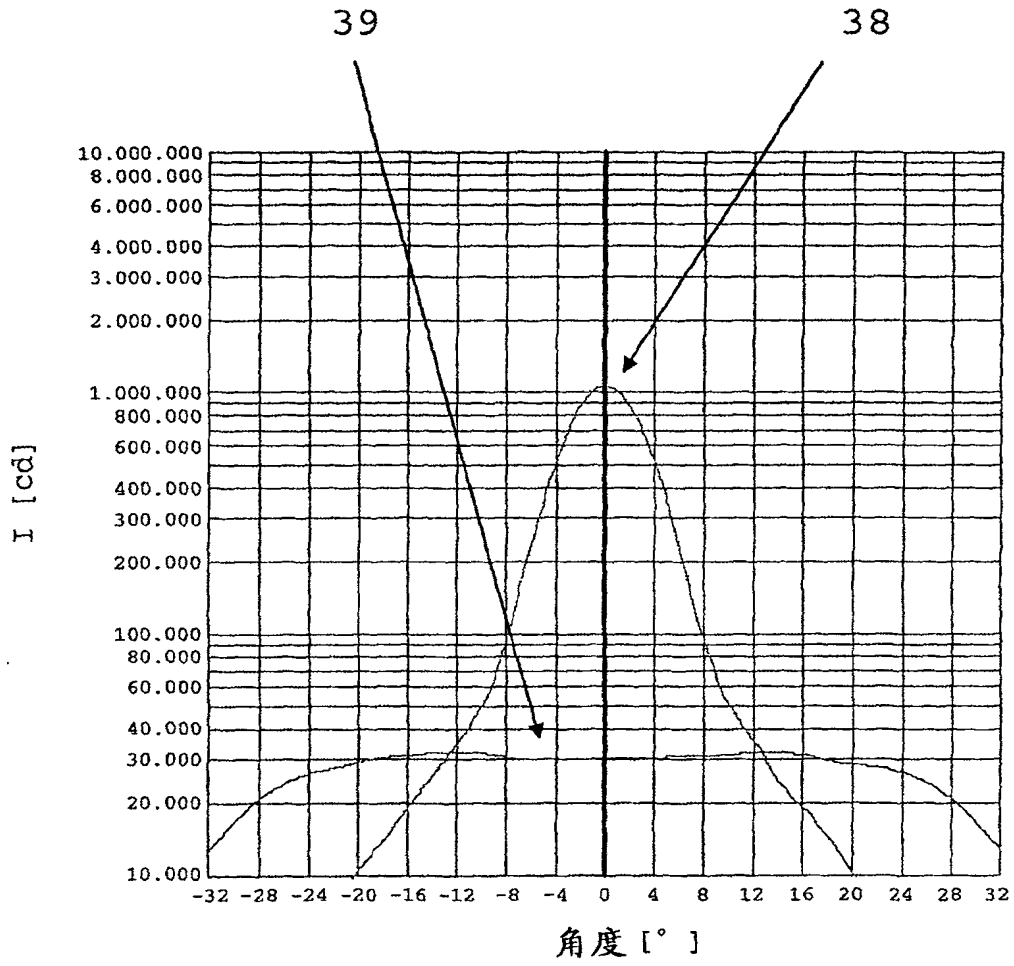


图 12

HESAI EX1002, P.532

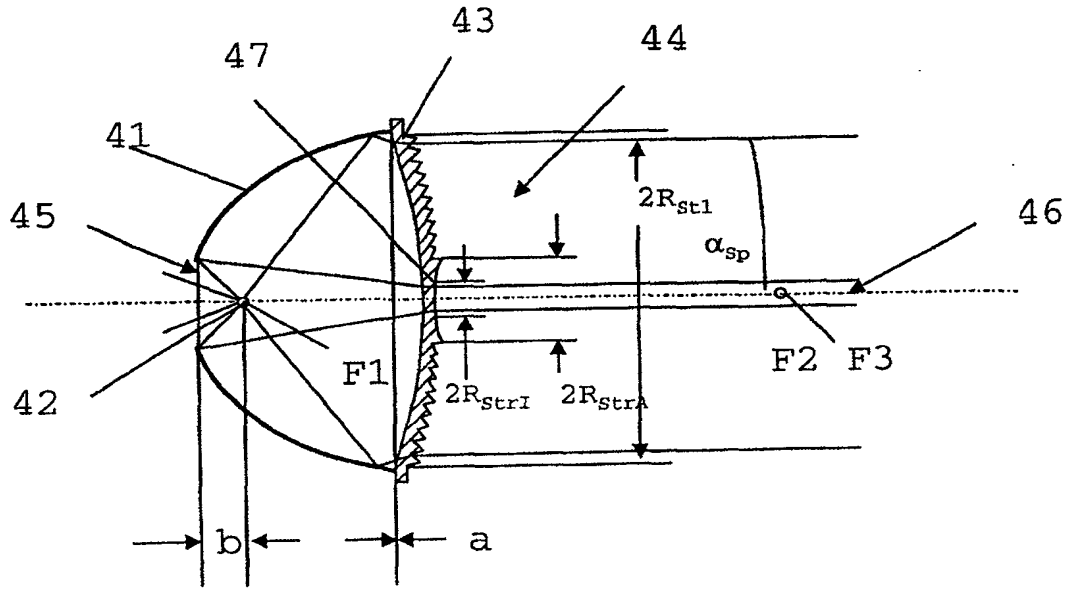


图 13

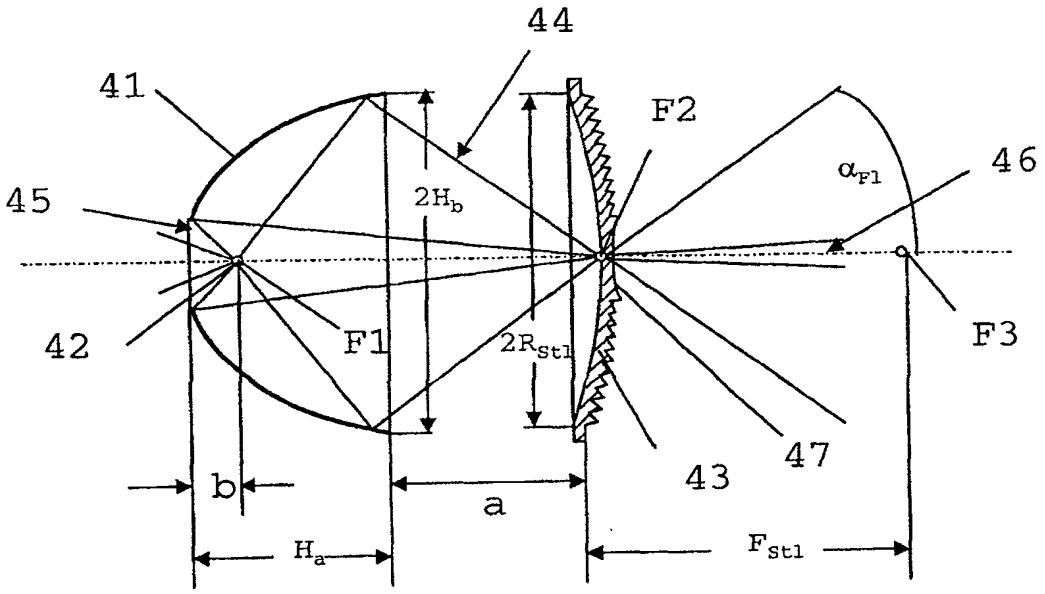


图 14

HESAI EX1002, P.533

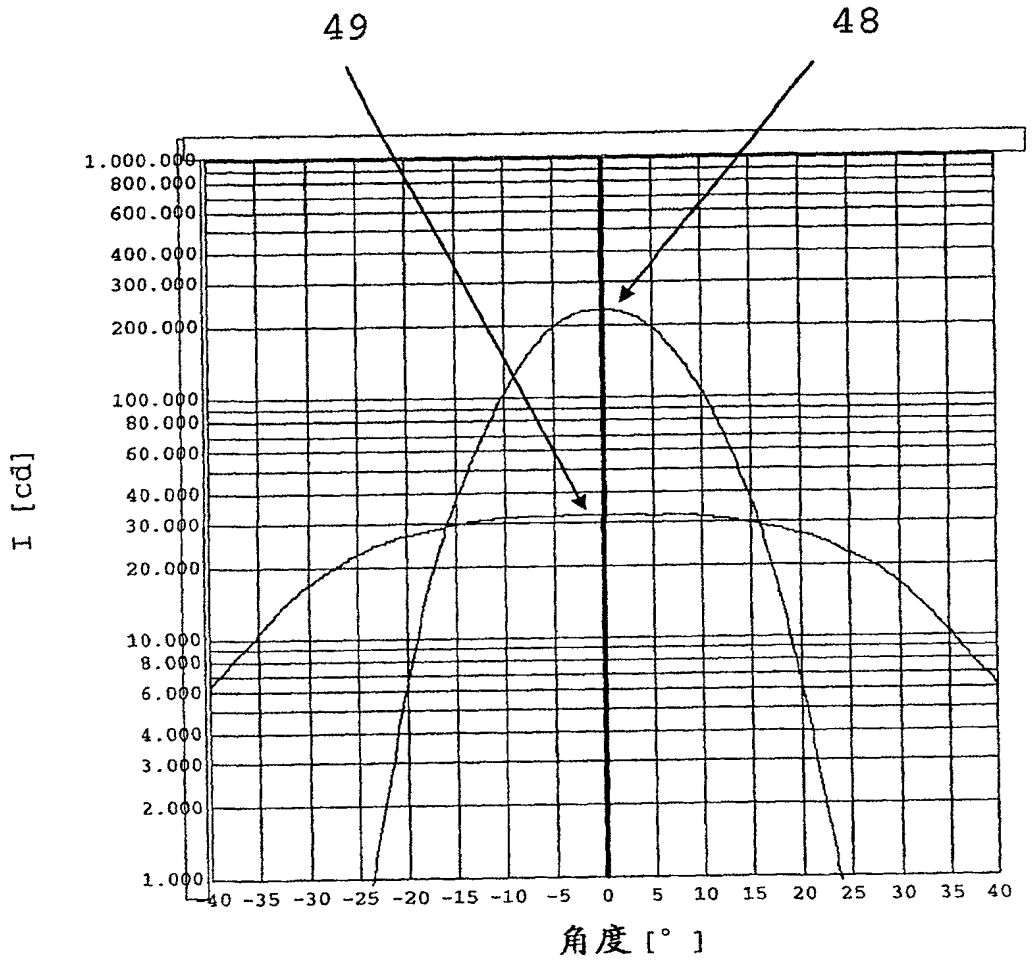


图 15

HESAI EX1002, P.534

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 193 539 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
09.11.2005 Bulletin 2005/45

(21) Application number: **01000336.6**

(22) Date of filing: **01.08.2001**

(51) Int Cl.[7]: **G02F 1/13357**, B41J 2/455, B41J 2/45, B41J 2/465, G02B 13/22, G02B 26/10, G02B 27/44, G02B 27/09

(54) **Illumination system for use in imaging systems**

Beleuchtungssystem zur Verwendung in abbildenden Systemen

Système d'illumination pour l'utilisation dans des systèmes de formation d'images

(84) Designated Contracting States:
DE FR GB

(30) Priority: **11.08.2000 US 637417**

(43) Date of publication of application:
03.04.2002 Bulletin 2002/14

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- **AMM D T, CORRIGAN R W: "Optical Performance of the grating light valve technology" PROCEEDINGS OF THE SPIE, vol. 3634, January 1999 (1999-01), pages 71-78, XP001179316**

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EP 1 193 539 B1

Description

BACKGROUND OF THE INVENTION

[0001] The invention relates generally to imaging systems, and particularly relates to illumination systems for use in imaging systems.

[0002] Conventional imaging systems typically include an illumination system for generating a field of illumination, and an optical assembly for applying the field of illumination in a modulated form to an imaging surface. Such illumination systems may provide a line of laser illumination so that a line of picture elements (or pixels) may be imaged at a time for efficiency in imaging. The field of illumination may be modulated by selectively controlling the illumination system (e.g., as disclosed in U.S. Patent No. 4,804,975), or by using a light modulator for selectively modulating the field of illumination. Illumination systems that modulate the illumination field generally require that relatively high powers be switched on and off at fairly high speeds. This may be relatively expensive and difficult to use to achieve high quality and/or high resolution imaging. It is desirable, therefore, that light modulators be used in certain applications. The use of light modulators permits the illumination system to provide a relatively uniform field of illumination. This allows the laser emitters to exhibit relatively uniform power consumption and be maintained at a relatively uniform temperature, which also contributes to uniformity of the illumination field.

[0003] Illumination systems for providing uniform fields of high power illumination typically include an array of laser diode emitters and a variety of optical elements that are positioned to adjust the size and uniformity of the field of illumination, and to direct the illumination field to a light modulator. U.S. Patent No. 4,786,918, for example, discloses a laser diode array that includes a plurality of spatially disposed laser emitters that may be used for printing with a laser line modulator. A light modulator for conventional systems may either transmit the modulated illumination field through the light modulator toward the imaging surface (e.g., as disclosed in U.S. Patent No. 5,521,748), or may reflect the modulated illumination field toward the imaging surface (e.g., as also disclosed in U.S. Patent No. 5,521,748 as well as U.S. Patents Nos. 5,132,723 and 5,049,901).

[0004] Conventional imaging systems that include a light modulator typically focus the near field image of the light source onto the light modulator. For example, the systems disclosed in U.S. Patent No. 5,521,748 each provide that the near field image of the light source is focused in the slow axis direction onto the light modulator by imaging optics. Near field imaging onto the modulator, however, requires that the physical arrangement of the light source, the imaging lenses and the modulator be very accurately positioned to ensure that the focal point for the light from each of the emitters be located on the modulator. If the focal point is not located on the light modulator, then the quality of the image may be compromised. Also, if the focal length is rather short, then divergence becomes a significant concern, since divergence is inversely related to the focal length of a lens. Moreover, small variations in the arrangement and/or power of the various emitters vis-à-vis each other may result in significant variations in the light field imaged onto the modulator.

[0005] Illumination systems as disclosed in U.S. Patent No.5,521,748 include an array of emitters and an array of lenslets located adjacent the emitters such that specific portions of the light modulator are each illuminated by a specific emitter and its associated lenslet. Such illumination systems may provide non-uniform illumination fields on the light modulator due, at least in part, to variations among emitter characteristics and/or any overlap of illumination portions at the modulator that may occur in an effort to ensure complete coverage of the modulator.

[0006] As discussed in U.S. Patent No. 5,900,981 a type of non-uniformity in an illumination field that may result from the use of a laser diode elements is the smile effect in which the centre portion of the illumination line sags, missing the active portion of the modulator. The systems disclosed in U.S. Patent No. 5,900,981 is disclosed to utilise natural aberrations and/or artificial aberrations for the stated purpose of decreasing the sensitivity of the optical system to the smile phenomenon. The systems of U.S. Patent No. 5,900,981, however, also provide that the near field image of the light source is focused in the slow axis direction onto the light modulator by imaging optics. Such systems may suffer from many of the shortcomings discussed above. Near field imaging, for example, does not permit the imaging system to be telecentric in the slow axis, allowing the distance between slow axis optical elements to be changed without affecting illumination quality. Telecentricity occurs when rays are normal to an incident surface.

[0007] Illumination systems for use in thermal imaging systems in which a thermal recording medium is imaged, typically require greater power than that required in light sensitive imaging systems, since at least a portion of the recording medium must be thermally ablated during imaging. If the illumination source is comprised of a plurality of laser diodes, thermal imaging systems generally require that the fill factor (width of each emitter / spacing of the emitters) be increased. Increasing the fill factor, however, generally causes divergence to increase as well. Divergence relates to the widening of a light field as it travels away from a source.

[0008] It is an object of the present invention to efficiently provide an illumination system for imaging systems that efficiently produces a uniform illumination area at a light modulator.

[0009] It is another object of the present invention to provide such an illumination system that exhibits minimal illumination divergence.

[0010] It is a further object of the present invention to

provide such an illumination system that exhibits telecentricity to facilitate magnification and/or focusing adjustments during use.

[0011] It is also an object of the present invention to provide an illumination system with a relatively high fill factor, yet relatively low divergence.

[0012] It is also an object of the present invention to provide an illumination system that achieves the benefits of near field imaging (e.g., magnification) and far field imaging (e.g., less divergence) in one system.

SUMMARY OF THE INVENTION

[0013] The above mentioned objects are realised by an illumination system having the specific features set out in claim 1, and a method according to claim 10. Specific features for preferred embodiments of the invention are set out in the dependent claims. Further advantages and embodiments of the present invention will become apparent from the following description and drawings.

[0014] The invention provides an improved illumination system for use in imaging systems that may produce a non-overlapped near field image in the slow axis direction, and a far field image of the illumination source in the slow axis direction at a light modulator. In an embodiment, the illumination system produces an area of illumination for a light modulator along a slow axis direction and along a fast axis direction, and includes a plurality of laser diode emitters, a first array of first micro lenses, and a second array of second micro lenses. The plurality of laser diode emitters are arranged in an array, and each of the laser diode emitters produces illumination in a slow axis direction and in a fast axis direction. Each first micro lens in the first array corresponds to one of the laser diode emitters, and collimates illumination in the slow axis direction. Each of the second micro lenses in the second array corresponds to one of the first micro lenses. Each of the second micro lenses is arranged to receive illumination from one of the first micro lenses. The first micro lenses produce a non-overlapped near field image in the slow axis direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The following description may be further understood with reference to the accompanying drawings in which:

Figure 1 shows an illustrative functional diagram of an imaging system including an illumination system of the invention;

Figure 2 shows an illustrative isometric diagram of an illumination system of the invention;

Figure 3 shows an illustrative view of the slow axis direction of the system of Figure 2 taken along line 3-3 thereof; and

Figure 4 shows an illustrative view of the fast axis direction of the system of Figure 2 taken along line 4-4 thereof.

[0016] The drawings are shown for illustrative purposes only, and are not to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0017] As shown in Figure 1, an embodiment of an imaging system incorporating an illumination system of the invention includes an illumination source 10 such as an array of laser emitters and associated optics, a field lens system 12 including one or more field lenses, a light modulator 14, imaging optics 16, and an imaging drum for supporting a recording medium 18. Generally, the illumination field is selectively focused onto the thermal recording medium to produce a desired image. The recording medium includes a protective coating that prevents the film from being imaged when exposed to light. The light protected recording medium may be selectively thermally ablated for printing in accordance with thermal printing techniques.

[0018] The illumination source 10 generates and emits a line of continuous wave energy. The light modulator 14 shown in Figure 2 is reflective, and in a preferred embodiment comprises a reflective grating light valve (GLV). The zero order diffraction of the illumination field from the GLV is imaged onto the thermal recording medium by the imaging optics 16. The higher order diffraction images may be blocked by appropriate optical devices (not shown). The imaging optics 16 transfer the image from the GLV to the recording medium.

[0019] As shown in Figure 2, the illumination source 10 of an embodiment of the invention includes an array of laser diode emitters 20, a fast axis collimating lens 22, a first array of microlenses 24, a second array of microlenses 26, and a fast axis narrowing lens 28. The array of laser diodes emitters 20 may include, for example, emitters that each provide an illumination area of 1 micron by 200 microns, and are spaced at intervals of 400 microns along the array 20. The field lens system 12 of the embodiment of Figure 2 includes slow axis collimating lens 30, and a fast axis collimating lens 32.

[0020] As further shown in Figure 3, in the slow axis direction, light from each emitter passes through the fast axis collimating lens 22, and is collimated in the slow axis direction by a respective microlens in the first array of first microlenses 24. The collimated light from each microlens in the first array is then focused by a respective microlens in the second array of second microlenses 26, the focal point of which lies on a near field image plane 34. The near field image plane 34 is comprised of portions of illumination from the emitters in the array 20 that are not overlapped in the slow axis direction. The magnification of the double microlens array may in an embodiment be specified as the inverse of the fill factor (FF) of the emitters, i.e., 1/FF.

[0021] The near field image then passes through a fast axis narrowing lens 28 to the slow axis collimating

lens 30, which collimates the illumination in the slow axis direction in formation of the far field image along the surface 15 of the light modulator 14. The illumination passes through the fast axis collimating lens 32 unaffected in the slow axis direction. The illumination system, therefore, provides in the slow axis direction, a non-overlapped near field image that is focused at an image plane 34, and a collimated far field image at the light modulator. Illumination, therefore, that originates from each emitter is spread across the entire light modulator 14 in the slow axis direction in the formation of the far field image. This improves beam uniformity and reduces divergence.

[0022] The slow axis divergence of the illustrated system may be described as:

$$\Theta_s = A_s * (L_b / L_l) * FF,$$

where

A_s is the slow axis deviance of the laser diode emitters,

L_b is the length of the bar of laser diode emitters, and

L_l is the length of illumination line on the modulator.

This divergence is relatively small, while the depth of focus is relatively large. Beam uniformity is improved because the illumination associated with each emitter is not overlapped with illumination from other emitters at the near field image located along image plane 34.

[0023] As shown in Figure 4, in the fast axis direction, light from the emitters 20 is collimated in the fast axis direction to reduce divergence by the fast axis collimating lens 22. The illumination then passes through the microlens arrays 24 and 26 unaffected in the fast axis direction, and then is narrowed in the fast axis direction by the fast axis narrowing lens 28. The illumination then passes through the slow axis collimating lens 30 (unaffected in the fast axis direction) and is collimated in the fast axis direction by the fast axis collimating lens 32. In the fast axis direction, therefore, the system provides a collimated far field image at the light modulator. Illumination from the emitters is spread across the entire light modulator in the fast axis direction.

[0024] The slow axis direction corresponds to the movement of the optical head along the longitudinal axis of an imaging drum which parallels the linear direction along the width (W) of the medium 18, whereas the fast axis direction corresponds to the spinning of a laser beam along the radial direction of the drum, e.g., along a swath of the medium 18.

[0025] The medium 18, shown in Figure 1, is positioned as supported on an external drum (not shown). A line of illumination (also referred to as a line of radiation), is coincident with the medium 18 at the image plane, and has a length (L) and a width (Z). Each line of illumination contains a predetermined number of sections that respectively correspond to a number of pixels on the GLV 14. The line of illumination is imaged at an initial position along a first swath (N) on the sheet of medium 18. As the drum rotates, pixels along the line of illumination are turned ON or OFF according to image information supplied by control electronics as well known in the art. Modulation of pixels is synchronised to the rotational speed of the drum. This procedure continues until imaging is complete on swath (N). The movement of the line of illumination from swath (N) to (N+1) is facilitated by movement of the imaging head along the longitudinal axis (i.e., the slow axis) of the rotating drum. The above-described imaging procedure is then repeated for swath (N+1) and all additional swaths until the image is completely transferred onto the medium 18. The imaging procedure may also be accomplished by other means such as a spiral scan of the media as well known in the art.

[0026] The GLV operates by diffracting light with the use of moveable ribbons in an array. For the present invention, energy from the GLV reaches the image plane when a GLV pixel is not activated. When a pixel is fully activated, i.e., when alternate ribbons are deflected approximately one-quarter wavelength, then light is diffracted and subsequently blocked from reaching the image plane. Pixels may be partially activated to control the amount of light reaching the image plane.

[0027] One exemplary GLV consists of 1088 individually addressable pixels. In the preferred embodiment a one-dimensional GLV array is used, although a multi - dimensional GLV could be used if desired to create an wider area of illumination rather than a line of illumination.

[0028] Various imaging resolutions are available by changing the grouping of the GLV pixels. Moreover, all pixels of the GLV need not necessarily be used in the formation of an image. For example, if 720 GLV pixels are imaged two-to-one at the image plane to produce a resolution of 2400 dpi, i.e. 94 dots per mm image pixels (i.e., writing dots) per inch, then a grouping of two GLV pixels per image plane pixel results in 360 writing dots at a resolution of 2400 dots per inch, i.e. 94 dots per mm. If a resolution of 1200 dpi, i.e. 47 dots per mm, is desired, the 720 GLV pixels should be imaged four-to-one at the image plane, resulting in 180 writing dots per inch or 7 dots per mm.

[0029] No additional moving parts are required to change spot size (i.e., the writing dots or image pixels) other than to select the number of GLV pixels for the desired resolution. Moreover, with constant illumination of the GLV, the energy at the image plane remains constant in terms of energy per unit area, thereby requiring no exposure energy changes with change in resolution. This provides a benefit over systems using optical demagnification to change addressability. With optical de-

magnification, the power in the imaging spot must be reduced e.g., by a power of 2, to the change in spot size causing more power to be discarded and slowing down the system by the same proportion. In the preferred system, throughput remains constant as the power is spread over proportionally more pixels. Other combinations of ribbons can be selected on the GLV with the appropriate demagnification selection. In each case the time of activation of each pixel is varied directly with the resolution selected while the scanning velocity remains constant.

[0030] The surface of the grating light valve preferably includes a diffraction grating, e.g., an array of narrow parallel slits or openings which, when white light is projected therethrough, breaks down the white light into all the colours of the spectrum due to the diffraction of light waves as they pass through the openings. The diffraction grating produces this spectral effect due to the reinforcement of the light waves from adjacent slits or openings.

[0031] The fact that individual GLV pixels may be actuated to different levels of diffraction efficiency can be used to great advantage. A first possible use is to equalise the energy distribution across the GLV. If a nominal energy level is set below the maximum, then individual pixels can be adjusted either up or down to cause all pixels to be equal. A second use is to desensitise the effects of pixel placement errors at the boundary between bands of multiple pixels. The pixels located at the boundary between the swaths of multiple pixels can be lowered in intensity and overlapped so as to average the effective position.

[0032] There are other advantages of using the above-described GLV in an imaging system. For example, manufacture of the GLV is cost effective compared with manufacture of other light modulators since the fabrication of the GLV uses standard fabrication methods employed in the semiconductor industry. Also, the pixels of the GLV are accurately located to tight semiconductor standards. The GLV is capable of modulating high power levels of radiation. Moreover, the reflective GLV results in a more compact system as compared to an inline multiple beam system. A transmissive modulator could be used to replace the GLV, but one of the tradeoffs would be a physically larger system. Due to the scale and materials employed, the GLV is inherently insensitive to damage from shock and vibration. The GLV is also sealed and insignificantly stressed in use, resulting in high reliability. Due to the fact that the GLV pixels can be pulled down to different levels, the GLV can be used with different wavelength sources. The GLV can also be used with both multi-mode and single mode lasers. Further, as compared to single beam methods of writing images, the adjacency of the pixels produced by the GLV reduces the power required to write equivalent images.

[0033] Due to the fact that a large number of pixels is used to create the GLV, it is possible to advantageously employ some number of pixels for uses other than as writing beams without incurring a penalty. These other uses include sourcing beams (1) to detect the edge of a plate so as to synchronise the image location with the position of the recording medium, or (2) to sense or to automatically adjust the focus of an imaging system.

[0034] The zero order diffracted light reflected from the object plane of the GLV passes through a first lens group and is directed to, and then passes through, an aperture. The first lens group may include at least one fixed lens and at least one adjustable lens for adjusting the image magnification independent of the image focus. The aperture is a single centrally located opening (preferably having an elliptical shape) on the stop. The stop blocks non-zero order diffractive rays while allowing zero order diffractive rays to pass through the aperture.

[0035] The principal rays of zero order radiation received from the first lens group are focused in the centre of the aperture, and passed to a second lens group. The second lens group includes one or more lenses for adjusting the image focus independent of the image magnification. The second lens group must contain at least one adjustable lens, and could contain zero, one or more fixed lenses. From the second lens group, the rays are focused along a line of radiation on the imaging medium.

[0036] One could alter the above embodiment to write using first order diffractive rays while blocking zero order diffractive rays. Similarly, the system could be designed to operate with either even or odd order diffractive light. Also variable is the ratio of pixels in the GLV to pixels on the image plane. In the preferred embodiment, each pixel on the image plane corresponds to two GLV pixels.

[0037] An imaging system of the invention may also include a first magnification lens group, a stop containing an aperture, and a second focusing lens group. The grating light valve of the present embodiment allows each pixel to be separately and individually controlled in accordance with signals from control electronics built into the GLV modulator. In other words, individual image pixels may be separately diffracted. Furthermore, the intensity of each GLV pixel may be electronically controlled by varying the voltage applied to the ribbons, thus controlling their deflection and ultimately the amount of energy that reaches the image plane. Varying the intensity of GLV pixels on the GLV object plane may correct non-uniformity of the line of illumination on the image plane.

[0038] The invention provides for an imaging system that exhibits dual telecentricity. Telecentricity occurs when rays are normal to an incident surface. The benefit of having an imaging system with dual telecentricity is to separate diffractive orders and separate magnification adjustments from focusing adjustments. With a dual telecentric arrangement, magnification of the system is insensitive to movements of the GLV or imaging medium 18. Either magnification or focus, therefore, may be ad-

justed independent of one another.

[0039] An optical imaging system including an illumination system of the invention is preferably used with an external drum imagesetter or platesetter, so that the image is transferred onto a medium supported by the external surface of the drum. The illumination system of the invention could also be used in direct-to-press imaging to project the line of illumination directly onto a plate cylinder of a printing press. In this case, the imaging system would be replicated at each station of the printing press. Furthermore, while the head is most appropriately used in the above-described applications, it may also be used in an internal drum or capstan style imagesetter or platesetter.

[0040] Those skilled in the art will appreciate that numerous modifications and variations may be made to the above disclosed embodiments without departing from the scope of the present invention.

Claims

1. An illumination system (10,12) for use in imaging systems, said illumination system (10,12) producing when in operation an area of illumination for a light modulator (14) along a slow axis direction and a fast axis direction, said illumination system (10,12) comprising:

   - a plurality of laser diode emitters arranged in an array (20), each of said laser diode emitters producing when in operation illumination in the slow axis direction and in the fast axis direction;
   - a first lens assembly (22,24,26) producing when in operation a near field image (34) in the slow axis direction from said produced illumination ;
   - a second lens assembly (30,32) collimating when in operation illumination from said first lens assembly (22,24,26) and producing when in operation at said light modulator (14) a far field image (15) that is collimated in the slow axis direction.

2. The illumination system (10,12) according to claim 1, wherein said first lens assembly (22,24,26) includes a first array (24) of first micro lenses, each of said first micro lenses corresponding to one of said laser diode emitters, preferably arranged to collimate illumination in the slow axis direction.

3. The illumination system (10,12) according to claim 2, wherein said first lens assembly (22,24,26) includes a second array (26) of second micro lenses, each of said second micro lenses corresponding to one of said first micro lenses and each preferably being arranged to receive illumination from one of said first micro lenses, said first micro lenses being arranged to produce a non-overlapped near field image (34) in the slow axis direction.

4. The illumination system according to any one of the previous claims, wherein said illumination system (10,12) further includes a fast axis collimating lens (32) arranged to collimate illumination in the fast axis direction, preferably positioned to receive light from each of said laser diode emitters, arranged to reduce divergence in the fast axis direction.

5. The illumination system (10,12) according to any one of the previous claims, wherein said illumination system (10,12) further includes a fast axis narrowing lens (28) arranged to narrow the illumination field in the fast axis direction.

6. The illumination system (10,12) according to any one of the previous claims, wherein a far field image (15) is formed on the light modulator (14) in both the slow axis direction and the fast axis direction.

7. The illumination system (10,12) according to any one of the previous claims, wherein said far field (15) image is formed on a grating light valve (14).

8. The illumination system (10,12) according to any one of the previous claims, including means for spreading illumination originating from each of said laser diode emitters across the light modulator (14) in the slow axis direction in forming the far field image (15).

9. The illumination system (10,12) according to any one of the previous claims, wherein said second lens assembly (30,32) includes a slow axis collimating lens (30) arranged to collimate illumination in the slow axis direction.

10. A method of emitting illumination in an imaging system for producing an area of illumination at a light modulator (14) along a slow axis direction and along a fast axis direction, said method comprising the steps of:

    - collimating (22) illumination from a plurality of emitters (20) in the fast axis direction;
    - focusing the collimated illumination in the fast axis direction in the formation of a near field image (34) in the fast axis direction; and
    - collimating illumination from the near field image (34) in the slow axis direction to produce a far field image (15) that is collimated in the slow axis direction.

11. The method of claim 10, wherein said near field image (34) is fo rmed of non-overlapping portions corresponding to each emitter (20).

Patentansprüche

1. Beleuchtungssystem (10, 12) zur Verwendung in Bildgebungssystemen, wobei das Beleuchtungssystem (10, 12) - wenn es in Betrieb ist - einen Beleuchtungsbereich für einen Lichtmodulator (14) entlang der Richtung einer langsamen Achse und der Richtung einer schnellen Achse erzeugt, wobei das Beleuchtungssystem (10, 12) folgendes umfaßt:

   - mehrere Laserdiodenemitter, die in einem Array (20) angeordnet sind, wobei jeder der Laserdiodenemitter - wenn er in Betrieb ist - Beleuchtung in Richtung der langsamen Achse und in Richtung der schnellen Achse erzeugt;
   - eine erste Linsenbaugruppe (22, 24, 26), die - wenn sie in Betrieb ist - ein Nahfeldbild (34) in Richtung der langsamen Achse aus der erzeugten Beleuchtung erzeugt;
   - eine zweite Linsenbaugruppe (30, 32), die - wenn sie in Betrieb ist - Beleuchtung von der ersten Linsenbaugruppe (22, 24, 26) kollimiert und - wenn sie in Betrieb ist - bei dem Lichtmodulator (14) ein Fernfeldbild (15) erzeugt, das in Richtung der langsamen Achse kollimiert ist.

2. Beleuchtungssystem (10, 12) nach Anspruch 1, wobei die erste Linsenbaugruppe (22, 24, 26) ein erstes Array (24) von ersten Mikrolinsen enthält, wobei jede der ersten Mikrolinsen einem der Laserdiodenemitter entspricht und vorzugsweise derart angeordnet ist, daß sie Beleuchtung in Richtung der langsamen Achse kollimiert.

3. Beleuchtungssystem (10, 12) nach Anspruch 2, wobei die erste Linsenbaugruppe (22, 24, 26) ein zweites Array (26) von zweiten Mikrolinsen enthält, wobei jede der zweiten Mikrolinsen einer der ersten Mikrolinsen entspricht und jede bevorzugt so angeordnet ist, daß sie Beleuchtung von einer der ersten Mikrolinsen empfängt, wobei die ersten Mikrolinsen so angeordnet sind, daß sie in Richtung der langsamen Achse ein nicht-überlapptes Nahfeldbild (34) erzeugen.

4. Beleuchtungssystem nach einem der vorhergehenden Ansprüche, wobei das Beleuchtungssystem (10, 12) weiterhin eine Kollimationslinse (32) für eine schnelle Achse enthält, die derart angeordnet ist, daß sie Beleuchtung in Richtung der schnellen Achse kollimiert, die bevorzugt so positioniert ist, daß sie Licht von jedem der Laserdiodenemitter empfängt und die derart angeordnet ist, daß sie Divergenz in Richtung der schnellen Achse reduziert.

5. Beleuchtungssystem (10, 12) nach einem der vorhergehenden Ansprüche, wobei das Beleuchtungssystem (10, 12) weiterhin eine Verengungslinse (28) für die schnelle Achse enthält, die derart angeordnet ist, daß sie das Beleuchtungsfeld in Richtung der schnellen Achse verengt.

6. Beleuchtungssystem (10, 12) nach einem der vorhergehenden Ansprüche, wobei auf dem Lichtmodulator (14) sowohl in Richtung der langsamen Achse als auch in Richtung der schnellen Achse ein Fernfeldbild (15) ausgebildet wird.

7. Beleuchtungssystem (10, 12) nach einem der vorhergehenden Ansprüche, wobei das Bild des Fernfelds (15) auf einem Grating Light Valve (14) ausgebildet wird.

8. Beleuchtungssystem (10, 12) nach einem der vorhergehenden Ansprüche, mit Mitteln zum Verteilen von Beleuchtung, die von jedem der Laserdiodenemitter kommt, über den Lichtmodulator (14) in Richtung der langsamen Achse beim Ausbilden des Fernfeldbilds (15).

9. Beleuchtungssystem (10, 12) nach einem der vorhergehenden Ansprüche, wobei die zweite Linsenbaugruppe (30, 32) eine Kollimationslinse (30) für die langsame Achse enthält, die derart angeordnet ist, daß sie Beleuchtung in Richtung der langsamen Achse kollimiert.

10. Verfahren zum Emittieren von Beleuchtung in einem Bildgebungssystem zum Erzeugen eines Beleuchtungsbereichs bei einem Lichtmodulator (14) entlang der Richtung einer langsamen Achse und entlang der Richtung einer schnellen Achse, wobei das Verfahren die folgenden Schritte umfaßt:

    - Kollimieren (22) von Beleuchtung von mehreren Emittern (20) in Richtung der schnellen Achse;
    - Fokussieren der kollimierten Beleuchtung in Richtung der schnellen Achse bei der Ausbildung eines Nahfeldbilds (34) in Richtung der schnellen Achse und
    - Kollimieren von Beleuchtung von dem Nahfeldbild (34) in Richtung der langsamen Achse zum Erzeugen eines Fernfeldbilds (15), das in Richtung der langsamen Achse kollimiert ist.

11. Verfahren nach Anspruch 10, wobei das Nahfeldbild (34) aus nichtüberlappenden Abschnitten entsprechend jedem Emitter (20) ausgebildet ist.

Revendications

1. Système d'illumination (10, 12) destiné à être utilisé dans des systèmes de formation d'images, ledit

système d'illumination (10, 12) produisant, lorsqu'il fonctionne, une zone d'illumination pour un modulateur de lumière (14) le long d'une direction d'axe lent et d'une direction d'axe rapide, ledit système d'illumination (10, 12) comprenant :

- une pluralité d'émetteurs à diode laser disposés dans une rangée (20), chacun desdits émetteurs à diode laser produisant, lorsqu'il fonctionne, une illumination dans la direction d'axe lent et dans la direction d'axe rapide ;
- un premier ensemble de lentille (22, 24, 26) produisant, lorsqu'il fonctionne, une image en champ proche (34) dans la direction d'axe lent à partir de ladite illumination produite ;
- un deuxième ensemble de lentille (30, 32) collimatant, lorsqu'il fonctionne, l'illumination provenant dudit premier ensemble de lentille (22, 24, 26) et produisant, lorsqu'il fonctionne, au niveau dudit modulateur de lumière (14) une image en champ lointain (15) qui est collimatée dans la direction d'axe lent.

2. Système d'illumination (10, 12) selon la revendication 1, dans lequel ledit premier ensemble de lentille (22, 24, 26) comporte une première rangée (24) de premières microlentilles, chacune desdites premières microlentilles correspondant à l'un desdits émetteurs à diode laser, et étant de préférence disposée pour collimater l'illumination dans la direction d'axe lent.

3. Système d'illumination (10, 12) selon la revendication 2, dans lequel ledit premier ensemble de lentille (22, 24, 26) comporte une deuxième rangée (26) de deuxièmes microlentilles, chacune desdites deuxièmes microlentilles correspondant à l'une desdites premières microlentilles et chacune étant de préférence disposée pour recevoir l'illumination provenant d'une desdites premières microlentilles, lesdites premières microlentilles étant disposées pour produire une image en champ proche sans chevauchement (34) dans la direction de l'axe lent.

4. Système d'illumination selon l'une quelconque des revendications précédentes, dans lequel ledit système d'illumination (10, 12) comporte en outre une lentille de collimation d'axe rapide (32), disposée pour collimater l'illumination dans la direction d'axe rapide, de préférence placée pour recevoir la lumière provenant de chacun desdits émetteurs à diode laser, disposée pour réduire la divergence dans la direction d'axe rapide.

5. Système d'illumination (10, 12) selon l'une quelconque des revendications précédentes, dans lequel ledit système d'illumination (10, 12) comporte en outre une lentille de rétrécissement d'axe rapide (28), disposée pour rétrécir le champ d'illumination dans la direction d'axe rapide.

6. Système d'illumination (10, 12) selon l'une quelconque des revendications précédentes, dans lequel une image en champ lointain (15) est formée sur le modulateur de lumière (14) à la fois dans la direction d'axe lent et dans la direction d'axe rapide.

7. Système d'illumination (10, 12) selon l'une quelconque des revendications précédentes, dans lequel ladite image en champ lointain (15) est formée sur une valve optique en réseau (14).

8. Système d'illumination (10, 12) selon l'une quelconque des revendications précédentes, comportant un moyen pour étaler l'illumination émanant de chacun desdits émetteurs à diode laser en travers du modulateur de lumière (14) dans la direction d'axe lent en formant l'image en champ lointain (15).

9. Système d'illumination (10, 12) selon l'une quelconque des revendications précédentes, dans lequel ledit deuxième ensemble de lentille (30, 32) comporte une lentille de collimation d'axe lent (30), disposée pour collimater l'illumination dans la direction d'axe lent.

10. Procédé d'émission d'une illumination dans un système de formation d'images pour produire une zone d'illumination au niveau d'un modulateur de lumière (14) le long d'une direction d'axe lent et le long d'une direction d'axe rapide, ledit procédé comprenant les étapes de :

- collimation (22) de l'illumination provenant d'une pluralité d'émetteurs (20) dans la direction d'axe rapide ;
- focalisation de l'illumination collimatée dans la direction d'axe rapide durant la formation d'une image en champ proche (34) dans la direction d'axe rapide ; et
- collimation de l'illumination provenant de l'image en champ proche (34) dans la direction d'axe lent pour produire une image en champ lointain (15) collimatée dans la direction d'axe lent.

11. Procédé selon la revendication 10, dans lequel ladite image en champ proche (34) est formée de portions non chevauchantes correspondant à chaque émetteur (20).

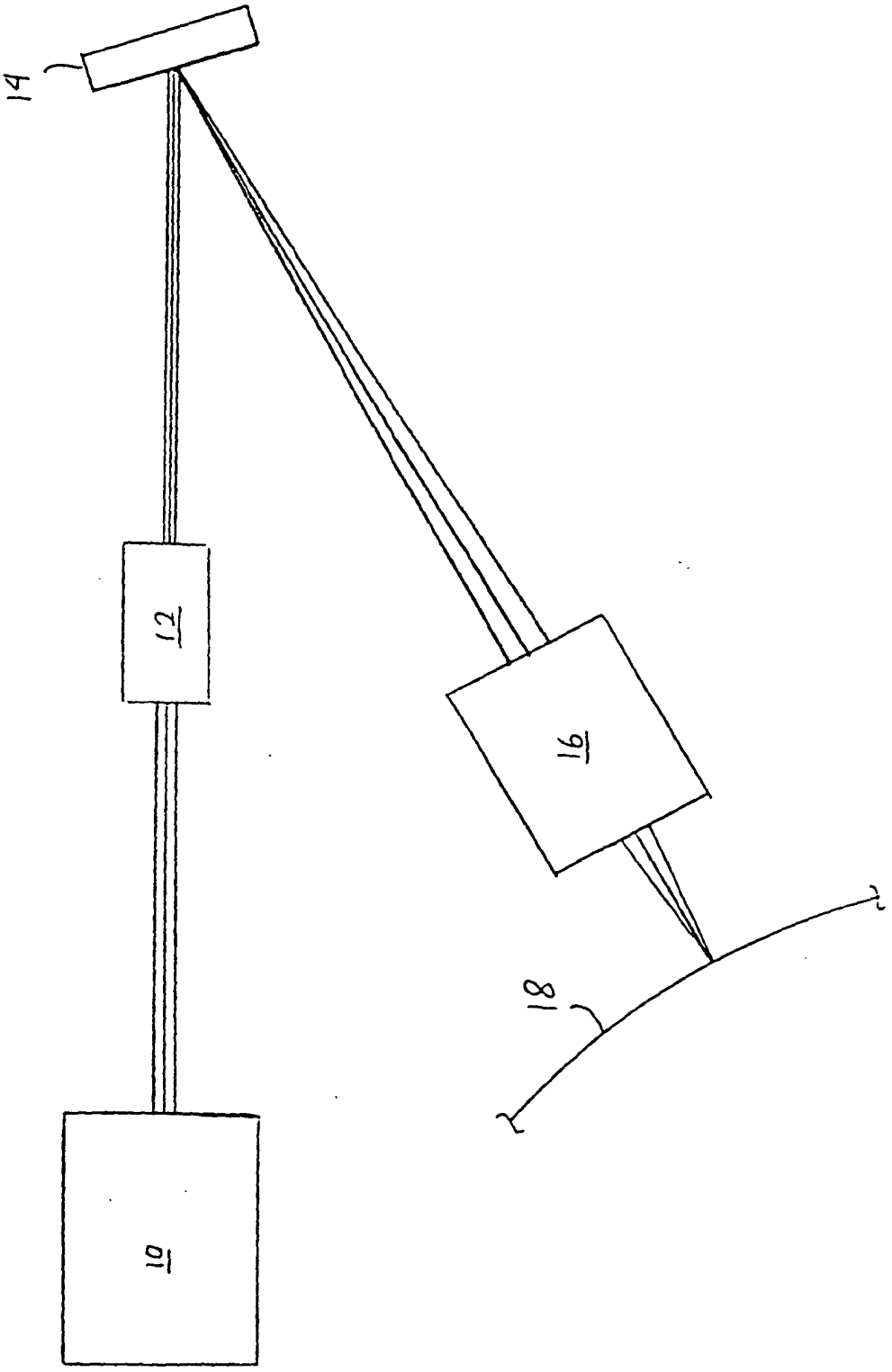


FIG 1

HESAI EX1002, P.543

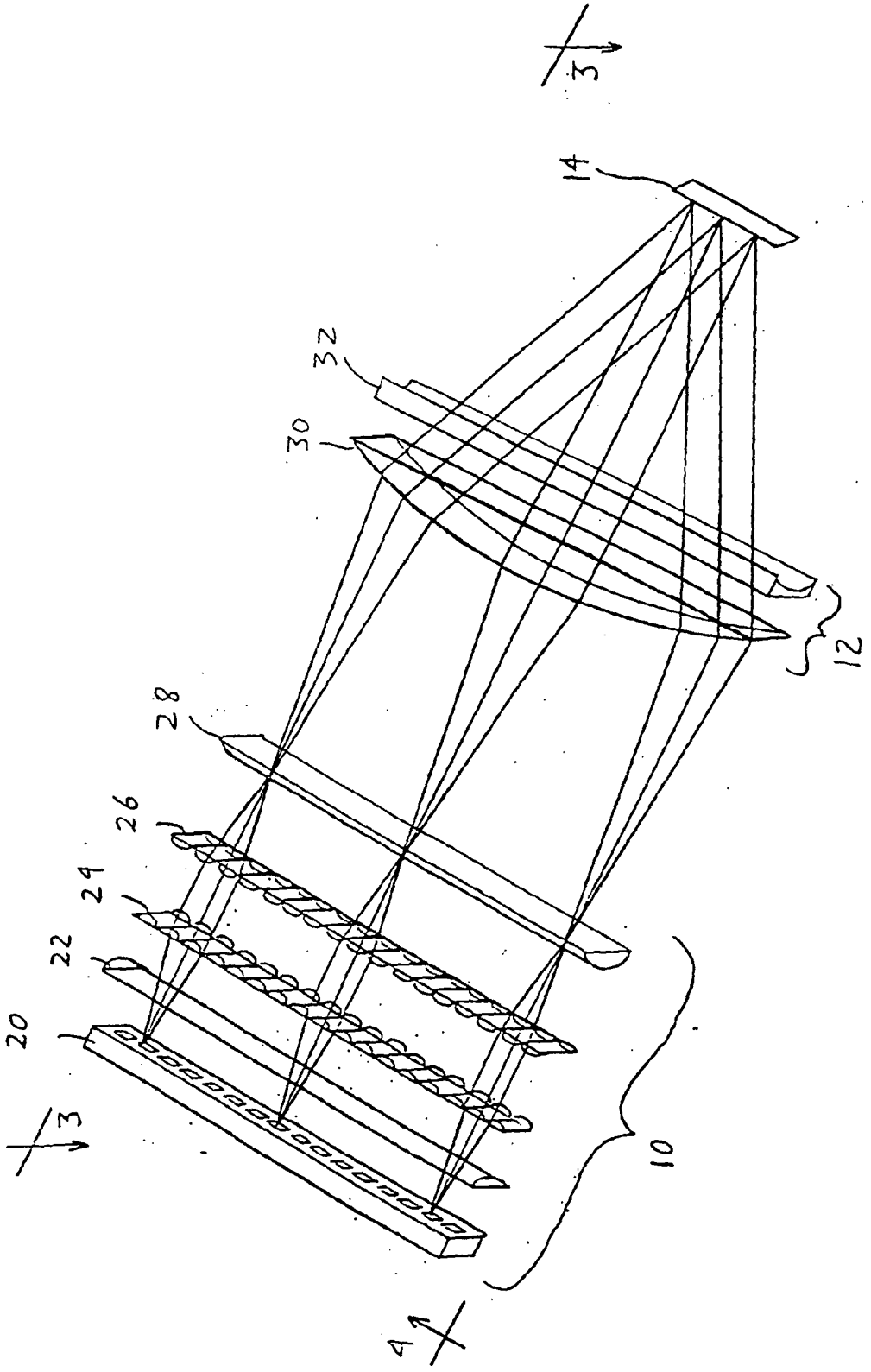


FIG 2

HESAI EX1002, P.544

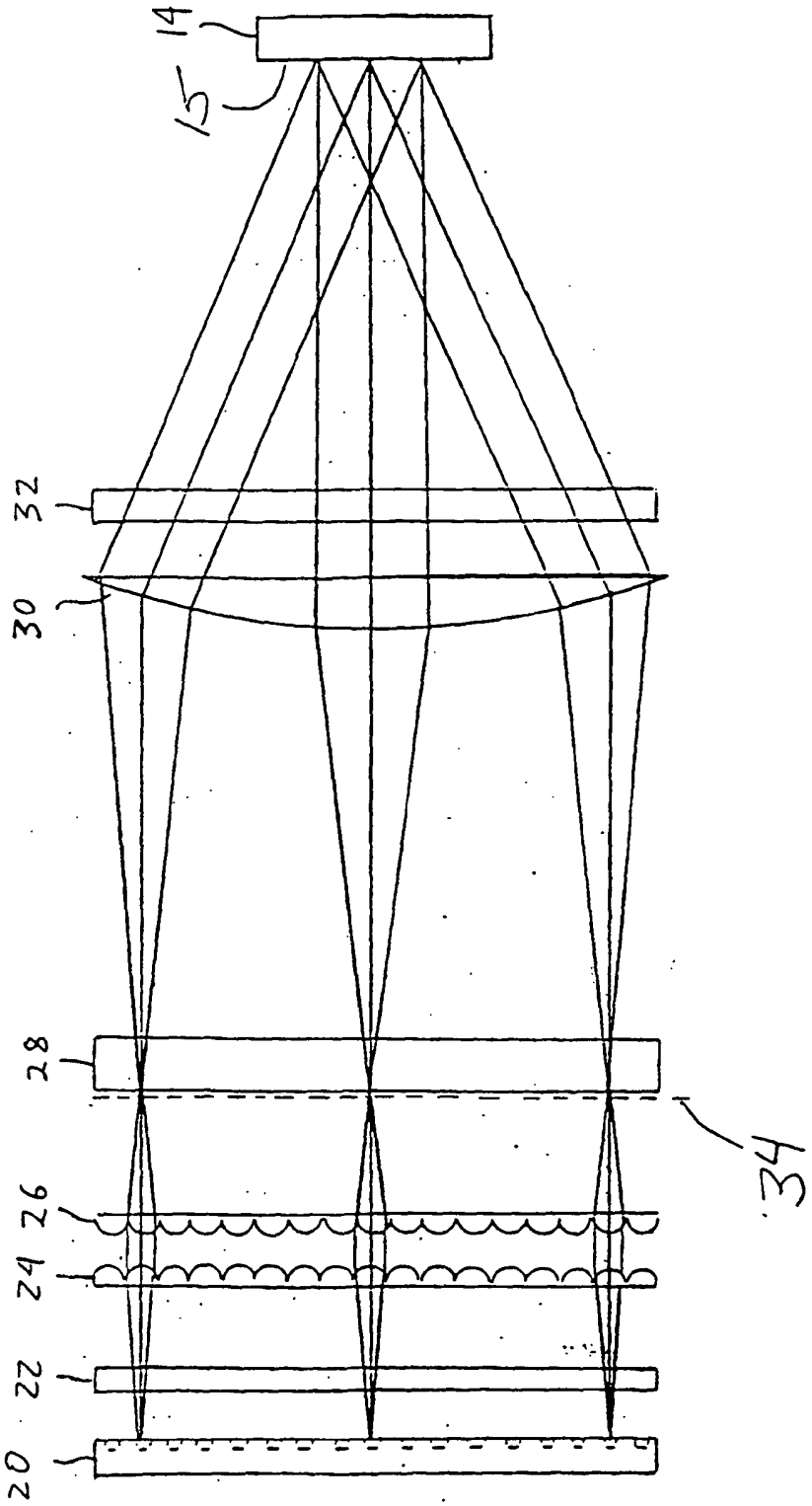


FIG 3

HESAI EX1002, P.545

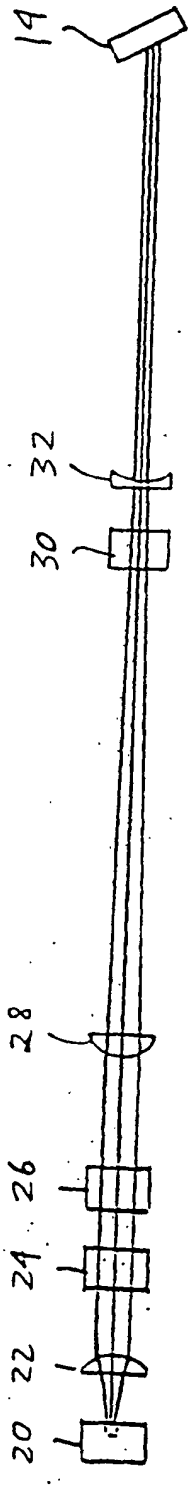


FIG 4

HESAI EX1002, P.546

Electronic Acknowledgement Receipt

EFS ID:	41198849
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	23-NOV-2020
Filing Date:	14-MAY-2018
Time Stamp:	14:15:02
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS-P006US3.pdf	187116 5a53fdc0d3c6d764a2db3f2e7943fce3fde30107	yes	4

	Multipart Description/PDF files in .zip description					
	Document Description		**Start**		**End**	
	Information Disclosure Statement (IDS) Form (SB08)		3		4	
	Transmittal Letter		1		2	
Warnings:						
Information:						
2	Non Patent Literature	EP-Search-Report.pdf	403282 787df035d391ffab731baeeefa593567cec8dfab	no	11	
Warnings:						
Information:						
3	Non Patent Literature	NPL_CN-Office-Action.pdf	385283 4eba2b6f54fa018220bf4df38e58d06cbc8dd866	no	9	
Warnings:						
Information:						
4	Foreign Reference	DE102015217908-with-abstract.pdf	331712 ca97095e11dd633c52c2e6c53948298dda3255e1	no	12	
Warnings:						
Information:						
5	Foreign Reference	EP2110699-with-abstract.pdf	275353 10a6961a7c7a1bbbc9a9e6372e04dc13070564ab	no	7	
Warnings:						
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6	Foreign Reference	CN102640037A-with-abstract.pdf	1687616 ad5c75d9a780b19caa3ce22128e98de03cab17cf	no	28	
Warnings:						
Information:						
7	Foreign Reference	CN101413905-with-abstract.pdf	970754 66e0449ae68b7a6e3eaedebb5be5726646d6208a	no	13	
Warnings:						

Information:					
8	Foreign Reference	CN1918427-with-abstract.pdf	1770585 174328867e15c7dba881acaadd4da91c0b34770c	no	31
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Information:					
9	Foreign Reference	EP1193539B1.pdf	539137 cce66e207e8269d41efa7963269e2af9e11df71d	no	12
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			Total Files Size (in bytes):	6550838	

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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-1086284-P006US3

U.S. PATENTS						
Examiner Initial*	Cite No	Patent Number	Kind Code [1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear

U.S. PATENT APPLICATION PUBLICATIONS						
Examiner Initial*	Cite No	Publication Number	Kind Code [1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	20180136321	A1	May 17, 2018	Verghese et al.	

FOREIGN PATENT DOCUMENTS								
Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]

1

NON-PATENT LITERATURE DOCUMENTS			
Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	2.	16/245,909 , "Notice of Allowance", January 14, 2020, 5 pages	
	3.	15/979,235 , "Non-Final Office Action", July 23, 2018, 5 pages	
	4.	15/979,235 , "Notice of Allowance", December 19, 2018, 5 pages	
	5.	15/979,253 , "Final Office Action", August 4, 2020, 9 pages	
	6.	15/979,253 , "Non-Final Office Action", March 20, 2020, 10 pages	
	7.	15/979,295 , "Non-Final Office Action", August 4, 2020, 15 pages	
	8.	16/245,909 , "Non-Final Office Action", September 18, 2019, 6 pages	

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-1086284-P006US3

EXAMINER SIGNATURE			
Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.
[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

Electronic Acknowledgement Receipt

EFS ID:	40797390
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	08-OCT-2020
Filing Date:	14-MAY-2018
Time Stamp:	16:50:39
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS-P006US3-1086284.pdf	184750 cab916ff85ace647b5176a75e403d701dcd84fcb	yes	4

	Multipart Description/PDF files in .zip description		
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KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1086284-P006US3
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus Pacala	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: 2875
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the remaining cited references are provided.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed *before* the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

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Attachment

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-1086284-P006US3

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PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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	Attorney Docket Number	103033-1086284-P006US3

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[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 002 548 B1**

(12) **EUROPÄISCHE PATENTSCHRIFT**

(45) Veröffentlichungstag und Bekanntmachung des Hinweises auf die Patenterteilung:
14.09.2016 Patentblatt 2016/37

(21) Anmeldenummer: **14187405.7**

(22) Anmeldetag: **02.10.2014**

(51) Int Cl.:
G01B 11/02 *(2006.01)* ***G02B 3/14*** *(2006.01)*
H01L 27/146 *(2006.01)* ***G06K 7/00*** *(2006.01)*
G02B 3/00 *(2006.01)* ***G02B 26/08*** *(2006.01)*
H04N 13/04 *(2006.01)*

(54) **Beleuchtungseinrichtung und Verfahren zum Erzeugen eines Beleuchtungsfeldes**

Illumination device and method for generating an illumination field

Dispositif d'éclairage et procédé destiné à la production d'une zone d'éclairage

(84) Benannte Vertragsstaaten:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(43) Veröffentlichungstag der Anmeldung:
06.04.2016 Patentblatt 2016/14

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(56) Entgegenhaltungen:
EP-A1- 1 394 593
WO-A1-01/59360
WO-A1-2008/157604
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DE-U1-202011 110 543
US-A- 5 438 486
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EP 3 002 548 B1

Beschreibung

[0001] Die Erfindung betrifft eine Beleuchtungseinrichtung zum Erzeugen eines Beleuchtungsfeldes nach dem Oberbegriff von Anspruch 1.

[0002] Für die Inspektion oder Vermessung von Objekten werden häufig Kamerasysteme eingesetzt, welche auch zum Lesen von Barcodes weite Verbreitung gefunden haben. Dabei werden Bilder des Objektes erfasst und entsprechend der Aufgabe durch Bildverarbeitungsverfahren ausgewertet. Eine weitere Anwendung von Kameras ist das Lesen von Codes. Derartige kamerabasierte Codeleser lösen die noch weit verbreiteten Barcode-Scanner zunehmend ab. Mit Hilfe eines Bildsensors werden Objekte mit den darauf befindlichen Codes aufgenommen, in den Bildern die Codebereiche identifiziert und dann decodiert. Kamerabasierte Codeleser kommen problemlos auch mit anderen Codearten als eindimensionalen Strichcodes zurecht, die wie ein Matrixcode auch zweidimensional aufgebaut sind und mehr Informationen zur Verfügung stellen.

[0003] Alle diese Anwendungen haben gemein, dass sie eine Beleuchtung benötigen, um den zu lesenden Barcode bzw. die zu inspizierenden und zu vermessenden Objekte unabhängig vom Umgebungs- oder Fremdlicht zu erfassen. Zu diesem Zweck weisen diese Kamerasysteme Lichtquellen auf, die häufig als LEDs ausgebildet sind. Im Vergleich zu den ebenfalls gelegentlich verwendeten Laserlichtquellen haben LEDs meist eine divergentere Abstrahlungscharakteristik und größere Abstrahlflächen.

[0004] Darüber hinaus ist bekannt, Vergusslinsen zur Strahlfokussierung direkt auf ein LED-Gehäuse aufzubringen.

[0005] In der DE 602 15 093 T2 ist eine steuerbare flüssige Mikrolinse offenbart, welche aus einer Isolierschicht und einem Tröpfchen einer transparenten leitenden Flüssigkeit besteht, die auf einem Trägermaterial angeordnet ist. Die Mikrolinse enthält mehrere Elektroden, wobei sich die Position der Mikrolinse durch die, an den Elektroden jeweilig angelegten Spannungen verändern lässt.

[0006] Aus dem Stand der Technik ist weiterhin eine Beleuchtungsvorrichtung bekannt, bei welcher eine LED ein Strahlführungselement in Form einer festen TIR-Linse (Total Internal Reflection) beleuchtet und welche zur effizienten Projektion des Lichtes in die Szene eingesetzt wird. An das Strahlführungselement schließt sich ein Mikrolinsenarray aus Silikon an, auf welchem eine Deckplatte aus Glas aufliegt. Durch eine Krafteinwirkung wird die Deckplatte an das elastische Mikrolinsenarray gedrückt und somit das Mikrolinsenarray deformiert. Durch die Deformation des Mikrolinsenarrays wird das Beleuchtungsfeld geformt.

[0007] Aus der WO2009/034511 A2 ist eine Beleuchtungseinrichtung nach dem Oberbegriff bekannt.

[0008] Es ist die Aufgabe der Erfindung, eine Beleuchtungseinrichtung zur Erzeugung eines Beleuchtungsfeldes für einen optoelektronischen Sensor anzugeben, der konstruktiv einfach herstellbar ist.

[0009] Diese Aufgabe wird durch eine Beleuchtungseinrichtung nach Anspruch 1 gelöst. Dabei geht die Erfindung von dem Grundgedanken aus, dass das optische Strahlformungselement direkt auf der Lichtquelle aufliegt und durch einen, an dem Strahlformungselement angreifenden Druck dieses Strahlformungselement zur Lichtformung deformiert wird. Das Strahlformungselement bildet dabei mit der Lichtquelle eine einfach zu betätigende kompakte Einheit. Auf ein Strahlführungselement kann dabei verzichtet werden.

[0010] In einem Strahlengang hinter dem Strahlformungselement, der Lichtquelle abgewandt, ist ein Mikrolinsen aufweisendes Mustererzeugungselement angeordnet, welches einen Erfassungsbereich des optoelektronischen Sensors durch ein Beleuchtungsmuster sichtbar macht. Ein solches Mustererzeugungselement erlaubt die Einstellung der Größe bzw. der Art der Zielgeometrie des optoelektronischen Sensors.

[0011] Das Mustererzeugungselement ist als adaptiver, Mikrolinsen aufweisender Punktmustergenerator ausgebildet, welcher bei einer mechanischen Druckbeanspruchung der elastisch ausgebildeten Mikrolinsen durch die aus einem festen Material bestehenden Deckplatte in Abhängigkeit der vertikal angreifenden Druckkraft ein Beleuchtungsmuster mit variierendem Punktdurchmesser erzeugt. Mittels einer solchen adaptiven Punktmusterbeleuchtung ist eine Umschaltung zwischen einem Punktlichtmuster und einer homogenen Beleuchtung, was ein Beleuchtungsmuster ohne Struktur darstellt, einfach möglich. Hierbei wird die homogene Beleuchtung der Szene verwendet, um neben der 3D-Information (mit strukturierter Beleuchtung) Grauwertbilder aufzunehmen. Diese zusätzliche Information kann zur reinen Darstellung oder algorithmischen Auswertung des Erfassungsbereiches des optoelektronischen Sensors verwendet werden.

[0012] Um beispielsweise bei einem Objektivwechsel des Kamerasystems des optoelektronischen Sensors die Zielgeometrie an den Sichtbereich des Objektivs anzupassen, bestehen die Mikrolinsen aus einem elastischen oder festen Material und sind auf einem festen Trägermaterial angeordnet, wobei eine beweglich gelagerte, vorzugsweise lateral verschiebliche, aus einem festen oder elastischen Material bestehende, transparente Abdeckung auf den Mikrolinsen aufliegt. Die Druckbeaufschlagung der Mikrolinsen bewirkt eine Vergrößerung der Krümmungsradien bzw. der Brennweiten der Mikrolinsen. Dies hat eine Verringerung der Strahldivergenz und somit eine Verkleinerung des Lichtmusters im Erfassungsbereich des optoelektronischen Sensors zur Folge. Die optische Strahlformung im deformierten bzw. undeformierten Zustand der Mikrolinsen kann durch eine asphärische oder frei geformte oder sphärische Linsenoberfläche und/oder Oberfläche der Deckplatte verändert werden. Die Mikrolinsen können dabei auch ein Mikrolinsenarray bilden. Anstelle eines elastischen Mikrolin-

senarrays und einer festen transparenten Deckplatte können ein festes Mikrolinsenarray und eine elastische Deckplatte verwendet werden.

[0013] Das Mustererzeugungselement besteht bevorzugt aus zwei gekreuzten, vorzugsweise senkrecht zueinander stehenden, elastischen Mikrolinsenarrays, die durch eine Trennplatte voneinander beabstandet sind, wobei jedes Mikrolinsenarray mit je einer festen Deckplatte abgedeckt ist und die Deckplatten unabhängig voneinander lateral und/oder vertikal beweglich ausgebildet sind. Durch die jeweilige Bewegung einer der Deckplatten in lateraler Richtung entsteht eine Scherung des jeweiligen Mikrolinsenarrays, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen führt. Dadurch wird das Beleuchtungsmuster im Erfassungsbereich des optoelektronischen Sensors lateral verschoben. Dies hat den Vorteil, dass die Position des Beleuchtungsmusters an den Sichtbereich der Kamera angepasst werden kann, wenn diese Kamera ein neues Objektiv erhält oder wenn das Beleuchtungsmustermuster an eine bevorzugte Stelle im Kamerasichtbereich positioniert werden soll. Die gekreuzte Ausführung der Mikrolinsenarrays ermöglicht darüber hinaus eine individuelle Einstellung der zwei Dimensionen des Beleuchtungsmusters.

[0014] Besonders einfach ist es möglich, von einem strukturierten auf ein homogenes Lichtmuster umzuschalten, wenn der Punktmustergenerator bei einer lateralen Deformation des Mikrolinsenarrays durch die Deckplatte ein Beleuchtungsmuster erzeugt, welches lateral im Erfassungsbereich verschoben ist. Durch diese laterale Verschiebung der festen Deckplatte entsteht eine Scherung des Mikrolinsenarrays, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen führt. Dies hat zur Folge, dass das Punktmuster lateral verschoben wird und auf diese Weise die Position des Punktmusters an die zu betrachtende Szene angepasst wird.

[0015] Für alle beschriebenen Ausführungsbeispiele gilt alternativ, dass anstelle der elastisch ausgebildeten Mikrolinsen auch feste Mikrolinsen verwendet werden können, wobei eine elastische Deckplatte an den Mikrolinsen angreift.

[0016] Die Erfindung wird nachstehend auch hinsichtlich weiterer Merkmale und Vorteile beispielhaft anhand von Ausführungsformen und unter Bezug auf die beigefügte Zeichnung näher erläutert. Die Abbildungen der Zeichnung zeigen in:

Fig. 1 eine schematische Schnittdarstellung einer optoelektronischen Kamera mit einer Beleuchtungseinrichtung,

Fig. 2 ein Ausführungsbeispiel einer erfindungsgemäßen Beleuchtungseinrichtung,

Fig.3 ein erstes Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig.4 ein weiteres Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig.5 ein weiteres Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig. 6 eine simulierte Oberflächengeometrie einer deformierten sphärischen Mikrolinse,

Fig.7 ein erstes Ausführungsbeispiel einer Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig.8 ein zweites Ausführungsbeispiel der Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig.9 ein weiteres Ausführungsbeispiel der Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig. 10 ein Ausführungsbeispiel zur Funktionsweise eines Punktmustergenerators,

Fig. 11 ein weiteres Ausführungsbeispiel zur Funktionsweise eines Punktmustergenerators.

[0017] Fig. 1 zeigt eine schematische Darstellung eines optoelektronischen Sensors 1. Der optoelektronische Sensor 1 ist beispielsweise ein kamerabasierter Codeleser, kann aber ebenso ein anderer optoelektronischer Sensor sein, dessen Erfassungsbereich 2 ausgerichtet werden soll und deshalb von einer Visualisierung mittels einer Zieleinrichtung profitiert.

[0018] Der optoelektronische Sensor 1 empfängt Licht aus dem Erfassungsbereich 2. Im Falle eines Codelesers können sich dort beispielsweise Objekte mit zu lesenden Codes befinden. Das Licht aus dem Erfassungsbereich 2 wird durch ein Aufnahmeobjektiv oder eine Empfangsoptik empfangen, die vereinfacht durch eine Linse 3 dargestellt ist. Ein Lichtempfänger 4 wandelt das Empfangslicht in ein elektrisches Signal um. Bei dem Lichtempfänger 4 handelt es sich beispielsweise um eine Photodiode oder, wie bei einem kamerabasierten Codeleser, um einen CCD- oder CMOS-Chip mit einer Vielzahl von zu einer Zeile oder einer Matrix angeordneten Pixelelementen.

[0019] Das elektrische Signal des Lichtempfängers 4 wird einer Auswerteeinheit 5 zugeführt, die daraus Objektinformationen des Erfassungsbereiches 2 gewinnt. Im Beispiel des Codelesers enthält das elektrische Signal Bilddaten aus einem Lesefeld in dem Erfassungsbereich 2. In diesen Bilddaten werden Codebereiche gesucht und die Codeinformationen innerhalb von Codebereichen

werden decodiert. Das Ergebnis der Auswertung wird an einem Ausgang 6 bereitgestellt.

[0020] Der optoelektronische Sensor 1 umfasst weiterhin eine Beleuchtungseinrichtung 7, welche eine kompakte Einheit 8 umfasst, bestehend aus einer Lichtquelle 9, beispielsweise eine Halbleiterlichtquelle, wie eine LED, eine Laserdiode oder eine VC-SEL, und einem Strahlformungselement 10. Weiterhin ist in der Beleuchtungseinrichtung 7 ein Mustererzeugungselement 11 angeordnet. In dem Erfassungsbereich 2 wird damit ein Beleuchtungsmuster erzeugt, um die Lage des Erfassungsbereiches 2 sichtbar zu machen und somit den optoelektronischen Sensor 1 auf einen gewünschten Erfassungsbereich 2 richten zu können.

[0021] In Fig. 2 ist ein erstes Ausführungsbeispiel der kompakten Einheit 8 der Beleuchtungseinrichtung 7 dargestellt, welche dabei als deformierbares LED-Vergusslinsen-Array 12 ausgebildet ist. Bei einem solchen LED-Vergusslinsen-Array 12 sind auf einer Trägerplatte 13 mehrere LEDs 14 befestigt, wobei jede einzelne LED 14 mit einer sphärisch ausgebildeten Vergusslinse 15 aus einem elastischen Material verspritzt ist, so dass die LED 14 und die Vergusslinse 15 die kompakte Einheit 8 bilden. Dabei wird in einem Spritzgussprozess die Vergusslinse 15 aus einem Polymer hergestellt und mit der LED 14 zu einer Beleuchtung assembliert. Ein solches LED-Vergusslinsenarray 12 wird mit einer transparenten, aus einem festen Material bestehenden Deckplatte 16, welche in vorliegenden Fall eine inhomogene Dicke aufweist, zusammengedrückt, wobei das so betätigte deformierte LED-Vergusslinsen-Array 12 zur adaptiven Strahlformung des von den LEDs 14 ausgestrahlten Lichtes genutzt wird.

[0022] Ein Ausführungsbeispiel einer Funktionsweise einer einzelnen, mit einer LED 14 vergossenen Vergusslinse 15, die eine sphärische Linsenoberfläche aufweist, ist in Fig. 3 ersichtlich. Dabei wird durch die feste Deckplatte 16 eine Kraft F1 auf die elastische Vergusslinse 15 ausgeübt (Fig. 3A). Wird die anliegende homogene Kraft F2 gegenüber der Kraft F1 verstärkt, wird die elastische Vergusslinse 15 zusammengedrückt und deformiert (Fig. 3B). Die Abflachung der sphärischen Linsenform im inneren Bereich führt zu einer optischen Strahlformung. Infolge der Deformation der elastischen Vergusslinse 15 wird das von der LED 14 ausgegebene Licht divergent beeinflusst. Alternativ zu der beschriebenen sphärischen Linsenform ist aber auch eine asphärische oder frei geformte Linsenoberfläche einsetzbar.

[0023] Wie aus Fig. 4 ersichtlich, funktioniert ein solches Strahlformungselement 10 aber auch dann, wenn die Vergusslinse 15 fest ausgebildet ist und die Deckplatte 16 aus einem elastischen Material besteht. Dabei verformt sich, wie aus Fig. 4 ersichtlich, die Deckplatte 16, was ebenfalls zu einer Strahlformung des von der LED 14 abgegebenen Lichtstrahles führt.

[0024] Somit sind unterschiedliche Materialkombinationen für Deckplatte 16 und Vergusslinse 15 möglich. Besteht die Vergusslinse 15 aus einem elastischen Material wie beispielsweise Silikon, so kann die Deckplatte 16 aus einem festen Material wie Glas oder Polymer ausgebildet sein. Alternativ kann die Vergusslinse 15 aber auch aus einem festen Material wie Glas und die Deckplatte 16 aus dem elastischen Material wie Silikon bestehen. In einer weiteren Alternative können sowohl Vergusslinse 15 als auch Deckplatte 16 aus einem voll- oder teilelastischen Material hergestellt sein.

[0025] In Fig. 5 ist auf der Oberfläche der sphärisch ausgebildeten Vergusslinse 15 eine Noppe 17 ausgebildet. Diese Noppe 17 ist insbesondere in dem Bereich der Oberfläche der Vergusslinse 15 ausgebildet, wo die Linsenoberfläche zuerst die Deckplatte 16 berührt. Diese Noppe 17 im Kontaktbereich zwischen elastischer Vergusslinse 15 und fester Deckplatte 16 hat den Vorteil, dass eine Hysterese der Beleuchtungsdivergenz unterbunden wird, indem die Kontaktfläche zwischen elastischer Vergusslinse 15 und fester Deckplatte 16 minimiert wird. Dieser Effekt kann verbessert werden, wenn auf der Oberfläche der Vergusslinse 15 in vorgegebenen Abständen mehrere Noppen 17 ausgebildet sind.

[0026] In Fig. 6 ist eine simulierte Oberflächengeometrie der beschriebenen deformierten sphärischen Vergusslinse 15 dargestellt, woraus hervorgeht, dass bei einem auf die Vergusslinse 15 wirkenden Druck infolge der homogenen Kraft die Abflachung der sphärischen Linsenform im inneren Bereich der Vergusslinse 15 erfolgt.

[0027] Fig. 7 zeigt ein Mustererzeugungselement 11 der Beleuchtungseinrichtung 7, welche ebenfalls als Mikrolinsenarray 18 ausgebildet ist, bei dem eine vorgegebene Anzahl aus elastischen Mikrolinsen 19 auf einem festen Trägermaterial 20 positioniert sind. Ein solches Mustererzeugungselement 11 wird bei einer Neujustierung des optoelektronischen Sensors 1 benötigt. Über den Mikrolinsen 19 ist eine transparente, aus festem Material bestehende Deckplatte 21 angeordnet, die in Fig. 7A ohne eine weitere Krafteinwirkung auf den Mikrolinsen 19 aufliegt. Das Ergebnis ist, dass das, von dem Mikrolinsenarray 18 im Erfassungsbereich 2 des optoelektronischen Sensors 1 erzeugte Beleuchtungsmuster ein Zielkreuz 22 darstellt. Wird auf die Deckplatte 21 mit einer homogenen Kraft F2, welche größer ist als F1, gegen die elastischen Mikrolinsen 19 gedrückt, so bewirkt diese Druckbeaufschlagung der Mikrolinsen 19 eine Vergrößerung der Krümmungsradien und somit der Brennweiten der Mikrolinsen 19. Dies hat eine Verringerung der Strahldivergenz und somit eine Verkleinerung der Dimension des Zielkreuzes 22 zur Folge, wie es in Fig. 7B dargestellt ist. Auch hier können anstelle eines elastischen Mikrolinsenarrays und einer festen transparenten Deckplatte ein festes Mikrolinsenarray und eine elastische Deckplatte verwendet werden.

[0028] Im druckbeaufschlagtem Zustand (F>0) des elastischen Mikrolinsenarrays 18 besteht die Möglichkeit, dieses lateral zu deformieren, wie aus Fig. 8 hervorgeht. Dabei befindet sich das Zielkreuz 22 im unbelasteten Zustand in der Mitte des Erfassungsbereiches 2 (Fig.8A). Durch die laterale Verschiebung der festen

transparenten Deckplatte 21 und der gleichzeitigen Druckbeaufschlagung der Mikrolinsen 19 entsteht eine Scherung des Mikrolinsenarrays 18, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen 19 führt, wie in Fig. 8B dargestellt. Dies hat zur Folge, dass das Zielkreuz 22 im Erfassungsbereich 2 lateral verschoben wird. Auf diese Weise kann die Position des Zielkreuzes 22 in dem Erfassungsbereich des optoelektronischen Sensors 1 angepasst oder an einer bestimmten bevorzugten Stelle im Erfassungsbereich 2 positioniert werden.

[0029] Es besteht auch die Möglichkeit, die zwei Dimensionen des Zielkreuzes 28 individuell voneinander einzustellen. Zu diesem Zweck besteht das Mustererzeugungselement 23 aus zwei gekreuzten elastischen Mikrolinsenarrays 24, 25. Die Orientierung von Mikrolinsenarray 24 ist senkrecht zur Orientierung vom Mikrolinsenarray 25, wobei die beiden Mikrolinsenarrays 24, 25 zu beiden Seiten eines Trägerelementes angeordnet sind. Im vorgegebenen Beispiel wird das erste Mikrolinsenarray 24 von einer ersten Deckplatte 26 aus einem festen transparenten Material abgedeckt, während das zweite Mikrolinsenarray 25 von einer zweiten Deckplatte 27 überdeckt wird. Wird keinerlei Kraft auf das erste und das zweite Mikrolinsenarray 24, 25 durch die Deckplatten 26, 27 ausgeübt, so ergibt sich ein Zielkreuz 28 wie es in Fig. 9A gezeigt ist. Durch die individuelle Druckbeaufschlagung des Mikrolinsenelementes 24 über die erste Deckplatte 26 und des zweiten Mikrolinsenarrays 25 durch die zweite Deckplatte 27 verschiebt sich die Dimension des Zielkreuzes 28 in beiden Richtungen unabhängig voneinander. So verkürzt sich der waagerechte Strich 29 des Zielkreuzes 28, wenn nur die Deckplatte 26 mit einer vorgegebenen konstanten Kraft F>0 auf das erste Mikrolinsenarray 24 drückt. Wird dem zweiten Mikrolinsenarray 25 keine Kraft zugeführt, so bleibt der vertikale Strich 30 des Zielkreuzes 28 unverändert (Fig. 9B). In einer Alternative, welche in Fig. 9C dargestellt ist, wird das zweite Mikrolinsenarray 25 durch die zweite Deckplatte 27 mit einer vorgegebenen Kraft F>0 beaufschlagt, wodurch sich der vertikale Strich 30 des Zielkreuzes 28 verkürzt. Da in diesem Fall das erste Mikrolinsenarray 24 druckunbeaufschlagt ist, bleibt der waagerechte Strich 29 des Zielkreuzes 28 unverändert.

[0030] Insbesondere bei der Verwendung eines optoelektronischen Sensors 1, der als 3D-Kamerasensor zur Entfernungsmessung ausgebildet ist, basiert das Detektionsprinzip auf Triangulation unter Zuhilfenahme einer aktiven Musterbeleuchtung. In Stereosystemen wird die Beleuchtung zur Generierung eines künstlichen Kontrastes eingesetzt, um dichte Tiefenkanten zu erzeugen und die Abstandswerte periodischer Objekte in der zu betrachtenden Szene eindeutig zu bestimmen. In diesem Fall ist das Mustererzeugungselement als Punktmustergenerator 31 auf der Basis eines Mikrolinsenarrays 32 ausgebildet. Die auf dem Mikrolinsenarray 32 angeordneten Mikrolinsen 33 bestehen aus einem elastischen Material, beispielsweise aus Silikon. Die elastischen Mikrolinsen 33 sind auf einem festen Trägermaterial 34 angeordnet und, wie im Zusammenhang mit Fig. 1 erläutert, ist dieses so geformte Mustererzeugungselement Bestandteil der Beleuchtungseinrichtung 7.

[0031] Ein Ausführungsbeispiel für die Funktionsweise eines solchen Punktmustergenerators 31 ist in Fig. 10 dargestellt. Das Mikrolinsenarray 32 des Punktmustergenerators 31 wird von dem Lichtstrahl der Lichtquelle 9 durchleuchtet, wobei, wie aus Fig. 10A ersichtlich, der Lichtstrahl konvergiert. Dies ist immer dann der Fall, wenn keine Kraft auf das Mikrolinsenarray 32 ausgeübt wird. Ohne diese mechanische Druckbeanspruchung bilden die Mikrolinsen 33 des Mikrolinsenarrays 32 in der Fokusebene des Projektionsobjektivs kleine Brennpunkte aus, dessen Lichtmuster zu einem Beleuchtungsmuster mit kleinen Punktdurchmessern führt. Wird gemäß Fig. 10B eine Kraft F2>0 durch die transparente Deckplatte 35 auf das Mikrolinsenarray 32 ausgeübt, deformieren sich die Mikrolinsen 33, wie im Zusammenhang mit Fig. 5 erläutert. Die Deformation führt zu einer Abflachung des Linsenkrümmungsradius in der Linsenmitte, was wiederum zur Verschiebung des Brennpunktes führt. Die Verschiebung des Brennpunktes in der Fokusebene des Projektionsobjektivs führt zur Vergrößerung des Punktdurchmessers des in der Fokusebene des Projektionsobjektivs dargestellten Beleuchtungsmusters.

[0032] Wird weiterhin der Druck (F>>0) auf das elastische Mikrolinsenarray 32 erhöht (Fig. 10C), verschwindet die gekrümmte Linsenform vollständig. Übrig bleiben zwei parallele Glasplatten in Form der transparenten Deckplatte 35 und des transparenten Trägermaterials 34 mit einem elastischen Material dazwischen. Bei dieser Position der Mikrolinsen 33 erlischt deren Strahlformungseffekt vollständig. In diesem Zustand wird die Fokusebene des Projektionsobjektivs homogen beleuchtet, was zu einer homogenen Beleuchtung der Szene führt.

[0033] Wird in einem druckbeaufschlagten Zustand des elastischen Mikrolinsenarrays 32 dieses lateral deformiert, wie in Fig. 11 dargestellt, indem eine laterale Verschiebung der Deckplatte 34 vorgenommen wird, entsteht eine Scherung des Mikrolinsenarrays 32, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen 33 führt. Dies hat zur Folge, dass das Punktmuster in der Fokusebene des Projektionsobjektivs in Richtung der Verschiebung der Deckplatte 34 verschoben wird (Fig. 11 B). Im Vergleich dazu befindet sich das Punktmuster immer dann, wenn das Mikrolinsenarray 32 frei von einer Druckbeaufschlagung ist, im Zentrum der Fokusebene des Projektionsobjektivs (Fig. 11A). Aufgrund der Verwendung eines solchen Punktmuster-Erzeugungselementes in einer 3D-Stereokamera, lassen sich die Beleuchtungsmuster adaptiv an die Gegebenheiten der zu beleuchtenden Szene anpassen, wobei das Beleuchtungsmuster zwischen strukturiert und homogen adaptiv umgeschaltet werden kann. Dieses Umschalten ermöglicht neben den 3D-Tiefendaten auch die Aufnahme von Grauwertbildern.

[0034] Es besteht ebenfalls die Möglichkeit, die Ver-

änderung bzw. Verschiebung des Punktmusters für sichere Stereokameras einzusetzen. In der Sicherheitstechnik muss sichergestellt werden, dass die Bildaufnahme immer zuverlässig funktioniert. Die Funktionalität der Bildsensoren wird dabei mit einem dynamischen Bildsensortest (Hell- und Dunkelbildern) in den Pausen der Stereobildaufnahme mit einer internen Beleuchtungs-LED überprüft. Der Bildsensortest mit interner Beleuchtungs-LED kann eingespart werden, wenn sich das Beleuchtungsmuster

[0035] (Position und Größe der Punkte) von Zeit zu Zeit ändert, um die dynamische Funktion der Bildsensoren mit den Grauwertbildern der beiden Kameramodule aus der Szene zu verifizieren.

Patentansprüche

1. Beleuchtungseinrichtung zum Erzeugen eines Beleuchtungsfeldes für einen optoelektronischen Sensor, die mindestens eine Lichtquelle (9), ein anpassbares optisches Strahlformungselement (10) und ein Druckelement aufweist, wobei das Druckelement an das Strahlformungselement (10) (16) angreift, und zur Lichtformung deformiert, und wobei die Lichtquelle (9) und das Strahlformungselement (10) direkt aneinander grenzen und eine kompakte Einheit (8) bilden, **dadurch gekennzeichnet, dass** im Strahlengang hinter dem Strahlformungselement (10), der Lichtquelle (9) abgewandt, ein Mikrolinsen (19) aufweisendes Mustererzeugungselement (11) angeordnet ist, welches einen Erfassungsbereich (2) des optoelektronischen Sensors (1) durch ein Beleuchtungsmuster (22, 28) sichtbar macht, dass das Mustererzeugungselement (11) als adaptiver, Mikrolinsen (33) umfassender Punktmustergenerator (31) ausgebildet ist, welcher bei einer mechanischen Druckbeanspruchung der elastisch ausgebildeten Mikrolinsen (33) durch die aus einem festen Material bestehenden Deckplatte (35) in Abhängigkeit der senkrecht an den Mikrolinsen (33) angreifenden Druckkraft das Beleuchtungsmuster mit variierendem Punktdurchmesser erzeugt.

2. Beleuchtungseinrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** der Punktmustergenerator (31) bei einer lateralen Deformation der Mikrolinsen (33) durch die Deckplatte (35) ein Beleuchtungsmuster erzeugt, welches lateral im Erfassungsbereich (2) verschoben ist.

Claims

1. An illumination device for producing an illumination field for an optoelectronic sensor which has at least one light source (9), an adaptable optical beam shaping element (10) and a pressure element, wherein the pressure element (16) engages at the beam shaping element (10) and deforms it for light shaping; and wherein the light source (9) and the beam shaping element (10) are directly adjacent to one another and form a compact unit (8), **characterized in that** a pattern generating element (11) having microlenses (19) is arranged in the optical path behind the beam shaping element (10) and facing away from the light source (9), said pattern generating element making a detection zone (2) of the optoelectronic sensor (1) visible by an illumination pattern (22, 28); **in that** the pattern generating element (11) is configured as an adaptive point pattern generator (31) which comprises microlenses (33) and which produces the illumination pattern with a varying point diameter on a mechanical pressure exertion on the elastic microlenses (33) by the top plate (35) comprising a solid material in dependence on the perpendicular pressure force engaging at the microlenses (33).

2. An illumination device in accordance with claim 1, **characterized in that** the point pattern generator (31) produces an illumination pattern, which is displaced laterally in the detection zone (2), on a lateral deformation of the microlenses (33) by the top plate (35).

Revendications

1. Dispositif d'éclairage destiné à la production d'une zone d'éclairage pour un capteur optoélectronique, qui comprend au moins une source de lumière (9) et un élément de formage de rayon (10) optique adaptable et un élément de compression, l'élément de compression attaquant l'élément de formage de rayon (10) et le déformant pour le formage de la lumière, et dans lequel la source de lumière (9) et l'élément de formage de rayon (10) sont directement adjacents l'un à l'autre et forment une unité compacte (8), **caractérisé en ce qu'**en arrière de l'élément de formage de rayon (10) dans le chemin optique, un élément de génération de motif (11) comprenant des microlentilles (19) est agencé en étant détourné de la source de lumière (9), qui rend visible une zone de détection (2) du capteur optoélectronique (1) par un motif d'éclairage (22, 28), **en ce que** l'élément de génération de motif (11) est réalisé sous forme de générateur de motif de points (31) adaptatif comprenant des microlentilles (33), qui, lors d'une sollicitation mécanique par pression des microlentilles (33) réalisées élastiques, génère le motif d'éclairage avec variation du diamètre des points par la plaque de couverture (35) constituée en un matériau solide, en fonction de la force de compression attaquant verticalement les microlentilles (33).

2. Dispositif d'éclairage selon la revendication 1, **caractérisé en ce que** lors de la déformation latérale des microlentilles (33) par la plaque de couverture (35), le générateur de motif de points (31) génère un motif d'éclairage qui est décalé latéralement dans la zone de détection (2).

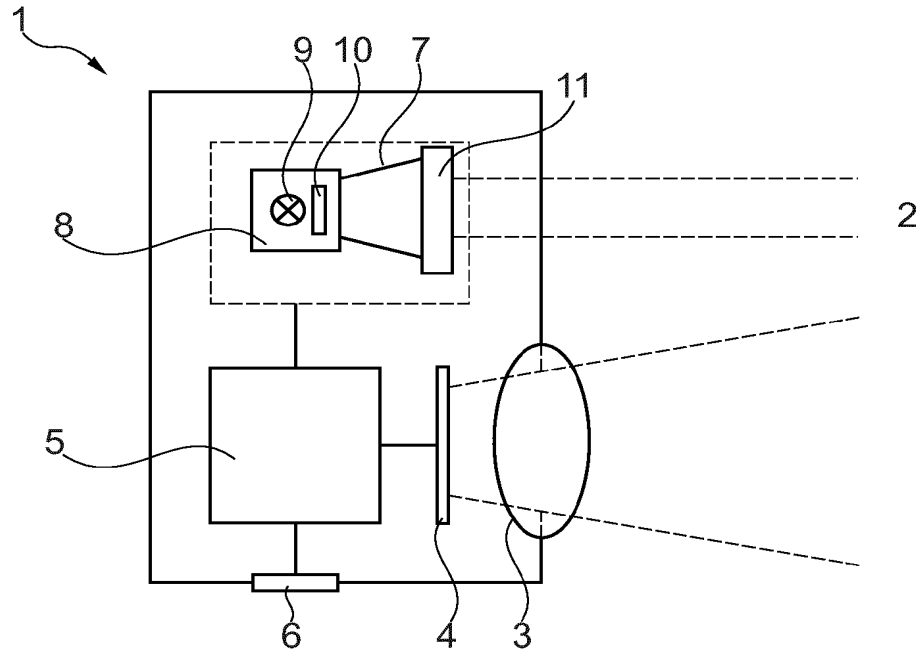


Fig. 1

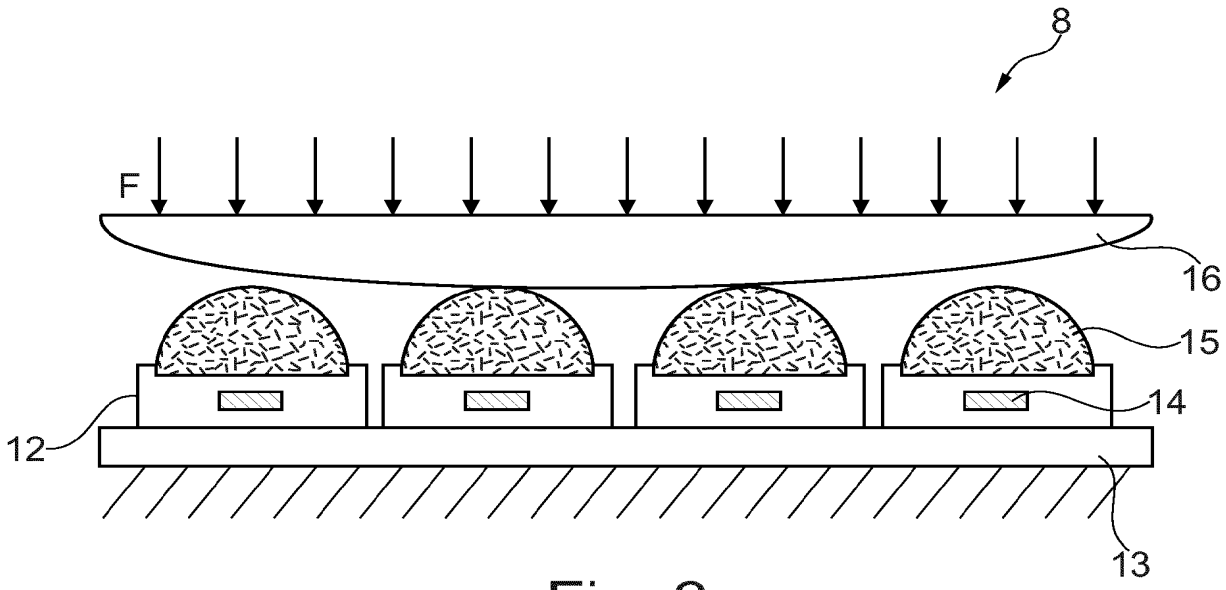


Fig. 2

HESAI EX1002, P.565

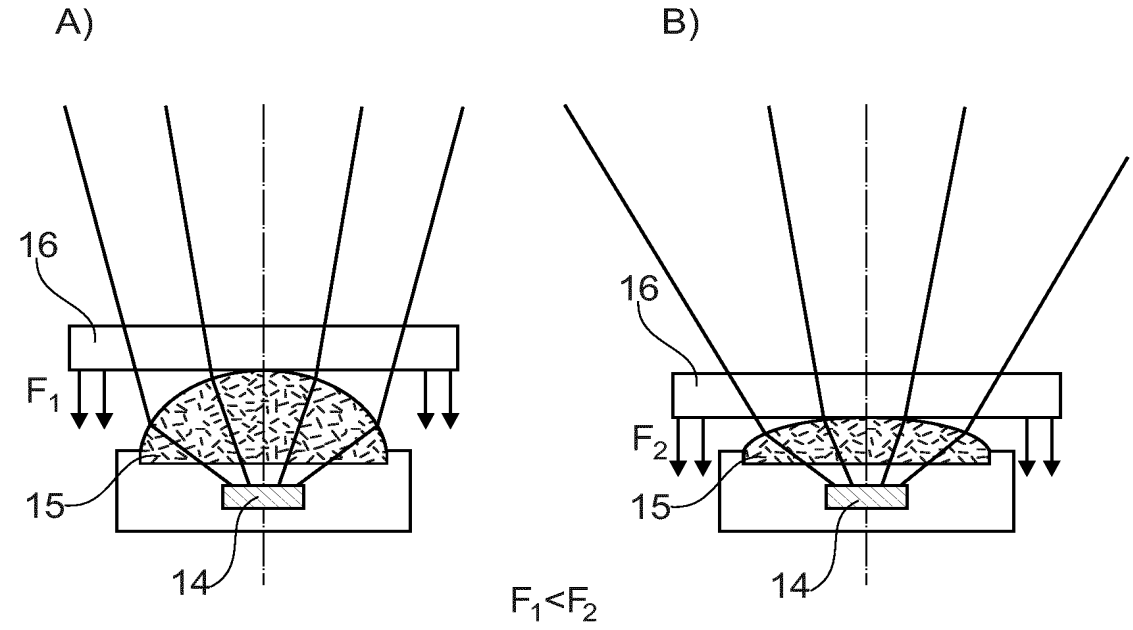


Fig. 3

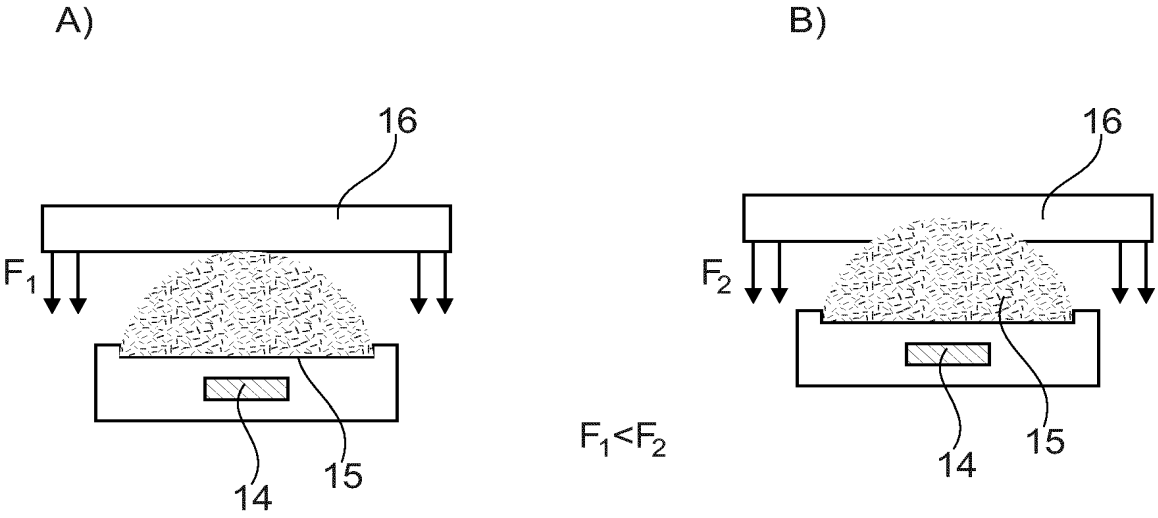


Fig. 4

HESAI EX1002, P.566

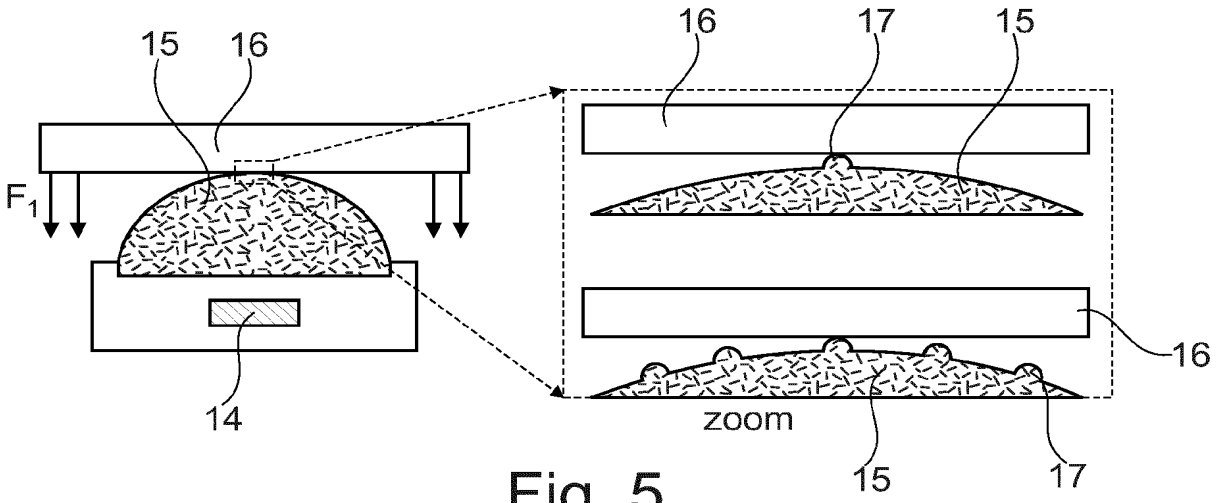

15
16
F1
14
16
17
15
16
zoom
15
17

Fig. 5

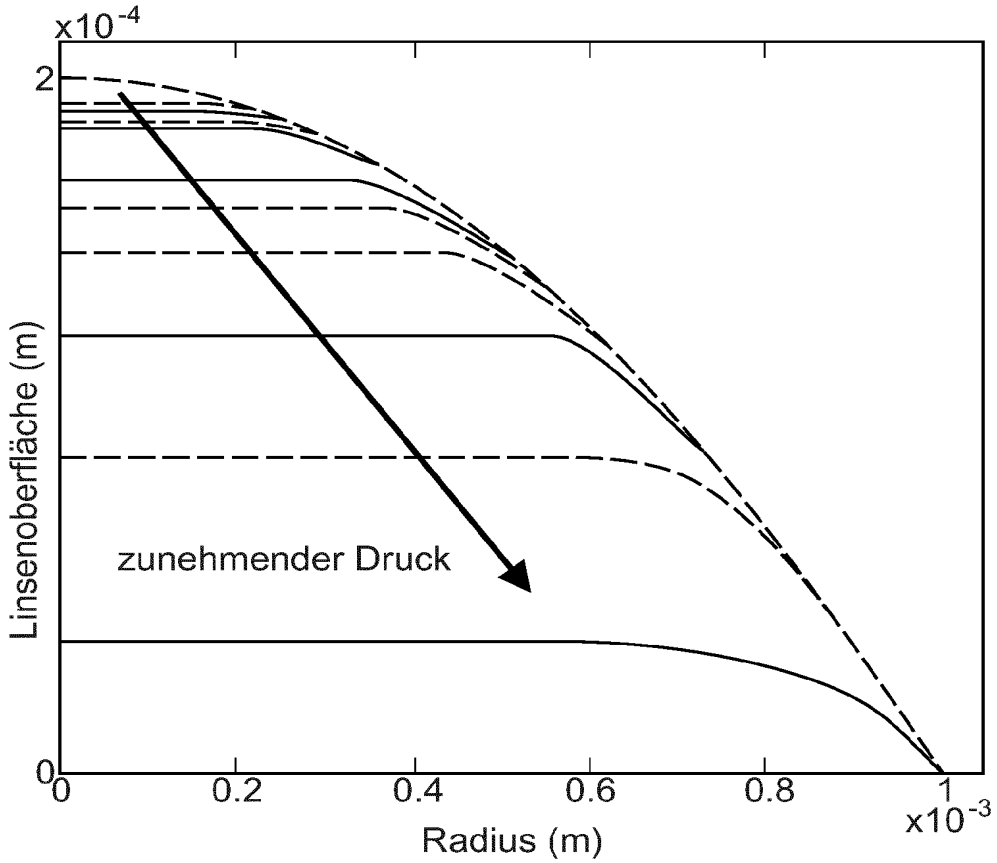

x10-4
2
0
Linsenoberfläche (m)
zunehmender Druck
0
0.2
0.4
0.6
0.8
1
x10-3
Radius (m)

Fig. 6

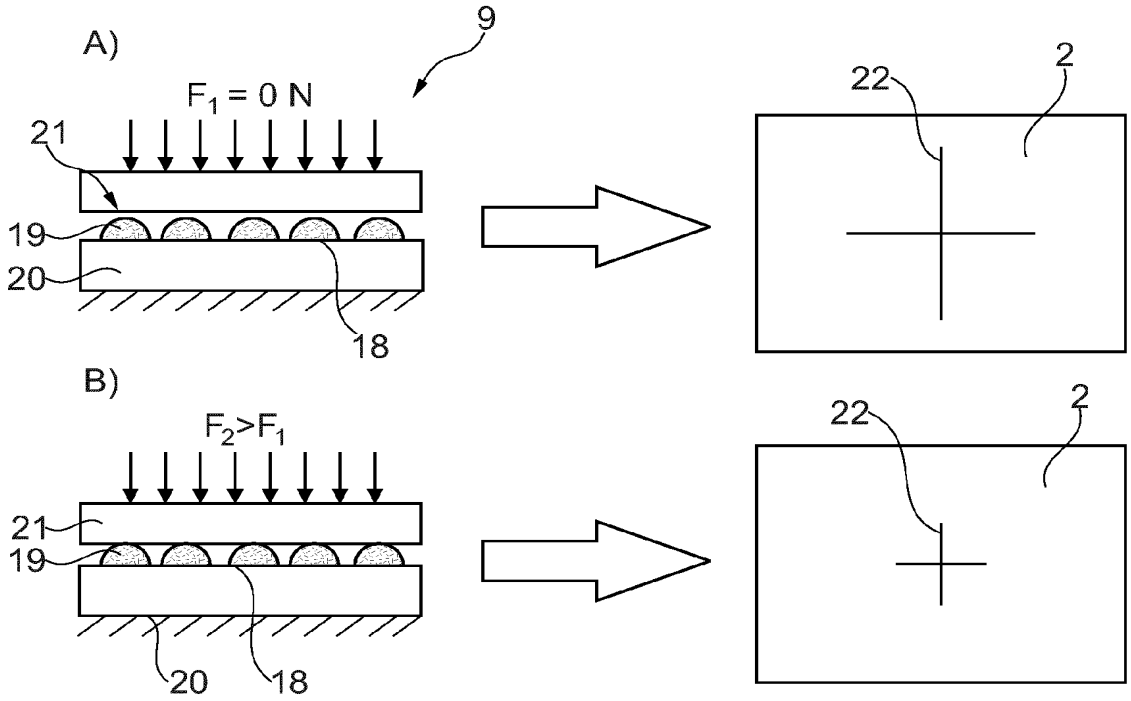


Fig. 7

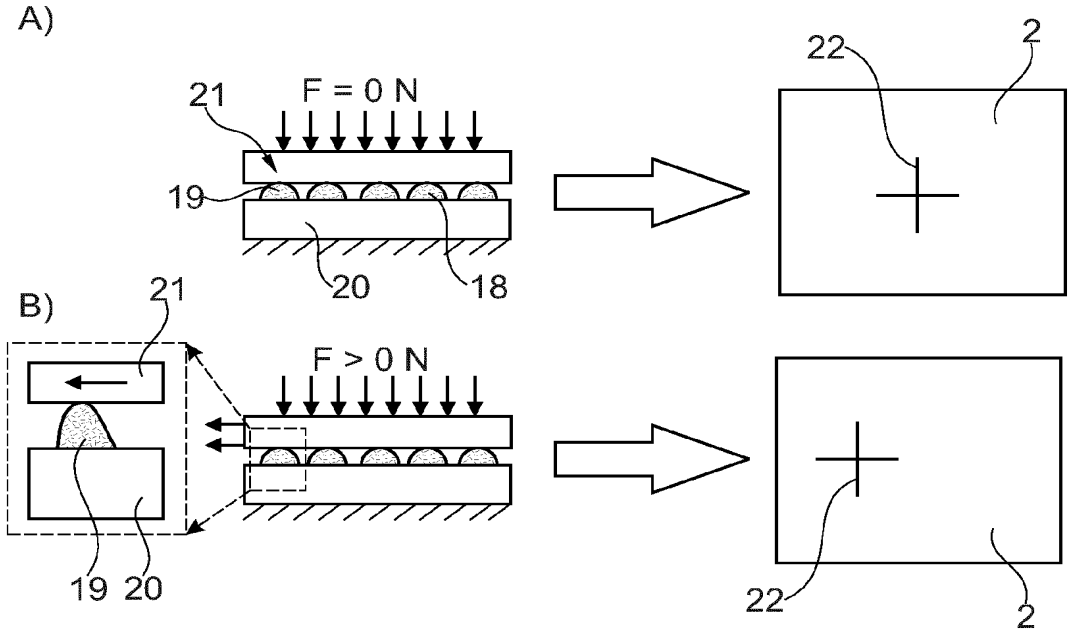


Fig. 8

HESAI EX1002, P.568

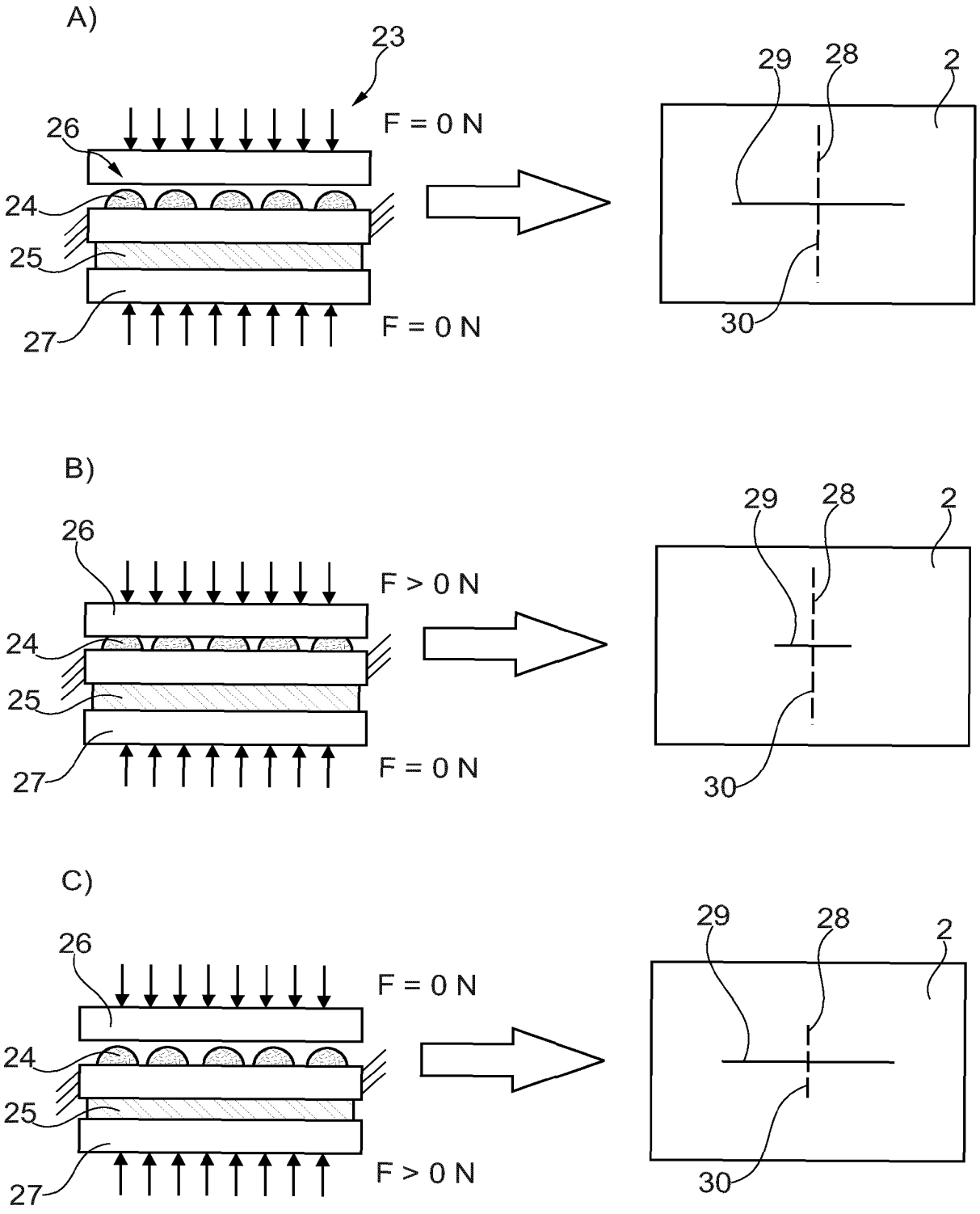


Fig. 9

HESAI EX1002, P.569

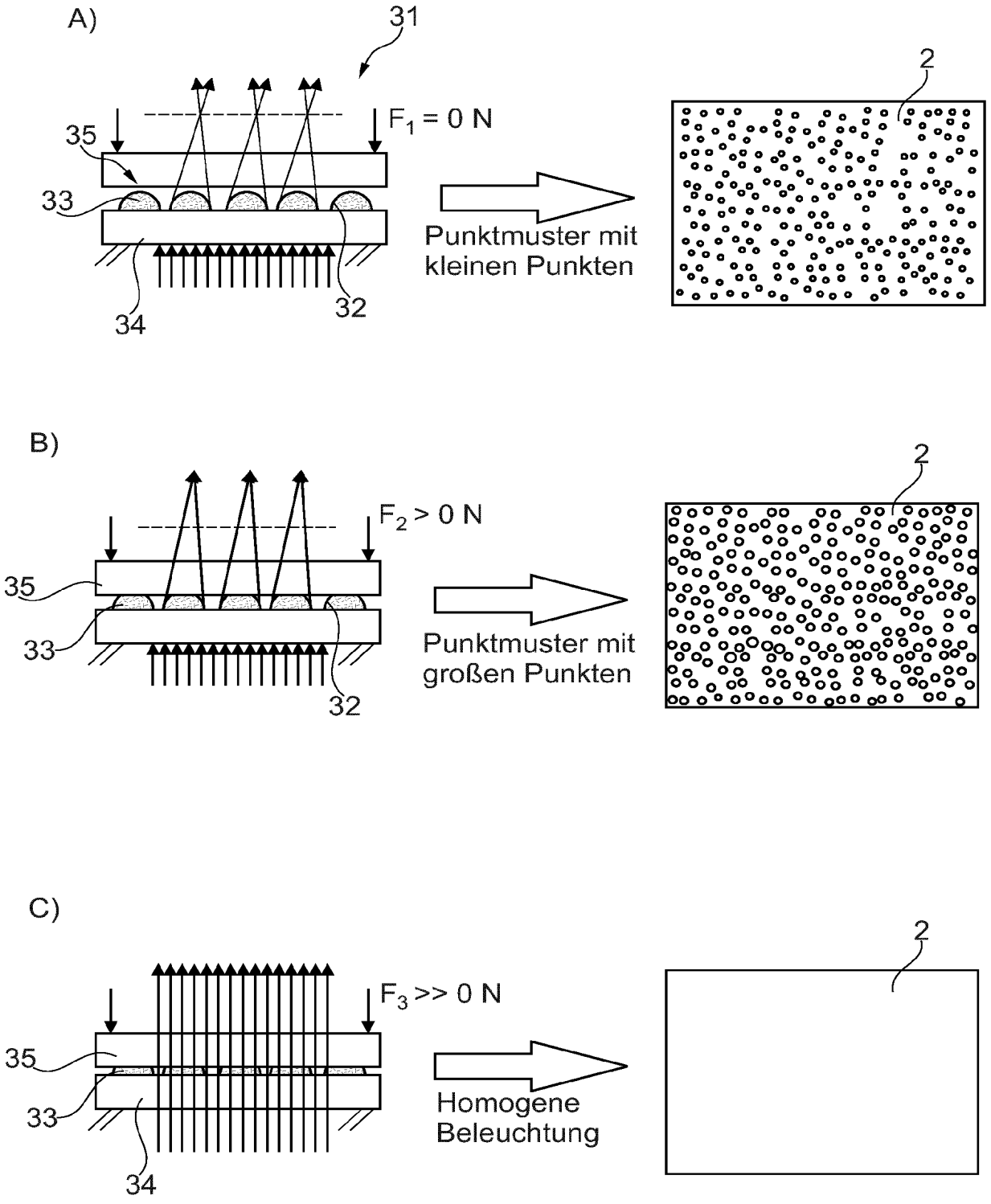

A)
31
35
F_1 = 0 N
33
34
32
Punktmuster mit kleinen Punkten
2
B)
35
F_2 > 0 N
33
32
Punktmuster mit großen Punkten
2
C)
35
F_3 >> 0 N
33
34
Homogene Beleuchtung
2

Fig. 10

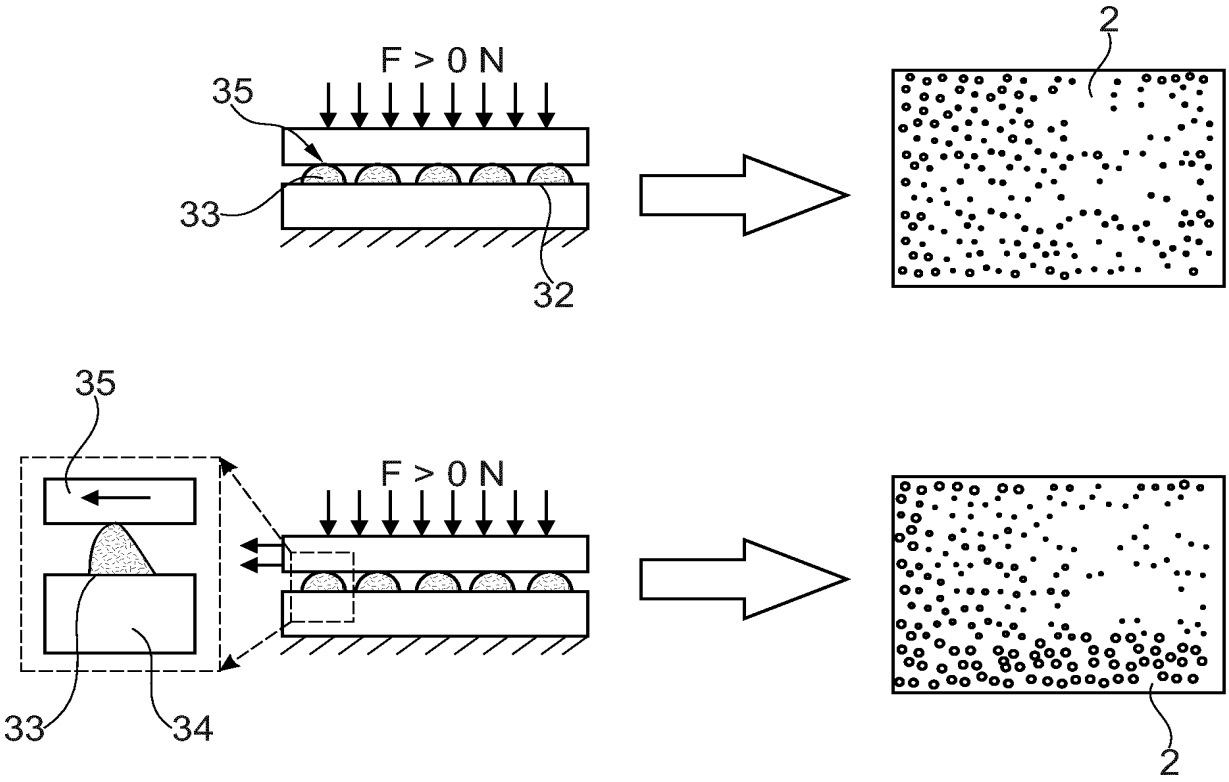


Fig. 11

HESAI EX1002, P.571

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In der Beschreibung aufgeführte Patentdokumente

- DE 60215093 T2 **[0005]**
- WO 2009034511 A2 **[0007]**

HESAI EX1002, P.572

Electronic Acknowledgement Receipt

EFS ID:	39856851
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	29-JUN-2020
Filing Date:	14-MAY-2018
Time Stamp:	15:28:56
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P006US3-IDS.pdf	186762 365147c30cc5f2a0a1cf54684bfc1d5dd0d79494	yes	4

	Multipart Description/PDF files in .zip description			
	Document Description	**Start**	**End**	
	Transmittal Letter	1	2	
	Information Disclosure Statement (IDS) Form (SB08)	3	4	
Warnings:				
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2	Foreign Reference	EP3002548B1.pdf	322468 d1ec1abdc8079bd72d1636fd10d35a57bbc1387e	no	15
Warnings:					
Information:					
3	Non Patent Literature	P006-AU-Full-Examination-Report.pdf	196417 799cefa137780452ef75d0796b10d3ea69a91353	no	5
Warnings:					
Information:					
4	Non Patent Literature	P006US3-singapore-written-opinion.pdf	196106 988fec2e298d163bb075d26d83c367c1d767bce	no	7
Warnings:					
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		Total Files Size (in bytes):	901753		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on June 29, 2020.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer-Johnson/

PATENT
Attorney Docket No.: 103033-1086284-P006US3
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus Pacala	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: 2875
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patents and U.S. Patent Application Publications are not provided. Copies of the remaining cited references are provided.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed *before* the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/ William L. Shaffer /

William L. Shaffer
Registration No. 37,234

KILPATRICK TOWNSEND & STOCKTON LLP

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	15/979,266
Filing Date	May 14, 2018
First Named Inventor	Angus Pacala
Art Unit	2875
Examiner Name	Alsomiri, Isam A.
Attorney Docket Number	103033-P006US3-1086284

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code [1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	5084596	A	01-28-1992	Borsh	
	2.	8633384	B1	01-21-2014	Shotey, et al.	

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Examiner Initial*	Cite No	Publication Number	Kind Code [1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	3.	20110266022	A1	11-03-2011	Jafari	
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Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	5.	EUROPEAN PATENT OFFICE; Extended European Search Report received in European Application No. 16865297.2, mailed June 11, 2019; 9 pages.	

EXAMINER SIGNATURE

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Electronic Acknowledgement Receipt

EFS ID:	36669555
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/LaRenda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	23-JUL-2019
Filing Date:	14-MAY-2018
Time Stamp:	18:23:30
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P006US3-1086284_SIDS.pdf	178167 c1ae7e29a05323737afc6b92fd6637a1c5327b99	yes	3

	Multipart Description/PDF files in .zip description			
	Document Description	**Start**	**End**	
	Transmittal Letter	1	2	
	Information Disclosure Statement (IDS) Form (SB08)	3	3	
Warnings:				
Information:				
2	Non Patent Literature	NPL_Extended-European-Search-Rpt.PDF	271571 51a4dfe051c44e66042473b5f01f83e020b3be67	no	9
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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
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If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
<u>New International Application Filed with the USPTO as a Receiving Office</u>
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By: /La Renda Meyer/

PATENT
Attorney Docket No.: 103033-P006US3-1086284
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus PACALA	Examiner: ALSOMIRI, Isam A.
Application No.: 15/979,266	Technology Center/Art Unit: 3645
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patent and U.S. Patent Application Publications are not provided.

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Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/Stephen A. Mao/

Stephen A. Mao
Registration No. 73418

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PTO/SB/08a (01-10)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	15/979,266
Filing Date	May 14, 2018
First Named Inventor	Angus Pacala
Art Unit	2875
Examiner Name	Not yet assigned
Attorney Docket Number	103033-P006US3-1086284

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
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	2.	9551791	B2	01-24-2017	Van Den Bossche, et al.	
	3.	9992477	B2	06-05-2018	Pacala	
	4.	10063849	B2	08-28-2018	Pacala	
	5.	9989406	B2	06-05-2018	Pacala	
	6.	10222458	B2	03-05-2019	Pacala, et al.	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	7.	20180299554	A1	10-18-2018	Dirk van Dyck	
	8.	20190041498	A1	02-07-2019	Pierre-Yves Droz, et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]
	9	3045935	EP	A1	07-20-2016	Xenomatix Nv		
	10	3316000	EP	A1	05-02-2018	Xenomatix Nv		
	11	2018065428	WO	A3	04-12-2018	Xenomatix Nv		
	12	2018065427	WO	A1	04-12-2018	Xenomatix Nv		

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
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	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-P006US3-1086284

	13	2018065429	WO	A1	04-12-2018	Xenomatix Nv		
	14	2018065426	WO	A1	04-12-2018	Xenomatix Nv		
	15	2018122415	WO	A1	07-05-2018	Xenomatix Nv		
	16	2018197441	WO	A1	11-01-2018	Xenomatix Nv		

NON-PATENT LITERATURE DOCUMENTS			
Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]

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[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.
[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
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	Application Number	15/979,266
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	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-P006US3-1086284

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KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer/

PATENT
Attorney Docket No.: 103033-P006US3-1086284
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus PACALA	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: 2875
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Respectfully submitted,

/Stephen A. Mao/

Stephen A. Mao
Registration No. 73418

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 045 935 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
20.07.2016 Bulletin 2016/29

(51) Int Cl.:
G01S 17/46 *(2006.01)* ***G01S 17/89*** *(2006.01)*
G01S 7/481 *(2006.01)*

(21) Application number: **15151031.0**

(22) Date of filing: **13.01.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) Surround sensing system with dome-filter assembly

(57) The invention pertains to a system (100) for detecting a characteristic of an object, comprising: a source (101) to generate a pulsed radiation pattern; a detector (102); a processor (103) to process data from the detector (102) when radiation from the radiation source is reflected by an object; a synchronization means (104) interfacing between the detector (102) and the radiation source (101); wherein: the detector (102) is synchronized with the source (101) so that radiation is detected only during the pulses, the processor (103) determines a characteristic of the object by determining displacement of spots with reference to reference positions, the source emits monochromatic light and the detector is equipped with a corresponding filter (1320) arranged on a dome (1310), wherein fish-eye optics (1330) arranged between said filter (1320) and said detector (102) guide light that has passed through said filter (1320) towards a light-sensitive area of said detector (102).

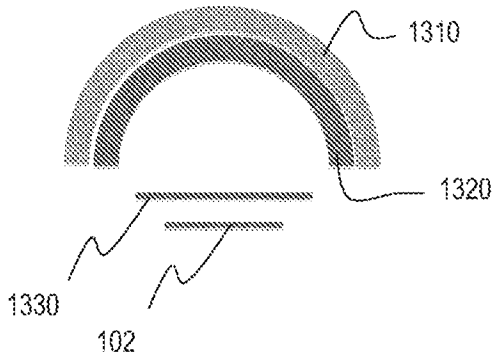


Fig. 13

EP 3 045 935 A1

Description

Field of the invention

[0001] The invention relates to the field of characterising a scene or part thereof. More specifically it relates to systems and methods for detecting the characteristic, e.g. a profile or property, of an object or person, in particular in the vicinity of a vehicle.

Background of the invention

[0002] There are a large number of applications where knowledge of the 3D profile of an object is relevant. Different techniques exist for scanning the profile of an object. Basically they can be subdivided into radar based systems, ultrasound based systems and optical sensing systems.

[0003] Radar based systems have the advantage that they can sense a long range but have the disadvantage that they have a poor angular and depth resolution with regard to certain applications (e.g. for tracking the profile in a road).

[0004] Ultrasound based systems can be useful for short range sensing but their narrow bandwidth limits the depth sensitivity and the sampling resolution and the strong absorption in air limits the range to a few meter.

[0005] Optical sensing based methods can be subdivided in different types measuring the distance through time of flight measurements or by triangulation.

[0006] In time of flight methods the object is illuminated by a light source. From the delay between the emission and the detection the distance travelled by the light can be determined. The time of flight methods can make use of pulsed illumination.

[0007] In triangulation based systems, the unknown position of an object is calculated using trigonometry. An example of such a system is the Kinect system of Microsoft described in US8320621. In this system structured infra-red light (e.g. circles) is projected and viewed with a 3D camera. This system, which is primarily intended for indoor gaming and entertainment applications, is not suitable for outdoor use, due to the intensity of the sunlight.

[0008] In stereovision the distance to an object is determined from the local shift between corresponding parts in the images obtained by two cameras under different viewing angles or by one stereo camera with two lenses. Stereovision based systems can make use of existing set-ups and algorithms from robot vision, can operate using ambient illumination, and do not require projection. On the other hand stereovision based systems have the disadvantage that calibrated cameras with sufficient distance are required. Furthermore, sufficient structure in the images is required to enable cross correlation for parallax, it is difficult to detect flat surfaces and water, a sufficient number of pixels is required, the depth sensitivity is limited, and typical cameras have insufficient dynamic range to cope with various light conditions. The biggest hurdle seems to be that stereovision based systems cannot work if there is insufficient structure in the object being scanned.

[0009] US 2005/195383 A1 discloses a method for obtaining information about objects in an environment around a vehicle in which infrared light is emitted into a portion of the environment and received and the distance between the vehicle and objects from which the infrared light is reflected is measured. An identification of each object from which light is reflected is determined and a three-dimensional representation of the portion of the environment is created based on the measured distance and the determined identification of the object. Icons representative of the objects and their position relative to the vehicle are displayed on a display visible to the driver based on the three-dimensional representation. Additionally or alternatively to the display of icons, a vehicular system can be controlled or adjusted based on the relative position and optionally velocity of the vehicle and objects in the environment around the vehicle to avoid collisions.

[0010] US 2007/177011 A1 relates to a movement control system which can be used to control moving platforms such as vehicles or robotic arms. It especially applies to a driving aid for vehicles and to a parking aid capable of self-parking a vehicle. A three-dimensional camera is located on the platform, say a car and arranged to view the environment around the platform. A processor uses the three-dimensional information to create a model of the environment which is used to generate a movement control signal. Preferably the platform moves relative to the environment and acquires a plurality of images of the environment from different positions.

[0011] US 2012/038903 A1 provides methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal.

[0012] The systems mentioned above are not capable of operating sufficiently accurately at a high vehicle speed for a long detection range.

[0013] Therefore there is still room for improvement of surround sensing scan systems that can be used in outdoor situations scanning the profile of objects over a large range with a high resolution and with a high speed.

[0014] An improved system is described in European patent application no. 13175826.0 and international patent application no. PCT/EP2014/064769 (unpublished at the date of filing of the present application) in the name of the present applicant. The present application disclos-

es further improvements relating to the capturing and detection of images, which can be used in systems such as the one of the aforementioned patent applications.

Summary of the invention

[0015] It is an object of embodiments of the present invention to provide good systems and methods for determining the profile of an object.

[0016] It is an advantage of embodiments of the present invention that it is robust against the variation in light conditions that can occur in an outdoor environment, such as daylight and/or rain. Moreover, it is an advantage of embodiments of the current invention that it is robust against the light of other vehicles.

[0017] It is an advantage of embodiments of the present invention that scanning is possible over a range from 1 to 15 m, in some embodiments even over a range from 1 to 30 m, and in some embodiments up to 200 m. By providing ranges up to 200 m, embodiments of the present invention are particularly suited for use in autonomous vehicles. The maximal range can be improved by using better cameras and lasers. Use can be made of the benefits of using semiconductor technology for manufacturing such components. The profiling precision is depending on the range to be scanned. In embodiments according to the present invention, a precision of 1/1000 of the range can be obtained.

[0018] Precision here means precision in distance between the car and the road. The vertical precision "local height of the road" can even be 10 times better.

[0019] It is an advantage of the embodiments of the present invention that a viewing angle of 1 radian horizontally and 1 radian vertically can be obtained. Depending on the application, one can choose for different horizontal and vertical angles. Furthermore, if larger viewing angles are required, more systems can be combined.

[0020] It is an advantage of embodiments of the present invention that they are robust against vibrations. It is an advantage of embodiments of the present invention that components used in systems according to embodiments of the present invention typically have a long lifetime.

[0021] It is an advantage of embodiments of the present invention that the average radiation power is below 1 mW per spot. In case a radiation pattern of 100x100 spots is used this results in an overall average radiation of 10 W. The power threshold is in agreement with commonly applied safety regulations. Furthermore, it is an advantage of embodiments of the present invention that the power consumption of systems according to embodiments of the present invention is low. This is of particular importance in a vehicular environment, where the vehicle's power system must not be overly burdened by the sensing system.

[0022] It is an advantage of embodiments of the present invention that they can be easily installed and that the alignment is easy and may even be automated. The initial alignment can e.g. be done by scanning a flat plane and recording the positions of the projected spots as initial reference. A possible change in relative position between projector and detector can easily be detected by observing the projected pattern as a whole.

[0023] It is an advantage of embodiments of the present invention that a low-weight and compact system can be provided. It is an advantage of embodiments of the present invention that a low cost system can be obtained, as e.g. it can be based on components that can be made using standard processing techniques. It is an advantage of at least some embodiments of the present invention that no mechanical scanning of the object under study is required resulting in a mechanically less complex system. It thereby is an advantage that the basic components can be available components such as for example CMOS and CCD cameras and laser arrays. These components are readily available or can be customized based on the invention requirements.

[0024] When multiple cameras are used in a system, use can be made of one or more radiation splitter such as a semi-transparent mirror, a beam splitter, a beam splitting cube, etc. for aligning the different cameras.

[0025] For the basic components such as CMOS and CCD cameras and laser arrays we profit for the steady increase in performance and decrease in cost.

[0026] It is an advantage of embodiments of the current invention that the performance is scalable.

[0027] It is an advantage of embodiments of the present invention that the system's design and component selection can make it reliably functioning independent of the weather conditions, e.g. whether the system is functioning at night, in rain, in fog, independent of the road quality, independent of the used surface material, etc. Systems according to embodiments of the present invention are very robust providing reliable operation in many different environmental conditions. Operation may be substantially independent of the road surface, the material type, the weather, day or night, etc.

[0028] It is an advantage of embodiments of the present invention that the sensed and/or processed data is used for saving energy and/or optimizing use of energy in the characterization system, e.g. the active suspension system.

[0029] Without changing the basic principles of the method the performance is increased by just using newer versions of camera and lasers. For instance, regarding only the resolution as a performance indicator, in 3 years CMOS cameras increase from 1 megapixel to 4 megapixel and the same cost.

[0030] There are different tradeoffs that can be tuned depending on the application requirements (e.g. tradeoff between power and field of view), resulting in optimum characteristics for particular applications.

[0031] In at least some embodiments according to the present invention, the object for which a characteristic, e.g. a profile or property, is to be determined is the road in front of a vehicle. In some embodiments according to

the present invention, information of the road in front of the vehicle is used for controlling the suspension system of the vehicle. It is an advantage of embodiments of the present invention, specifically when applied in automotive applications, that they are still working up to speeds of 50 m/s.

[0032] It is an advantage of embodiments of the current invention that besides information of the monitored object such as a profile, also several other parameters can be derived. For example, when applied in an automotive environment, also the 3D orientation of a car, the speed of the car, the presence of approaching cars or other objects, the presence of water on the road surface, etc. can be obtained.

[0033] The above objective is accomplished by a method and device according to the present invention.

[0034] According to an aspect of the present invention, there is provided a vehicle-mountable system for detecting a characteristic of an object, the system comprising: a radiation source adapted to generate a simultaneously pulsed radiation pattern composed of radiation spots; at least one detector having a plurality of pixels; a processor adapted to process data from the at least one detector when radiation from the radiation source is reflected by an object and detected by the at least one detector; a synchronization means interfacing between the at least one detector and the radiation source; wherein the synchronization means is adapted for synchronizing the at least one detector with the radiation source so that detection by the detector of radiation to be processed is detected only during the radiation pulses, the processor is adapted for determining a characteristic of the object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions; and the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter arranged on a dome, the system further comprising fish-eye optics arranged between the narrow bandpass filter and the at least one detector to guide light that has passed through the narrow bandpass filter towards a light-sensitive area of said at least one detector.

[0035] Known vehicle-mounted object detection systems have to be able to detect the reflections of the projected pattern, i.e. the projected spots, over a potentially intense "background radiation" consisting of sunlight in the order of 500 W/m^2. An approach to overcome this problem, is to filter the light to be detected to a narrow band around the wavelength of the projected spots, thus reducing the amount of sunlight to be dealt with to the light present in the relevant band. However, known optical systems do not deliver the incoming radiation at a sufficient perpendicular angle onto the narrowband filter to obtain satisfactory results. The inventors have found that extremely accurate filtering can be obtained by combining a specific optical arrangement with a narrowband filter arranged on a dome, operating on the light before it reaches the sensor. The phrase "arranged on a dome" is used to indicate that the surface of the filter follows the surface of the (transparent) dome, i.e., it has substantially the same curvature. The filter may be arranged on the inside or the outside of the dome. It is an advantage of the invention that accurate detection of radiation spots becomes possible at longer ranges and/or with reduced output power.

[0036] As used herein, monochromatic light is understood to include laser light as produced by common semiconductor laser devices. The monochromatic light may have a wavelength spread of less than ± 5 nm, preferably less than ± 3 nm, most preferably less than ± 1 nm. Accordingly, the narrow bandpass filter preferably has a passband bandwidth in the range of 1-3 nm The radiation source may be adapted to generate laser light in the spectrum of 700-1500 nm, preferably 800-1000 nm. In a specific embodiment, the optics further comprise a minilens array arranged between the narrow bandpass filter and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

[0037] According to an embodiment of the present invention, the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

[0038] Known vehicle-mounted object detection systems are not always accurate, especially at longer ranges. The inventors have discovered that this is in part due to the highly variable lighting conditions in which such systems may be used. Indeed, it turns out that the background light intensity may vary over many orders of magnitude between different pixels of the same sensor at the same time, for instance because of the occurrence of bright sunlight and deep shadows in the same scenery, or a because a generally dark scenery (at night) is only partially lit by the vehicle's headlights. In such cases, it is common to attempt to avoid pixel saturation in the brighter areas by reducing the overall intensity of the light arriving at the detector. However, that approach may lead to blind spots in areas where the projected spots are already particularly weak (long range). It is therefore an advantage of the present invention, that improved operation of the vehicle-mounted object detection system is obtained at long ranges in situations with highly variable lighting. The inventors have found that this advantage can be obtained with a sensor having a dynamic range of at least 90 dB, a range that may be spanned by a digital representation of 16 bits (this dynamic range covers the intensity ratio between a spot at a distance of 1 m and a similar spot at a distance of 150 m, leaving margin for environmental variations and object variations such as varying surface reflectivity). The advantage is even more pronounced with a sensor having a dynamic range of at least 120 dB.

[0039] According to an embodiment of the present invention, the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

[0040] Known vehicle-mounted object detection systems have to be able to detect the reflections of the projected pattern, i.e. the projected spots, over a potentially intense "background radiation" consisting of sunlight in the order of 500 W/m^2. An approach to overcome this problem, is to emit the radiation pattern at a very high intensity, i.e. an intensity which exceeds the intensity of the sun light in the relevant spectral band. This becomes a challenge, especially at long ranges. The inventors have found that the power requirement of the projection system can be reduced by performing a differential measurement at the sensor. As the projected pattern is emitted in a pulsed manner, and the timing of each pulse is known, it is possible to compare the detected level of incident light during the on-phase of the pulse with the detected level of incident light during the off-phase of the pulse, whereby the magnitude of the difference is indicative of the presence of a projected spot. The inventors have found that it is possible to perform this subtraction at the level of individual pixels. It is an advantage of this embodiment that accurate detection of radiation spots becomes possible at longer ranges and/or with reduced output power.

[0041] In a specific embodiment, the comparing is performed at individual pixels of said at least one detector. It is advantage of this specific embodiment, that the subtraction can be performed on the basis of signals that have a very low noise content. In such an embodiment, the pixels adapted to perform the comparing may be pixels with an increased dynamic range (i.e., at least 90 dB, or preferably at least 120 dB) as described above.

[0042] The predetermined reference spot positions may for example be determined in a calibration phase. The pulsed nature of the pattern implies that the radiated spots are intermittently switched on and off. The duration of the "on" phase may be much shorter than the pulsation frequency. For example, the pattern may be switched on every 16.6 ms (60 Hz frequency), but the duration of illumination within each period may be an order of magnitude shorter. The radiation source may be composed of a plurality of devices. The determining of the displacement may be performed with sub-pixel accuracy by multipixel fitting the detected spots.

[0043] The radiation source may be adapted to project light at an intensity of 10 W/m^2, optionally at least 100 W/m^2, optionally even at least 500 W/m^2, and is operated at a pulse width and a pulse frequency which are determined so as to keep the average emitted power per spot below 1 mW. The relevant light intensity is the intensity at the intersection of the object and the emitted light. It is an advantage of this embodiment that the brightness of the projected spots exceeds the expected brightness of sunlight. The stated intensity criterion is preferably met up to a range of 30 m when projecting obliquely downwards (for road inspection) and preferably up to 200 m when project forward (for obstacle detection).

[0044] The radiation source may comprise a VCSEL array with a low beam divergence, the VCSEL array being configured to simultaneously transmit individual spots of the radiation pattern.

[0045] In particular, the system may further comprise micro array optics configured to focus and/or orient each laser spot of the VCSEL array. Alternatively, the system may further include a macroscopic optical system to project the light emitted by the VCSEL array into the desired spot pattern.

[0046] The at least one radiation source may comprise at least one laser radiation source for generating laser spots constituting the pulsed radiation pattern.

[0047] The processor may be adapted for processing the detected data based on triangulation. The at least one radiation source may comprise a phase grating for simultaneously generating the combination of radiation spots. It is an advantage of embodiments of the present invention that efficient phase gratings can be obtained, the gratings comprising a system of grooves with a specific depth in a specific transparent material. In an advantageous embodiment, a set of horizontal and vertical grooves can be applied. The design furthermore is flexible so that it can be optimized with respect to the target specifications. The phase grating may be a discrete phase grating such as but not limited to a dammann grating.

[0048] The at least one radiation source may be constructed to generate the radiation pattern as a combination of radiation spots and whereby groups of the radiation spots are generated sequentially in time, each group comprising simultaneously pulsed spots.

[0049] The at least one radiation source may comprise a MEMS-scanner. The detector may comprise a MEMS-scanner and the system may comprise a synchronization device for synchronizing the MEMS-scanner of the radiation source with a MEMS-scanner of the detector.

[0050] The system may comprise a shutter whereby the shutter, when closed, blocks radiation from arriving at the detector and whereby the synchronization means is adapted for synchronising the pulses of the at least one radiation source with the opening and closing of the shutter.

[0051] The obtained data can be used as an input for a more refined model based fitting of a characteristic, e.g. a profile or property, of the road or object, such as spline fitting and even to more sophisticated models for the motion of the object.

[0052] The at least one radiation source may be conceived for generating monochromatic radiation in the near infrared spectrum.

[0053] The at least one radiation source may comprise a semiconductor laser.

[0054] The at least one radiation source may comprise a single VCSEL source or a VCSEL array. The at least one detector may be a plurality of detectors, e.g. two detectors or more detectors. In addition to the triangulation principle based on a single detector, embodiments of the present invention also may make use of a parallax between different detectors. Furthermore embodiments of the present invention optionally also may be combined with stereovision.

[0055] The at least one radiation source and the shutter may be adapted for pulsing with pulse widths in the microsecond range.

[0056] The system may comprise an interface for outputting obtained information.

[0057] The system may further comprise means for modifying an intensity of respective ones of said radiation spots in function of their distance from said system so as to equalize their perceived intensity, the means operating in conjunction with said radiation source or with said at least one detector. It is an advantage of such embodiments that clipping (detector saturation) of the detected spots can be avoided (for the spots that would otherwise have the highest intensity), such that the accurate spatial detection of the spot is not impaired (in particular, the image size analysis using multipixel fitting). In particular, the means for modifying the intensity may comprise an aperture placed in the optical path of said at least one detector, the aperture having an asymmetric shape relative to any horizontal plane. Hence, the aperture is a non-symmetrical lens pupil that modulates the intensity of the received light in function of its angle of incidence, such that reflections from a nearby road area are more strongly attenuated relative to reflections from far away areas. Additionally or alternatively, the projector may project blocks of spots or individual spots with mutually different intensities, or different duration, so as to reduce the intensity or duration of nearby spots relative to far-away spots. Additionally or alternatively, the processor may perform software-based post-processing to remove the effects of clipping (saturation) from the detected spot profiles.

[0058] The system may further be adapted to perform the detecting in a range between 1 m and 30 m. This is the range that is preferably covered for the purpose of inspecting the road profile.

[0059] The system may further be adapted to perform the detecting in a range between 0 m and 200 m. This is the range that is preferably covered for the purpose of detecting obstacles and/or when the system is applied in autonomous vehicles.

[0060] The present invention also relates to a vehicle with controllable suspension, the vehicle comprising a system as described above, a suspension system, and a control system, whereby the control system is adapted for receiving profile information of the system for determining a characteristic of an object and is adapted for using the characteristic, e.g. a profile or property, of the object for controlling the suspension system.

[0061] The present invention also relates to a camera, the camera comprising a system as described above whereby the system is adapted to add 3D information to the camera image making it possible to create a 3D image.

[0062] According to an aspect of the present invention, there is provided a method for detecting a characteristic of an object, the method comprising the following steps: emitting a pulsed radiation pattern composed of radiation spots on the object using a radiation source, detecting the reflected pattern using at least one detector having a plurality of pixels, whereby the detection is synchronized with the pulsed radiation pattern for detecting radiation to be processed only during the radiation pulses, and processing the data from the detector for determining a characteristic of an object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions, wherein said emitting uses monochromatic light and said at least one detector is equipped with a corresponding narrow bandpass filter arranged on a dome, wherein fish-eye optics arranged between said narrow bandpass filter and said at least one detector guide light that has passed through said narrow bandpass filter towards a light-sensitive area of said at least one detector.

[0063] Further optional features of embodiments of the system according to the present invention may be applied *mutatis mutandis* to embodiments of the method according to the present invention to obtain the corresponding effects and advantages.

[0064] The present invention also relates to the use of a system as described above for detecting a characteristic of an object in a vicinity of a vehicle, the use taking place in an outdoor environment. In particular, the use may be for measuring a characteristic, e.g. a profile or property, of the road in front of a car, or for controlling autonomous vehicles.

[0065] The present invention also relates to a computer program product comprising code means adapted to cause a processor to perform the determining of said characteristic of the method described above.

[0066] Particular and preferred aspects of the invention are set out in the accompanying independent and dependent claims. Features from the dependent claims may be combined with features of the independent claims and with features of other dependent claims as appropriate and not merely as explicitly set out in the claims.

[0067] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

Brief description of the drawings

[0068]

FIG. 1 gives a schematic overview of different components and their interactions in an exemplary sys-

tem according to embodiments of the present invention.

FIG. 2 illustrates a schematic representation of an exemplary method for obtaining a characteristic, according to an embodiment of the present invention.

FIG. 3 illustrates a schematic representation of a triangulation principle as can be used in an embodiment of the present invention.

FIG. 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom).

FIG. 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel.

FIG. 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention.

FIG. 7 schematically illustrates further aspects of the operation of a high-dynamic range pixel for use in embodiments of the present invention.

FIG. 8 schematically illustrates an embodiment of a sensor for use in embodiments of the present invention, the sensor including a pixel area having pixels that provide a differential output (target light- background light) in hardware.

FIG. 9 schematically illustrates the structure of a pixel that provides a differential output (target light-background light).

FIG. 10 schematically illustrates a first exemplary optical arrangement.

FIG. 11 schematically illustrates a second exemplary optical arrangement.

FIG. 12 schematically illustrates a third exemplary.

FIG. 13 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention.

[0069] The drawings are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. Any reference signs in the claims shall not be construed as limiting the scope.

Detailed description of illustrative embodiments

[0070] The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not correspond to actual reductions to practice of the invention.

[0071] Furthermore, the terms first, second and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

[0072] Moreover, the terms top, under and the like in the description and the claims are used for descriptive purposes and not necessarily for describing relative positions. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other orientations than described or illustrated herein.

[0073] It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

[0074] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0075] Similarly it should be appreciated that in the description of exemplary embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within

the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0076] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

[0077] Where in embodiments of the current invention reference is made to an object, reference is made to any objects that are stationary or moving relative to the vehicle, which may include the road; road signage; humans using the road as pedestrians, cyclists, etc.; animals; other vehicles; substances on the surface of the road, such as water, sand, mud, leaves, snow, ice, dirt, debris and the like; in agricultural applications, crops, cut grass or hay (baled or loose) on the ground.

[0078] Where in embodiments of the current invention reference is made to a vehicle, reference is made to cars, trucks, trains, fork lifts, etc., regardless of whether they are propelled by an internal combustion engine, an electrical motor, or the like, and regardless of the interface with the ground.

[0079] Where in embodiments of the current invention reference is made to the near infrared region reference is made to radiation with wavelength between 700 and 1500 nm, in particular between 800 and 1000 nm.

[0080] Where in embodiments according to the present invention reference is made to a radiation pattern, the radiation pattern is physically or logically composed of radiation spots characterized by their spot size and intensity. According to the invention, the radiation pattern comprises simultaneously radiated spots or groups of spots, which are turned on and off in a pulsed manner.

[0081] Where in embodiments according to the present invention reference is made to triangulation, reference is made to the use of observation of an object under an angle and determining the distance to the spot based on a shift between a reference position and an observed position of a corresponding spot in the image viewed by the camera. Where in embodiments of the present invention reference is made to a MEMS scanner reference is made to a MEMS scanning micro-mirror whereby the mirror can oscillate in at least one dimension.

[0082] The present invention relates to a system for detecting a characteristic, e.g. a profile or property, of an object. A schematic overview of different components which are comprised in the system according to embodiments of the present invention are illustrated in FIG. 1. FIG. 1 shows a radiation source **101** for generating a pulsed radiation pattern. The radiation pattern advantageously is spot pattern. The system may be mounted at any suitable position. If e.g. the system is mounted to a vehicle, this can be at the top thereof, the side thereof or may be integrated in existing cavities and openings, such as for example in cavities for the head lights or back lights or in the head or back lights themselves, at or near the number plate, etc.

[0083] The radiation pattern is reflected by the object under study and captured by a detector **102** also shown in FIG. 1. The radiation source **101** and the detector **102** are synchronized by a synchronization means **104.** In embodiments according to the present invention also a shutter **105** might be present whereby the shutter **105** is also synchronized by the synchronization means **104** such that it blocks radiation from the detector **102** as long as no radiation pattern is being transmitted. Alternatively, the detector may be oversampled and only the samples corresponding with time slots wherein pulses are given are considered. Systems according to embodiments of the present invention may comprise one or more radiation sources. The processor **103** in FIG. 1 processes the data coming from the detector **102** thereby revealing profile information of the object under study. The processing advantageously can be based on triangulation. The processor may be adapted for determining a characteristic of an object by determining a displacement of detected spots, the spots being detected with the at least one detector with reference to predetermined reference spot positions. The triangulation principle used in embodiments of the present invention is illustrated by way of example in FIG. 3. The triangulation method used can be based on a single detector, although the invention should not be considered limited to systems comprising only a single detector. In addition to spot shift calculations (triangulation), the system may also analyze the intensity, size, and shape of the reflected spots, to detect further characteristics of the surface from which the spots are reflected.

[0084] By way of illustration, embodiments of the present invention not being limited thereto, the different elements of an exemplary system according to an embodiment of the present invention will further be discussed.

[0085] In embodiments of the current invention the at least one radiation source **101** is designed to generate radiation, e.g. monochromatic radiation or radiation from a particular wavelength range, in the near infrared region. The near infrared region has the advantage that it is invisible to humans and that CMOS or CCD sensors are still sufficiently sensitive for radiation with a wavelength in this region. In this way, the user is not disturbed by the radiation. The at least one radiation source **101** typically is adapted for extending over the complete object to be monitored. Optical elements therefore may be provided or may be part of the at least one radiation source. In embodiments according to the present invention this object is a viewing scene in front of a car.

[0086] The object to be monitored is irradiated using a radiation pattern. In some embodiments according to the present invention this pattern is a regular or irregular ar-

ray of spots, e.g. sharp spots. The size of the spots may be of the order of 1/1000 of the range. Thus 1 cm at a distance of 10 meter.

[0087] According to embodiments of the present invention, the radiation pattern may be an m x n pattern, wherein m is at least 1 and n is at least 1. The spots may be of any geometrical form such as for example an oval, a line, a circle, a disc. The radiation pattern may be regular, i.e. a full matrix, or may be irregular. The radiation pattern may be repetitive, random, etc. The arrangement of the spots in the radiation pattern may be selected as function of the application.

[0088] The irradiation is performed during short periods of time, i.e. in a pulsed manner. This has the advantage that a lot of irradiation power can be generated - in pulsed irradiation the momentaneous intensity can be significantly higher than in continuous wave - but that meanwhile the average radiation power can be kept low. In the particular example wherein a spot-like pattern is used for irradiating, the intensity is local on particular positions on the object, which also reduces the total amount of power required by the radiation source **101** to surpass the intensity of the daylight. Advantageously, the spot size may be selected in relationship to the pixel size of the detector **102.**

[0089] In embodiments according to the present invention irradiation pattern may be induced using laser beams. It is an advantage of embodiments of the present invention that laser beams can yield a very large depth of focus with simple optics.

[0090] The irradiation pattern can be irradiated simultaneously. Alternatively, different parts of the irradiation pattern can be irradiated sequentially, such that over time the irradiation pattern is built up, but the irradiation pattern is not provided in a single illumination pulse. According to some embodiments of the present invention, where a plurality of m x n beams is used, the system may be equipped with an optical element, such as for example a prism based microlens, for grouping the beams into an a x b pattern thus increasing the spot intensity at the point of incidence by a factor of a * b compared to a single beam. Individual parts of the irradiation pattern may be, in one embodiment, may be obtained by positioning a MEMS scanner after the radiation source **101** for deflecting the laser beam in the wanted direction and thus irradiating the object in a scanning manner.

[0091] In some embodiments according to the present invention, the irradiation source comprises one or more semiconductor lasers. These semiconductor lasers have a very good cost/performance relationship.

[0092] In some embodiments according to the present invention where individual spots of a radiation pattern are transmitted simultaneously different alternatives exist to realize the radiation pattern. A single laser may be used in combination with a diffractive grating for inducing an array of spots. The laser must have sufficient power.

[0093] In some embodiments, micro array optics can be used for focusing each laser spot of the laser, e.g. VCSEL.

[0094] The peak power of the laser must be sufficient (order of 0.1 to 2 kilowatt) so that the intensity in every spot of the projected pattern surpasses the daylight in the relevant spectral band. For a projected array of 100x100 spots and a range of 10 m the total peak power of the complete laser must be of the order of 250 Watt. But the average

[0095] (continuous) power of the individual spots may not surpass the safety requirements of 1 mW. Thus for a pattern of 100x100 spots the total average power of the single laser may not exceed 10 Watt. This high peak power versus low average power can be realised by using short pulse times.

[0096] Another requirement for practical use is that the electric power of the laser does not exceed 50 Watts. But with an average optical power of 10 watts this requirement can easily be met for semiconductors lasers which have a large efficiency.

[0097] The power budget can be improved by emitting spots with a very narrow spectral width and detecting them with a sensor that is equipped with a filter that has a corresponding very narrow pass band. Additionally or alternatively, the power budget can be improved by performing differential detection, i.e. by detecting the presence of the spot in the portion of the image detected by a given pixel by comparing the measured intensity at a point in time when the spots are not being projected with the measured intensity at point in time when the spots are being projected. This comparison may be performed in appropriately adapted hardware or in software.

[0098] In case we use a VCSEL laser array instead of a single laser the power requirements of the single laser have to be met by the array as a whole.

[0099] The laser may be a surface edge emitting laser. The irradiation source also may comprise a diffraction grating for generating a grid or other irradiation pattern. Different types of diffractive gratings could be used. For efficiency a phase grating in a transparent material can be used. Ease of manufacturing (simple and cheap) is enhanced if the phase grating has linear grooves in two orthogonal directions. The depth of the grooves typically may corresponds with a phase shift of 180°. The width of the grooves can be calculated such that the intensity envelope matches the required field of view. The FOV of source and detector is both of the order of 1 radian horizontally and 1 radian vertically

[0100] In other embodiments according to the present invention, where individual spots of the radiation pattern are transmitted simultaneously, a VCSEL array is used as radiation source **101.** Such a VCSEL array may be an array with a low beam divergence. The size of the VCSEL may be 10x10, but may be larger. It is an advantage of embodiments using VSCEL arrays that the geometry of the array and the shape of the spots can be tuned depending on the application. The principle may be combined with scanning irradiation as will be discussed later, such that subsequently an array of spots is transmitted.

[0101] In some embodiments, at least two radiation sources, also referred to as projectors, may be included, one projector being fixed and another projector being steerable over at least one axis and preferably steerable over two axis for operating in a smaller field of view angle than the fixed projector. The steerable projector may thus be suitable for zooming. Such a function may be used for detecting with more detail certain objects such as for examples holes, birds, children, etc. Additionally or alternatively, the detector **102**, described hereunder, may be steerable or include steerable components. The steering of the detector components may occur at the sensor level, or at the level of individual optical components, or even at the level of pixel-specific components (such as microlenses forming an array, which may be steered by means of MEMS).

[0102] The detector **102** may be a CMOS or CCD detector. After the object under study is irradiated by the at least one radiation source **101**, the reflected radiation is detected by the detector **102**. In order to avoid interference from daylight different precautions can be taken. In embodiments according to the present invention a small band spectral filter can be positioned in front of the detector **102**. The small band filter only passes through radiation in the specific wavelength range emitted and blocks the rest of the daylight spectrum.

[0103] In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient resolution in the darkest part of the scene, is an advantage of the present invention. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However this nonlinear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

[0104] Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both *Vgate1* and *Vgate2* gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage *Vgate2* is set low. The electrons reflow towards capacitor **7**, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on *Vgate1*. The electrons reflow towards the floating diffusion **2**. Figure 7 schematically illustrates how to achieve multiple gains using the same technique.

[0105] In embodiments according to the present invention, a synchronization means may be provided that synchronizes the detection with the pulses, resulting in the fact that unwanted irradiation on the detector outside the pulse time of the radiation source can be avoided. This can be implemented in a plurality of ways, e.g. by oversampling by the detector and only taking into account samples wherein a reply on the pulse is expected. Alternatively, a shutter **105** can be used in front of the detector **102**. The synchronization means **104** then opens the shutter **105** during the time window the reflected radiation arrives at the detector **102**. Therefore the synchronization means **104** gets its synchronization input signal from the radiation source **101**. The time window is dependent on the pulse width and on the object range.

[0106] In some embodiments, the above said detector may be able to subtract the background light from the scene and sense only the required signal, i.e. the laser beam information. An example of such a detector is schematically presented in Figure 8, with further details on the pixel structure being shown in Figure 9. With reference to Figure 9, the pixel comprises a photodiode that can be read with 2 transfer gates controlled by *transfer* and *transferb* signals. The transfer signals are synchronized with the laser pulse emission as follows:

- When *transferb* is on, the electrons generated in the photodiode by the scene AND the laser pulse are transferred to a particular storage node, CCD1.
- When *transfer* is on, the electrons generated in the photodiode by the scene WITHOUT the laser pulse are transferred to a particular storage node, CCD2.

[0107] In a particular embodiment, the storage element can be manufactured using a CCD gate, in an adequate CCD/CMOS process. This implementation is advantageous because the consecutive accumulation of charges due to multiple transfers remains in the charge domain, without detrimental noise accumulation.

[0108] Once the frame information has been acquired, after one or several transfer activations, the pixel data can be read using *read1* and *read2*. The conversion of charge to voltage happens at this moment, on the floating diffusion. Both data are then read via two different chan-

nels using the *Select1* and *Select2* switches. Outside the pixel array, both voltages are subtracted to retrieve only the desired laser pulse data.

[0109] This embodiment is advantageous because it allows CDS operation on both floating diffusions, reducing the readout noise. The removal of the scene illumination from the actual data further allows maximizing voltage dynamic usage by applying analog gain after background subtraction.

[0110] In embodiments according to the present invention, the detector **102** optics may be focused to the largest range so as to resolve the spots at that distance and to match it with the pixel size. However because the depth of focus is much smaller than the range, the images of the spots will be broadened at shorter distances. On the other hand the intensity of the spots increases with decreasing distance so that the accuracy in the determination of the position increases. Calculations show that this easily compensates the increased spot size. In embodiments according to the present invention the distance between the spots is chosen such that overlap of spots at the detector **(102)** side is avoided. In an exemplary embodiment the distance between the spots is equal to ten times the diameter of the spots.

[0111] In embodiments according to the present invention the detector **102** may have a number of pixels NxN and the detector **102** optics are selected to match this large number of pixels with the angular resolution (1/N = 1 millirad). Moreover the radiation source **101** and accompanying projection optics can be selected to have the same angular resolution (so that the spot size matches the pixel size).

[0112] In embodiments of the present invention, large ranges can be bridged. For example radiation spots can surpass the daylight intensity over a large range by a sufficient factor for accurate measurements hereby keeping the individual laser beams below the safety guidelines of 1 mW continuous. Such a range may e.g. be between 1m and 15m, or even between 1m and 30 m.

[0113] In embodiments according to the present invention, the system also comprises a processor **103** for processing the data received by the detector **102.** The detected radiation pattern may for example be analyzed trough triangulation. For example if a spot pattern is used, the spot pattern is observed under a different angle with a detector, e.g. high resolution CMOS or CCD megapixel camera. The distance travelled by a light ray, being part of the radiation pattern, to a particular spot can then be determined by triangulation from the shift between the theoretical and observed position of the corresponding spot in the image viewed by the camera.

[0114] The position of a spot can be determined by image processing in which one calculates the weighted center of intensity of the pixels (cfr. center of mass). The calculation of a center of intensity is very simple and can be done in real time with simple and cheap hardware. If the angular resolution of the radiation source **101** and the detector **102** are worse than 1/N then the observed spot size in the image is larger than one pixel. But since the spot profile is known, one can in principle obtain sub pixel accuracy by multipixel fitting of the whole spot. In an embodiment according to the present invention the theoretical resolution can be calculated using the following formulas. In the embodiment a pattern of light spots is generated by a radiation source **101** and the monitored object is the road in front of a car whereby:

- *D* is the distance between the radiation source **101** and the detector **102**
- *Z* is the range over which the road is monitored
- *N* the number of pixels of the detector **102** in both directions
- The angular resolution of the projection and of the detection are 1/*N*
- The opening angle of the detector an optional lenses is 1 steradian
- H is the height of the projector above the road

[0115] The obtainable resolution can be subdivided in:

- *d:* the distance resolution
- v: the vertical resolution

[0116] The theoretical distance resolution can be calculated as:

$$d = \frac{Z^2}{D.N}$$

[0117] The theoretical vertical resolution in the profile of the road can be calculated as:

$$v = \frac{Z.H}{D.N}$$

[0118] Thus for a 4 Megapixel detector 101 (N=2000) *D* = 2 m *H* = 1 m and Z = 20 m a distance resolution of 10 cm (0.5 %) and a vertical resolution of 5 mm can be obtained.

[0119] At a distance of 1 m the distance resolution is 0.5 mm and the vertical resolution is also 0.5 mm.

[0120] As can be seen in the formulas, both the distance resolution and the vertical resolution are inversely proportional to the distance D between the radiation source **101** and the detector **102.** Since this distance can be made much larger than the distance between the lenses in a 3D camera, the depth resolution is then also proportionally better for the same illumination.

[0121] In one example, a spot profile design is used wherein an interspot distance of 10 spot diameters is present. This then corresponds with a grid of N/10 x N/10 spots. For a 1 Megapixel camera the grid then consists

of 100x100 points. With a frame rate of 100 Hz we then efficiently sample the road in front of the tires with a vertical resolution of about 1 mm at a lateral sampling distance of 1 cm. The sampling distance in the moving direction depends on the speed of the vehicle.

[0122] At the maximal speed of 50m/sec the sampling distance in the moving direction is of the order of 5 mm. This is quite sufficient for most applications that one can envisage which makes the concept very generic.

[0123] The maximal continuous power of 100x100 spots (at the safety level of Imilliwatt) is then 10 watt which is within all realistic requirements.

[0124] In embodiments of the current invention processing the data from the detector **102** can be done on binarized images. It is an advantage of embodiments of the current invention that the required processing power of the processor **103** for processing the data is limited.

[0125] For projecting a grid of 100x100 points at a repetition rate of 100 Hz a peak power of the order of 100 Watt and an average power of 10 Watt is required, as also discussed above. A first estimation shows that even with an isotropic reflection coefficient of 1/1000 the total number of detected photons per pixel is above the detection sensitivity of the camera. For triangulation, the radiation source **101**, the detector **102**, and the object under study form a triangle. The line between the detector and the radiation source **101** is known. The radiation angle is known, allowing to determine distances.

[0126] In some embodiments according to the present invention, instead of simultaneously projecting the individual spots of the radiation pattern, the individual spots or groups of spots of the radiation pattern are transmitted sequentially by the radiation source **101**. This can be realized by projecting a pulsed laser beam on a scanner, e.g. a micro-machined scanner, the micro-machined scanner having two degrees of freedom. In embodiments according to the present invention a complete image of 1000x1000 spots can be projected with a repetition rate of 30 Hz or more.

[0127] In one embodiment, at the receiving side, a CMOS or CCD detector **102** captures the pulsed radiation source **101** after it was reflected by the object under study. At the receive side, similar embodiments can be realized as is the case for simultaneous projection of the radiation pattern. The radiation source **101** and the detector **102** are synchronized such that each transmit angle can be associated with a detection spot on the detector 102.

[0128] In an embodiment, the receive side also comprises a micro-machined scanner with 2 degrees of freedom. The scanner can track the reflected radiation, by synchronously moving with the micro-machined scanner at the transmit side.

[0129] The radiation captured by the micro-machined scanner is projected on to a photodetector (an analog linear photosensitive detector). In this way, an optical scanner with a high dynamic range can be realized. A radiation pattern comprising 1000x1000 spots can be transmitted and detected with a repetition rate of 30 Hz or more (for example, with a repetition rate of 60 Hz) using such an embodiment.

[0130] In embodiments according to the present invention a characteristic, e.g. a profile or property, of the monitored object is determined or reconstructed through triangulation on the received radiation pattern knowing the transmitted radiation pattern. The radiation pattern can be transmitted sequentially or simultaneously. In order to surpass daylight interference the power of the transmitted radiation pattern is increased keeping the average power constant by decreasing the transmitting pulse width.

[0131] The following non-limiting example concerns the application of a system 100, according to an embodiment of the present invention, on a vehicle for monitoring a characteristic, e.g. a profile or property, of the road in front of the vehicle.

[0132] To have a large range of visibility the radiation power should be sufficiently high.

[0133] For a laser beam with divergence d the area S of the laser beam at a distance Z and measured perpendicular to the beam is of the order of $S = (Z*d)^2$. If the projector is positioned at a height H from the road the area Sp of the projected laser spot is $Sp=(Z/H)*(Z*d)^2$.

[0134] For the values Z = 30 m, d = 1 mrad, H = 1 m, this yields Sp = 270 cm^2.

[0135] A typical value for the power of daylight is 500 W/m^2 (the actual value depends on the geographical location and atmospheric conditions).

[0136] Thus if one wants the projected spot intensity to be of the same order as the daylight, one needs a power of 500 W/m^2. And for an area of 270 cm^2 one thus needs an optical power of 13.5 W. If we use monochromatic light and a spectral filter, one can gain a factor of 150. Thus one needs an optical power of 0.09 W per spot (hereinafter rounded to 0.1 W per spot). For safety reasons, the average power of the laser cannot exceed 1 mW. Thus the duty cycle of the laser can not exceed 0.001/0.1= 1/100. This can be realized by pulsing the laser in synchronization with the CMOS detector. If we use a CMOS detector at 60 Hz, the frame time is 16 ms. And then the pulse time is 16 ms/100 = 160 μs.

[0137] The following non-limiting example concerns the application of a system 100, according to an embodiment of the present invention, on a vehicle for use as an autonomous sensor. The objects to be sensed are assumed for this example to have a typical reflectivity of 10%; accordingly 10% of the incident intensity is reflected back isotropically over the relevant half of the space (over 2π sr). Absorption by air is neglected. Thus, the total reflected energy for an exemplary spot at a power of 20 mW (resulting for example from a total electric peak power of 120 W divided over 3000 VCSEL lasers with 50% efficiency), integrated over a pulse duration of 100 μs and reflected at 10%, is 2×10^{-7} J. Due to physical limitations, the maximum effective opening angle of the lens is of the same order as the area of the CMOS sensor

chip **102**, which is assumed to be about 25 mm^2 for the purposes of the present example. Thus, the solid angle as seen from the reflecting point is about 2.5×10^{-9} sr, and the fraction of the reflected pulse that is captured by the camera is then 2.5×10^{-9} sr / 2n sr = 4.0×10^{-10}, which leads to a captured energy of 8.0×10^{-17} J, which represents approximately 160 photons (assuming infrared light at 850 nm, with 2.3 eV per photon). In a 1 megapixel camera with a viewing angle of 1 rad × 1 rad, with a conservative hypothetical beam divergence of 3 mrad, a spot would cover about 10 pixels, such that each pixel receives at most about 16 photons, without considering the further reduction due to the fill factor. This example illustrates that it is of particular importance in such cases to use a sensor with a very low noise level, preferably down to 10 electrons per pixel. The detector **102** only captures incoming radiation when radiation pulses are arriving. Therefore the detector is synchronized with the radiation source 101 through the synchronization means **104**.

[0138] In case of a camera of 1 Megapixel the number of measurements per second is also of the order of 1 million. When the vehicle moves at a speed of 50 m/s and the road has a width of 20 m the road will be sampled with a resolution of 3x3 cm.

[0139] For time of flight based systems, monitoring the same range of 30 m, a radiation beam requires 0.2 μs to travel the whole distance back and forth. During this time the detector **102** is open monitoring the complete field of view. This means that with a fixed average power of 10 Watt illumination over only 1/100 of a second is possible. It also means that with a required detector opening time of 0.2 μs only 10000 measurements per second can be achieved. Therefore embodiments according to the present invention can monitor at measurement rates which are a factor 20 better than time of flight based systems.

[0140] In some embodiments, the system may be adapted for eliminating or minimizing reflection of sun light and/or for reducing direct reflection of sunlight in reflective surfaces such as water. One or more of the at least one radiation source, the detector and/or the processor may be adapted therefore. In one embodiment, the at least one radiation source may be adapted for generating radiation with one or more predetermined polarization states and the at least one detector may be adapted for receiving only radiation of that one or more predetermined polarization states. The latter may be obtained by providing a polarization filter before the at least one detector for selecting the one or more predetermined polarization states. In another embodiment, the at least one radiation source may be adapted for generating radiation of one or more predetermined wavelengths, which may be in or out of the water spectrum, and the detector may be adapted, e.g. using wavelength filters, to limit the detection substantially to the one or more predetermined wavelengths. Alternatively, these wavelengths may be selected at the level of the processor from images recorded with a larger wavelength spectrum. Another alternative is that the at least one radiation source is not specifically adapted but that the at least one detector filters one or more predetermined wavelengths from the image, which may be in or out of the water spectrum. The filtering also may be performed at the level of the processor from images recorded with a larger wavelength spectrum. In yet another embodiment, the processor used may be adapted for eliminating the daylight or sunlight from a picture by image processing, e.g. by correcting image frame(s) with a fitted reference contribution for daylight/sunlight, thus eliminating the daylight/sunlight.

[0141] In some embodiments, the at least one radiation source may be adapted for radiation with at least two different wavelengths thus creating a multispectral radiation source. The latter may be advantageous for detecting certain objects, such as for example detecting organic material, detecting ice, water, snow, etc. Similar as for blocking sunlight, the detector typically also may be adapted with a filter for filtering the corresponding wavelengths emitted by the radiation source to work selectively. In some embodiments, a corresponding filter may be provided for each wavelength. The predetermined wavelengths may be detected each separately or in a single detection. In one embodiment, the processor also or alternatively may be adapted for filtering these wavelengths from an image recorded in a broader wavelength range. The information recorded at specific wavelengths thus may be used for selective detecting certain objects which are more sensitive to these specific wavelengths.

[0142] In some embodiments, the processor may be adapted for calculating a relation between consecutive frames. The frames thereby do not need to be directly subsequent frames, in other words, some frames may be skipped. Calculating the relation may be based on correlation, least square fitting, etc. but is not limited thereto. Such a relation may serve to determining a property of the moving object, e.g. vehicle, for example for determining a dynamic property. The relation may for example be used for determining a speed, a pitch, a roll, a yaw, etc. of a moving object. Such a relation also may be used for determining a height measurement of complete surfaces of the object or parts of the object. The object thereby may be in relative movement or may be stationary.

[0143] In some embodiments, the processor may alternatively or in addition to other tasks be configured for interpreting image or pixel information for different applications. Such different applications may be - but are not limited to - pavement detection, road detection, road inspection, inspection of the state of the pavement, detection of obstacles such as for example living or non-living creatures, moving or stationary obstacles, etc. Also detection of objects in relationship to their environment may be envisaged.

[0144] In some embodiments, the present invention also relates to a system comprising a plurality of systems

as described above. The latter may allow to cover a larger field of view. The plurality of systems thereby comprises as much systems as required to cover the field of view one is interested in. The plurality of systems thereby may be mounted such that they cover the field of view of interest. This may be a system that covers 360° horizontally and 180° vertically to obtain surround viewing. Alternatively, any other field of view size may be obtained by appropriately selecting the number of systems and their position. Advantageously, the field of view realized by multiplicating the system at different physical locations may be organized specifically for certain applications such as for example but not limited to autonomous cars, warehouse transport, inspection vehicles, etc. Alternatively or in addition thereto, one or more systems or components thereof may be adjustable to cover different fields of view. The latter may be obtained by making one or more systems moveable to different positions, e.g. to different positions around a car in vehicle applications, by tilting the system under different angles, e.g. change the mounting angle, by making a system steerable, by creating overlap between the system's field of view or a combination thereof.

[0145] In some embodiments, the system may be adapted for covering a field of view from near the vehicle to the radar range. Consequently, the system may be combined with radar sensing as to extend the range for certain applications, such as pedestrian detection, collision avoidance or other safety and autonomous vehicle related applications or so as to provide additional and/or complementary measurement data serving the application. More generally, the system can be combined with additional sensors such as radar(s), infrared camera sensor(s), etc. In particular, the system may be used to determine the presence and speed of other vehicles or objects, and that information may in turn be used to control direction and speed of the vehicle, e.g. to avoid collisions, or to maintain a safe and substantially fixed distance to the vehicle ahead (smart cruise control).

[0146] In some embodiments, the system may be adapted for performing egomotion related applications. The processor may be adapted to supply data usable for egomotion related applications. The projector, i.e. the radiation source, and/or the detector also may be arranged for creating/recording relevant data for egomotion related applications. In one particular example, egomotion related data may be based on a vehicle's motion based on its motion relative to lines on the road or relative to street signs as observed from the vehicle itself. Egomotion related information may for example be used in autonomous navigation applications.

[0147] In some embodiments, the system may be adapted for providing odometry information. The processor may be adapted for determining equivalent odometry information using sequential detector images for estimating distances travelled. The latter may for example be used for enhanced navigational accuracy in robots or vehicles using any type of locomotion on any type of surface.

[0148] In some embodiments, a spot pattern may be introduced, whereby some spots, some groups of spots or each spot is addressable and configurable in intensity, spot size,... This allows grouping of spots, introducing irregularities for example in order to render the image processing easier, changing the distance between the lines i.e. making the distance variable, ...

[0149] In some particular embodiments, the intensity of the VCSEL's may be controlled, such that the spots all have the same shape, the same intensity independent of the distance or the location in the projected spot pattern,. The latter enhances the data processing and allows to obtain a more accurate measurement e.g. to avoid clipping of pixel charge and allow multipixel fitting for all spots in the spot pattern. It also allows to fit a curve between profiles that have about the same geometry.

[0150] In some embodiments, the radiation source, e.g. VCSEL, may be split in several zones and the different zones may be driven differently to compensate for example for an intensity decrease for spots imaged further away from the source and/or detector. For example, different zones may be driven with a different power or ON time so as to partially or fully compensate for the different intensity loss for the different spots, depending on the position where they are imaged. The latter thus allows that the spots positioned further from the detector are driven at a higher power than the spots closer to the detector. The latter also allows to optimally make use of A/D conversion ranges, where required. In one example, control of one or more spot properties also may be performed for compensating for differently reflecting objects, which otherwise could result in substantially different geometries of the reflected spot. For example, white lines for guiding traffic on the road have a substantially different reflectivity than other parts of the roads. The system can be adapted for compensating geometry changes of the reflected spot caused thereby.

[0151] The above control may be referred to as intensity servoing.

[0152] In some embodiments, the wavelength of the radiation source used may be controlled (thermal servoing) such that it optimally fits filters, e.g. bandpass filters, used. The wavelength shift may for example be performed using a peltier or heating element. A good fit between the wavelength of the radiation source and the filters used may result in the possibility to reduce and/or minimize the influence of environmental disturbing radiation such as daylight.

[0153] Figures 10-12 illustrate exemplary cameras that may be used in systems, where the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The

term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter). In particular, in Figure 8, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

[0154] These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

[0155] The correction of the angle of incidence is of particular importance in systems where the entire space around the vehicle is to be monitored with a limited number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad.

[0156] Figure 10 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length *f*, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds to a cone angle of 9.3° (half cone angle). The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102**, would thus be 9.3°.

[0157] As illustrated in Figure 11, the preferred design consists of a tandem of two lenses **1130, 1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150**, a spectral filter **1160** and a CMOS detector **102**. Since the center O of the first lens **1130** is in the focus of the second lens **1140**, every ray that crosses O will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130**. Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140**. The light rays that are emitted from the spot S**1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140**. The central axis of this light cone crosses the point O and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens 1150. In this way all the imaging rays of the spot S**1110** are bent in a direction nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the diaphragma can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150**. In this way the sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

[0158] For the first and second lenses **1130, 1140**, commercially available lenses may be used, such as the lenses used in the iSight camera of the iPhone 6 smart phone from Apple Corp. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 μm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the diaphragma.

[0159] Figure 12 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous example, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250**. The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones). A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240, 1250, 1260, 1270, 102** has its own function to meet the requirements

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imposed by the present invention.

[0160] As the minimal angle of a cone generated by a lens of diameter d is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter d = 8.5 μm and λ = 850 nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

[0161] Figure 13 illustrates an optical arrangement according to the present invention, comprising a dome **1310** (e.g., a bent glass plate) with the narrow bandpass filter **1320** disposed on its inside (as illustrated) or outside (not illustrated). The advantage of disposing the filter **1320** on the inside of the dome **1310,** is that the dome **1310** protects the filter **1320** from outside forces. The dome **1310** and the filter **1320** optically cooperate to ensure that incident light passes through the filter **1320** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1330** are provided between the dome-filter assembly and the sensor **102,** which may be a CMOS or a CCD sensor. The fish-eye optics **1330** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor.

[0162] Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realised over a spatial angle of m x 1 rad in height and n x 1 rad in width.

[0163] In some embodiments of the present invention, the camera, the detector is slightly rotated relative to the projector or vice versa e.g. over an angle of 4°, allowing an improved image processing and facilitating the identification of the spots as the chance of overlap between the segments of the 2D projection on the image sensor of the 3D epipolar lines on which the spots are searched for is reduced.

[0164] In some embodiments of the present invention, the type of road can be determined from the spreading of the measured values and from the variation of the intensity, e.g. in a predetermined zone (advantageously the area where the tires will roll).

[0165] In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

[0166] In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop.

[0167] In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

[0168] In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageously directed downwards, i.e. towards the road.

[0169] In embodiments of the present invention, advantageously the distance between the detector and the projector is not too small, in order to allow for accurate image processing.

[0170] In a second aspect, the present invention relates to vehicles in which the detection system 100 is implemented for monitoring road conditions and as input for controlling the suspension system of the vehicle.

[0171] In embodiments according to the present invention, the system for detecting a characteristic, e.g. a profile or property, of an object is placed in front of a vehicle. The object under study is in that case the road in front of the vehicle. Ranges of 1m to 15 m, even 1m up to 30 m in front of the car can be monitored.

[0172] In advantageous embodiments, the detection system 100 interfaces with the suspension system through an interface or output means. The data may be communicated to a controller for controlling the active suspension system. The result is that the vehicle smoothly moves over the road, also referred to as "flying carpet".

[0173] Note that the image of the viewing scene is taken repeatedly with the frame rate of the camera. Thus the characteristic of the road is continuously updated and fed back to the active suspension system.

[0174] In one particular example, the controlling may include controlling of the suspension such that the roll vector lies in the same direction as the centrifugal force, so that passengers are pressed against their seats. In another example, the controlling may include active lifting of the chassis of the vehicle when a braking manoeuver so that a higher downforce on the vehicle and a higher friction force on the tires is obtained, resulting in a shorter braking distance. Yet another example of controlling is increasing the pitch of a vehicle maximally for collision damage control, resulting in an increased front side of the vehicle for restricting the risk of sliding under a truck. In other circumstances, the controlling may be such that fuel use is minimized by reducing the pitch of a vehicle and thus reducing the air resistance.

[0175] In some embodiments, compensation of the active suspension occurs based on the average height in a zone with a surface area as large as the surface of the contact area of the tire on the road. Such compensation may be performed about 50 to 100 ms before the event.

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The distance of the relevant zone to monitor is a function of the speed of the vehicle. The lateral position (left - right) of the relevant zone is a function of the steering angle. The transformation to be performed for the three degrees of freedom (X, Y and theta) can be identified based on an optimal correlation between two consecutive images. This transformation is then used for determining a new set of height measurements. The roll and/or pitch of the vehicle can be identified based on the 6 degrees of freedom transformation of the coordinate system of the vehicle with respect to a least squares plane fitted through the measurement points. In embodiments according to the present invention, the depth information of the road in front of the car detected by the detection system can be used as a 3D component that can be added to the image of a color camera to render this image into a 3D image.

[0176] It is an advantage of embodiments of the present invention that the system can also be used for warning the driver for bad conditions, such as for example rain or snow.

[0177] In embodiments according to the present invention, a processor can also be used for deriving the speed of the car from the data coming from the detection system.

[0178] In embodiments according to the present invention, the orientation of the car with regard to the road can be derived from the data coming from the detection system. The orientation can then be expressed as the car making an angle with the central line of the road, or in any other suitable way. A processor adapted for deriving such information may be embedded in the detection system or in another system, e.g. control system of the car. In embodiments according to the present invention the presence and speed of approaching objects can also be detected using the detection system. A processor adapted for deriving such information may be embedded in the detection system or in another system, e.g. control system of the car.

[0179] The output of the detection system mounted on a vehicle can thus be used, not only for the suspension system, but as an input for several active components in a car enabling the car to be autonomously controlled.

[0180] It is an advantage of embodiments of the present invention that they can be combined with other techniques for extending the possibilities. For example, in one embodiment, the system may be extended with a radar system in order to extend the range that can be monitored.

[0181] Generally, when the system according to the invention is mounted to a vehicle, it may be arranged in such a way that the system can move relative to the vehicle, to select a desired field of view. The projector can have angular rotation relative to the detector or vice versa, e.g. over an angle of 4°, allowing an improved image processing and facilitating the identification of the spots as the chance of overlap between the segments of the 2D projection on the image sensor of the 3D epipolar lines on which the spots are searched for is reduced. To obtain a high accuracy in the spot shift analysis more specifically with respect to the vertical resolution, the detector is preferably placed at some distance from the projector. With

D is the distance between projector and detector

Z is the range over which e.g. the road is monitored

ϑ is the angular resolution (corresponding to a pixel, so for a 1 Megapixel camera and an angle of 1 rad this corresponds to 1mrad or 1/1000 rad)

H is height of the projector above the object

the distance resolution corresponds to

$$d = \vartheta * Z^2 / D$$

and the vertical resolution

$$v = d * (H/Z)$$

[0182] Thus in the conditions Z = 30 m and ϑ = 1/1000 and D = 1 m and H = 1 m following results are calculated

D = 90 cm

V = 3 cm

In case Z = 10 m other parameters equal

d = 10 cm

z = 1 cm

[0183] In order to realize a vertical resolution of 3cm at 30m and 1cm at 10m with a 1 Megapixel camera the distance between projector and detector/camera must be 1m.

[0184] Depending on the extent of the field of view required for a particular application, multiple projectors and detectors may be used, whereby ultimately a full 360° viewing angle could be obtained. In view of the scarcity of space for technical components in modern vehicles, the system according to the invention is preferably integrated in the vehicle using existing cavities or newly created spaces for seamless integration.

[0185] In a third aspect, the present invention relates to a method for detecting a characteristic, e.g. a profile or property, of an object. Such a method can advantageously be used in combination with a system as described in the first aspect, although embodiments of the present invention are not limited thereto. The method may advantageously be used for determining a characteristic such as a profile of a road. The method may be incorporated in a method for controlling a suspension of a car, the method comprising performing a method for detecting a characteristic, e.g. a profile or property, of a road and a step of using such information for actively controlling a suspension. Nevertheless, the method for detecting a characteristic, e.g. a profile or property, of an object also may be used outside automotive, for any other suitable application.

[0186] In a first step **201** a radiation pattern is emitted on the object under study using a radiation source. The radiation pattern can be emitted in one shot (i.e. simultaneously) or sequentially. In any case, the radiation pattern is emitted in a pulsed manner. The latter advantageously results in a better signal to noise resolution, as the amount of power that can be provided during the pulse can be higher, thus resulting in less disturbance of environmental light, such as e.g. daylight.

[0187] In a second step **202**, the reflected pattern is detected using a detector **102.** The detector has a plurality of pixels such that it can detect the complete reflected radiation pattern with a resolution that is sufficient to resolve the pattern. The detection is synchronized with the radiation through a synchronization means **104.**

[0188] In a third step **203**, the data from the detector **(102)** is processed using a processor **(103).** Triangulation based methods on the data allow to retrieve profile information from that data. The method may comprise an auto-calibration phase.

[0189] A schematic representation of a method according to embodiments of the present invention is shown in FIG. 2.

[0190] Whereas the above method has been described for detecting a characteristic in an object, e.g. a profile in a road, it will be clear to the skilled person that a number of other applications can be performed using the present system. Particular applications may be based on a particular interpretation of the measured raw data in combination with for example calibration datasets.

[0191] In a first example, as discussed in more detail above, the application envisaged is increasing driving comfort. Active suspension is steered based on the obtained measurements to adjust for road imperfections, to adjust for type of pavement, to adjust for road conditions such as ice, water, snow, grind, etc. (this can also be a safety application) to adjust for pitch, roll, etc.

[0192] Another example of an application is autonomous or assisted driving of vehicles. The system may for example be used for providing or assisting in a steering function. It may provide steering instructions for semi-autonomous or autonomous steering of vehicles of any means, for example in agriculture, for any type of transport, for road inspection, for a garbage collection truck, for pick and collect tasks in warehouses, for load applications, etc. The system thereby may perform one or more of speed calculation, determination of moving or stationary objects in relation to their environment, etc.

[0193] Another example of an application is the provision of safety information or the performance of safety actions. The system may be used for detecting traffic signs, moving objects, vicinity of objects, detection of any moving or stationary object in relation to its environment, road conditions, road types, etc.

Claims

1. A vehicle-mountable system (100) for detecting a characteristic of an object, the system comprising:

   - a radiation source (101) adapted to generate a simultaneously pulsed radiation pattern composed of radiation spots;
   - at least one detector (102) having a plurality of pixels;
   - a processor (103) adapted to process data from the at least one detector (102) when radiation from the radiation source is reflected by an object and detected by the at least one detector (102);
   - a synchronization means (104) interfacing between the at least one detector (102) and the radiation source (101);

   wherein:

   - the synchronization means (104) is adapted for synchronizing the at least one detector (102) with the radiation source (101) so that detection by the detector of radiation to be processed is detected only during the radiation pulses,
   - the processor (103) is adapted to determine a characteristic of the object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions, and
   - the radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter (1320) arranged on a dome (1310), said system further comprising fish-eye optics (1330) arranged between said narrow bandpass filter (1320) and said at least one detector (102) to guide light that has passed through said narrow bandpass filter (1320) towards a light-sensitive area of said at least one detector (102).

2. The system (100) according to claim 1, wherein the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

3. The system (100) according to claim 1 or claim 2, wherein the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

4. The system (100) according to any of the preceding claims, wherein said determining of said displace-

ment is performed with sub-pixel accuracy by multipixel fitting said detected spots.

5. A vehicle comprising the system (100) according to any of the preceding claims.

6. The vehicle according to claim 5, further comprising a suspension system, and a control system, whereby the control system is adapted for receiving profile information of the system for determining a characteristic of an object and is adapted for using the information for controlling the suspension system.

7. A camera, the camera comprising a system (100) according to any of claims 1 to 4, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

8. A method for detecting a characteristic of an object, the method comprising the following steps:

- emitting (201) a pulsed radiation pattern composed of radiation spots on the object using a radiation source (101),
- detecting (202) the reflected pattern using at least one detector (102) having a plurality of pixels, whereby the detection is synchronized with the pulsed radiation pattern for detecting radiation to be processed only during the radiation pulses, and
- processing (203) the data from the detector (102) for determining a characteristic of an object by determining a displacement of detected spots detected with the at least one detector with reference to predetermined reference spot positions,

wherein said emitting (201) uses monochromatic light and said at least one detector (102) is equipped with a corresponding narrow bandpass filter (1320) arranged on a dome (1310), and wherein fish-eye optics (1330) arranged between said narrow bandpass filter (1320) and said at least one detector (102) guide light that has passed through said narrow bandpass filter (1320) towards a light-sensitive area of said at least one detector (102).

9. The method according to claim 8, wherein the at least one detector comprises a CMOS sensor or a CCD sensor having a dynamic range of at least 90 dB, preferably more than 120 dB.

10. The method according to claim 8 or claim 9, wherein the at least one detector comprises a CMOS sensor or a CCD sensor configured to subtract background illumination from the radiation from the radiation source by comparing a signal sensed during an on-phase of said pulsed radiation pattern with a signal sensed during an off-phase of said pulsed radiation pattern.

11. The method according to any of claims 8-10, wherein said determining of said displacement is performed with sub-pixel accuracy by multipixel fitting said detected spots.

12. A computer program product comprising code means adapted to cause a processor to perform the determining of said characteristic of the method according to any of claims 8 to 11.

13. Use of a system (100) according to any of claims 1 to 4 for detecting a characteristic of an object in a vicinity of a vehicle, said use taking place in an outdoor environment.

14. Use according to claim 13 for measuring the profile of the road in front of a car or for controlling of autonomous vehicles.

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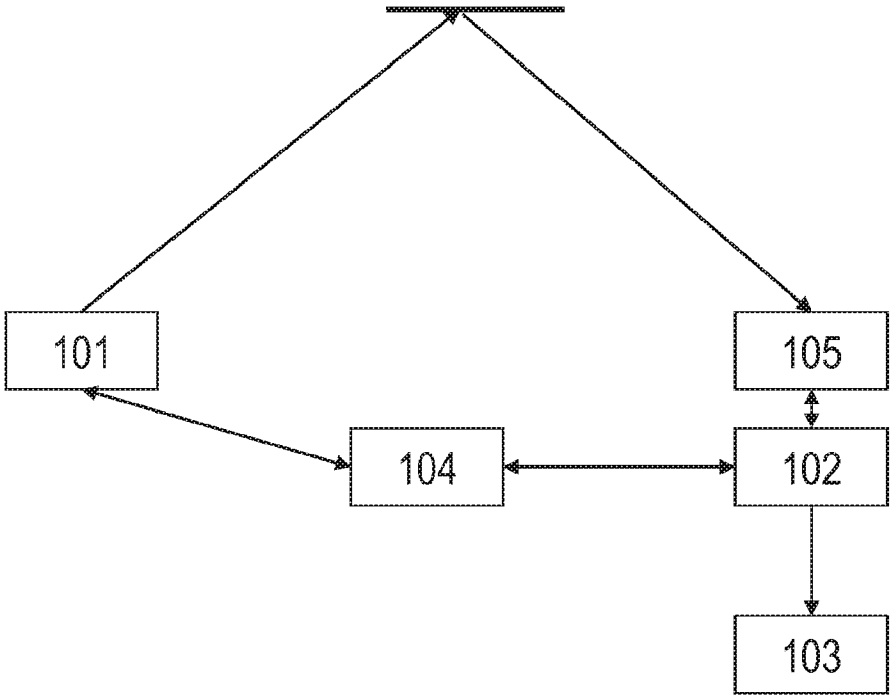


Fig. 1

HESAI EX1002, P.606

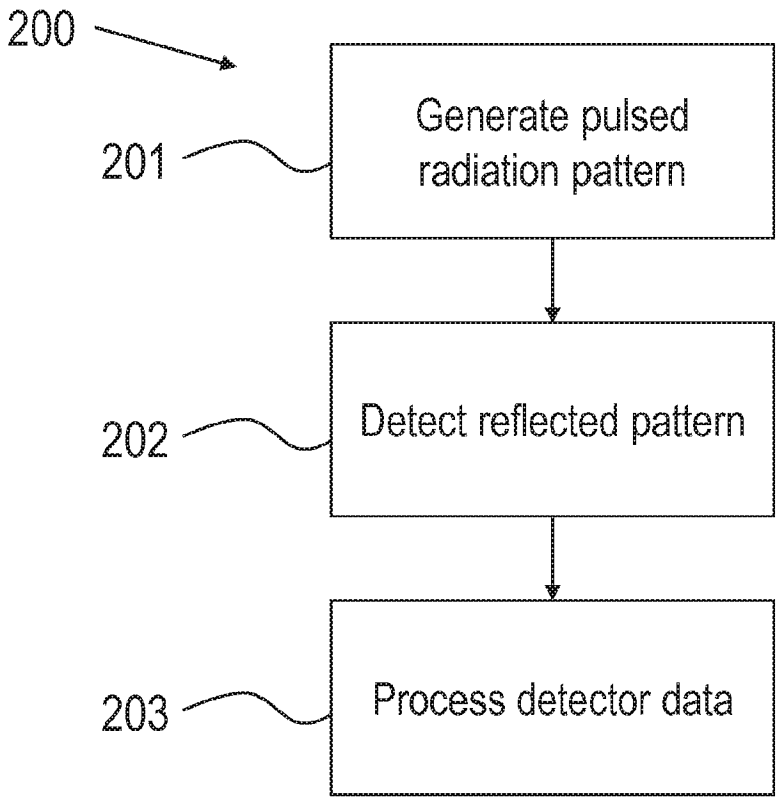


Fig. 2

HESAI EX1002, P.607

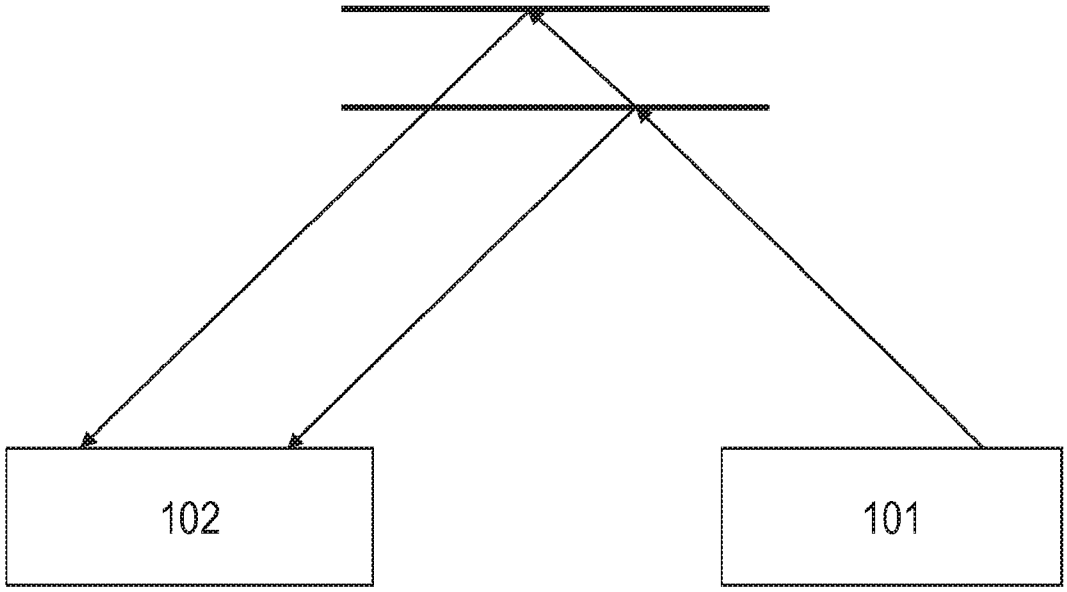


Fig. 3

HESAI EX1002, P.608

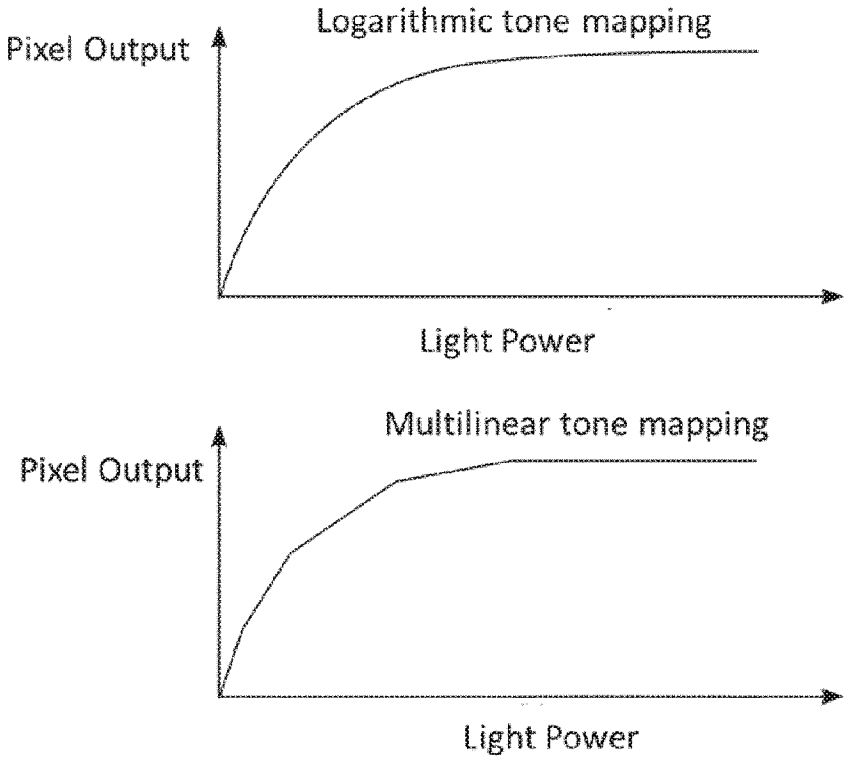


Fig. 4

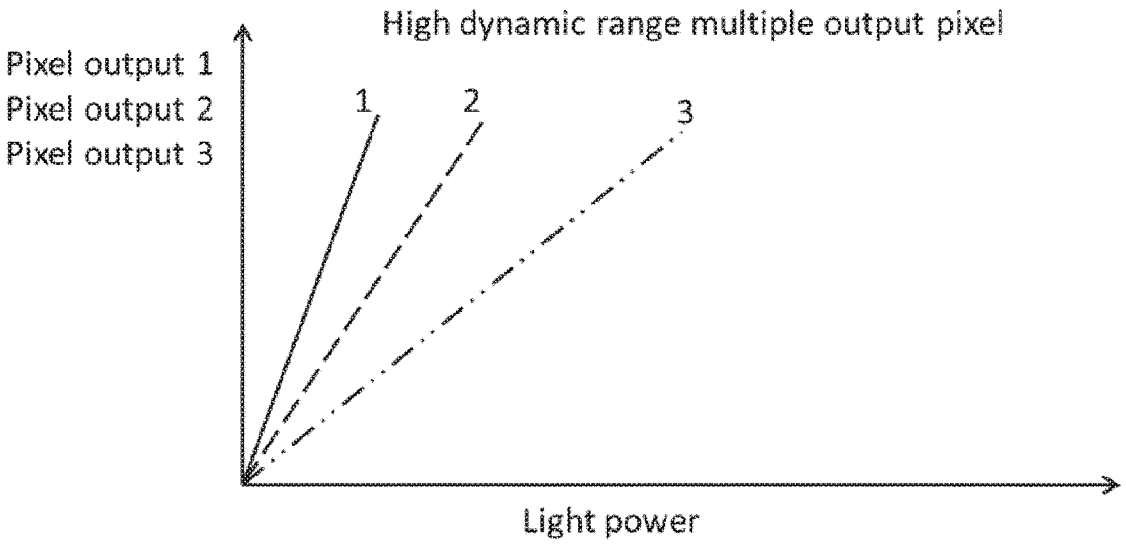


Fig. 5

HESAI EX1002, P.609

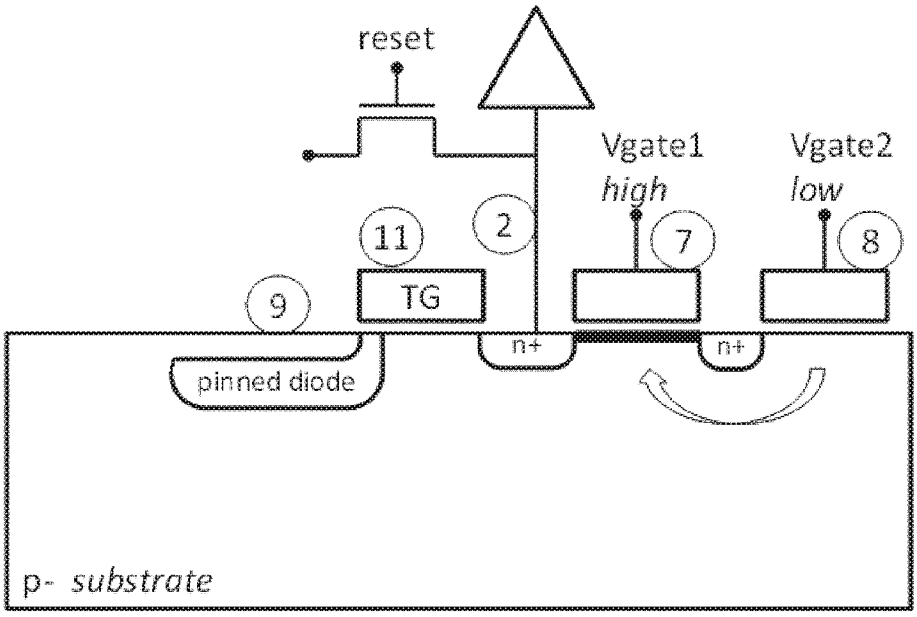


Fig. 6

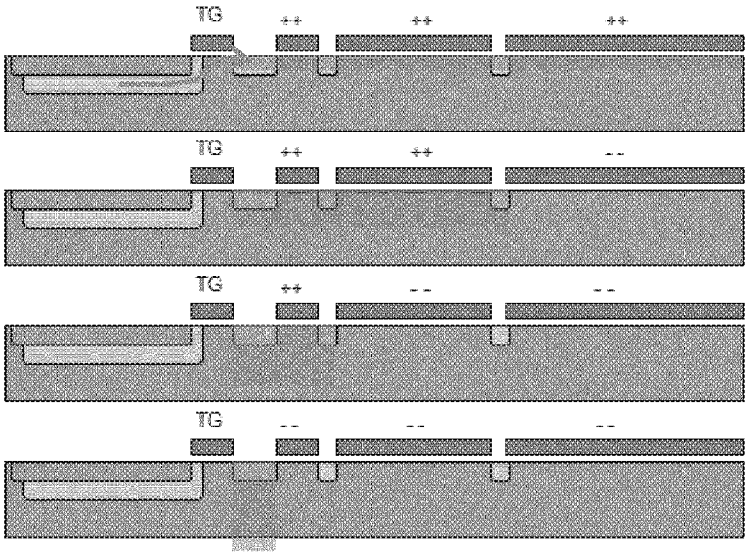


Fig. 7

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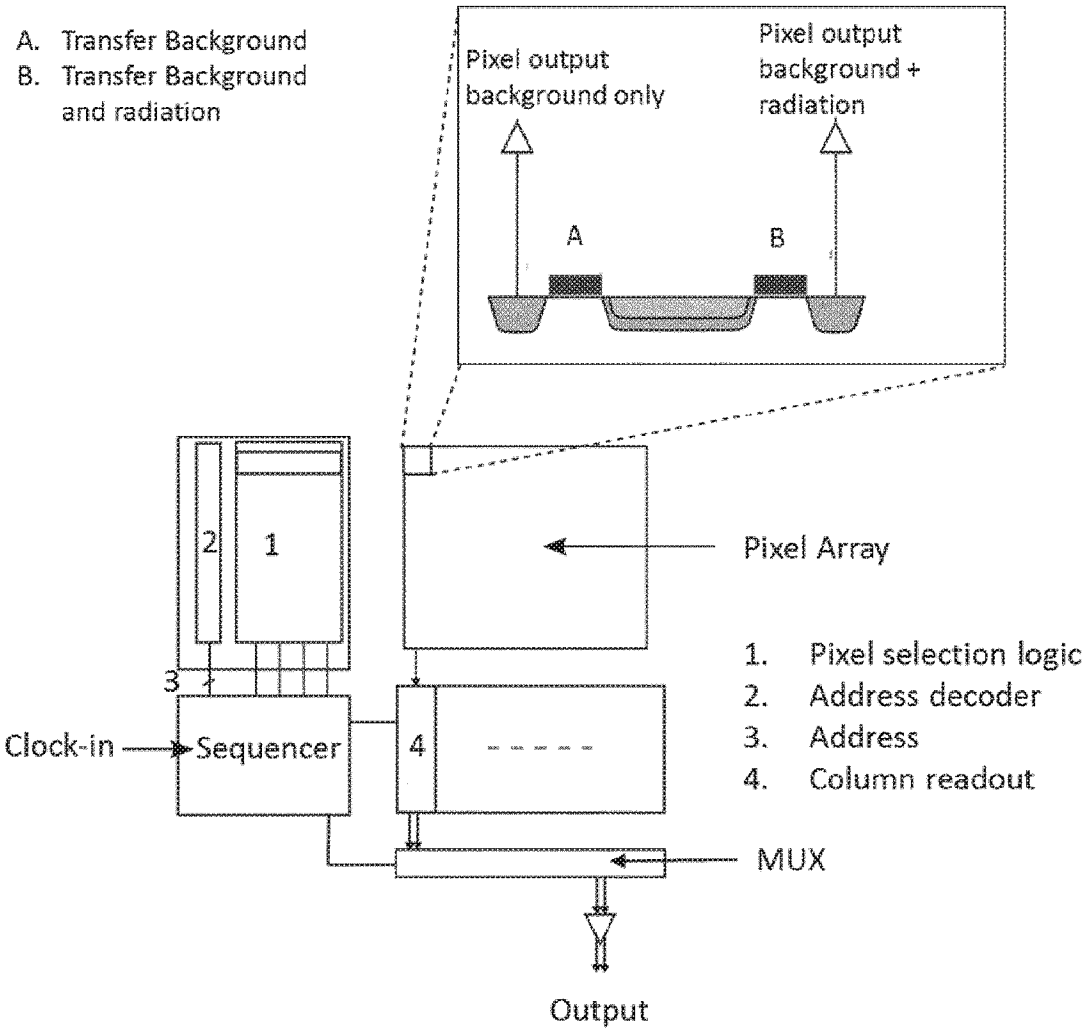


Fig. 8

HESAI EX1002, P.611

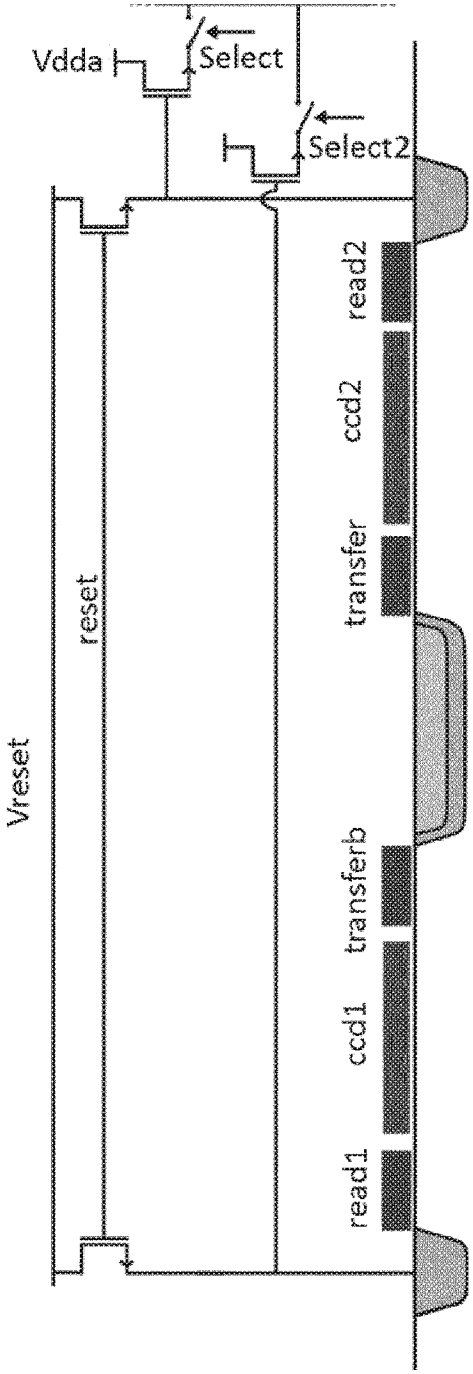


Fig. 9

HESAI EX1002, P.612

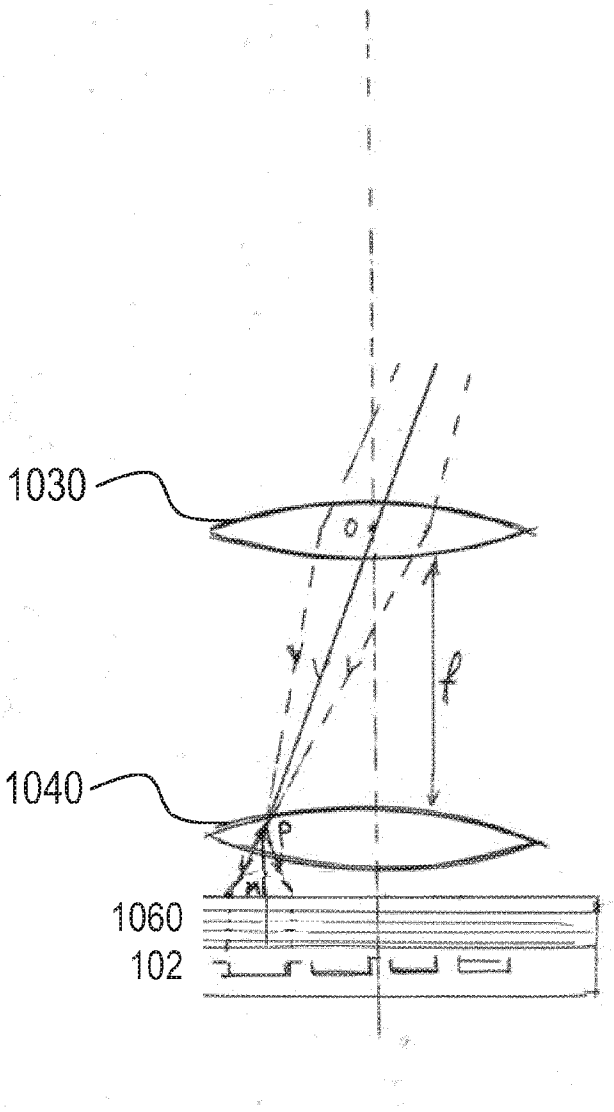


Fig. 10

HESAI EX1002, P.613

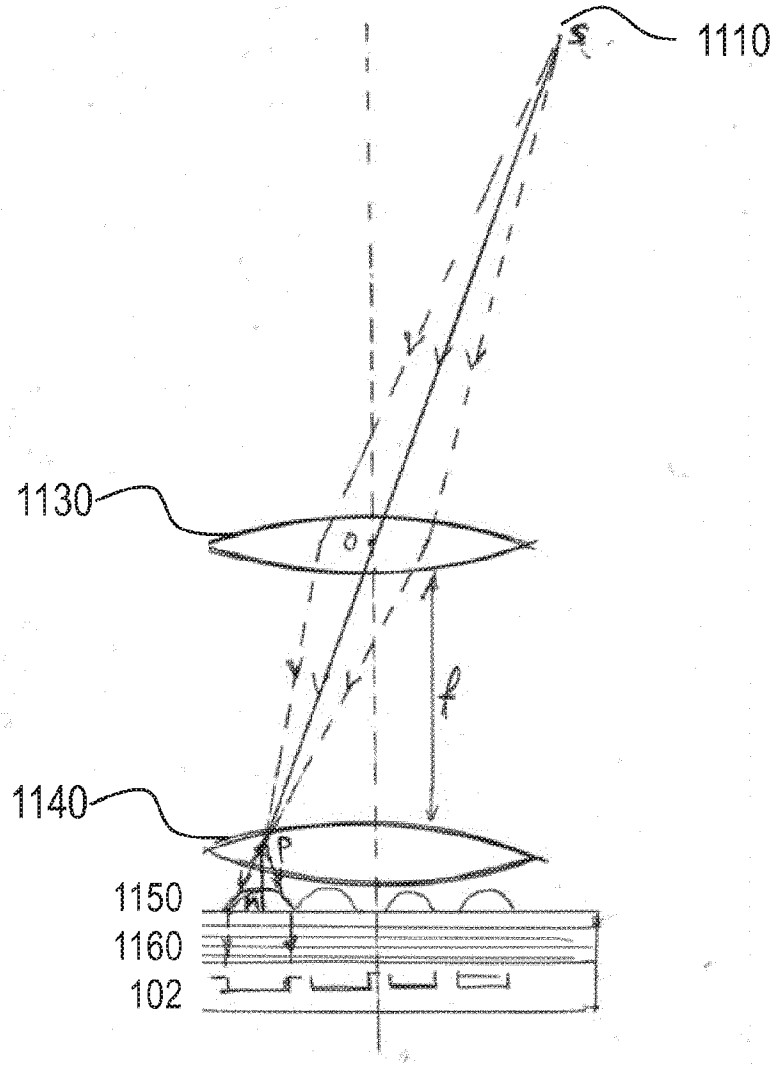


Fig. 11

HESAI EX1002, P.614

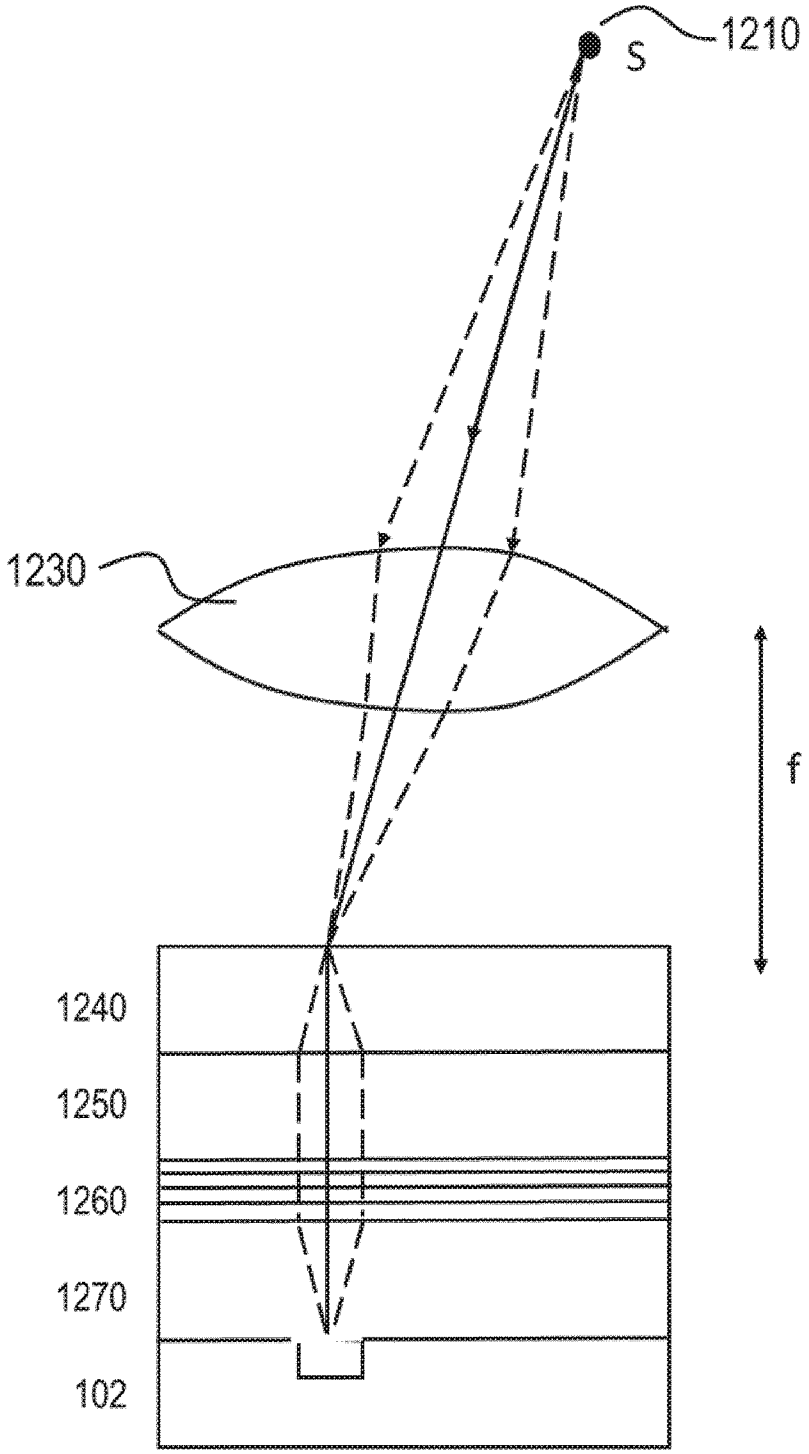


Fig. 12

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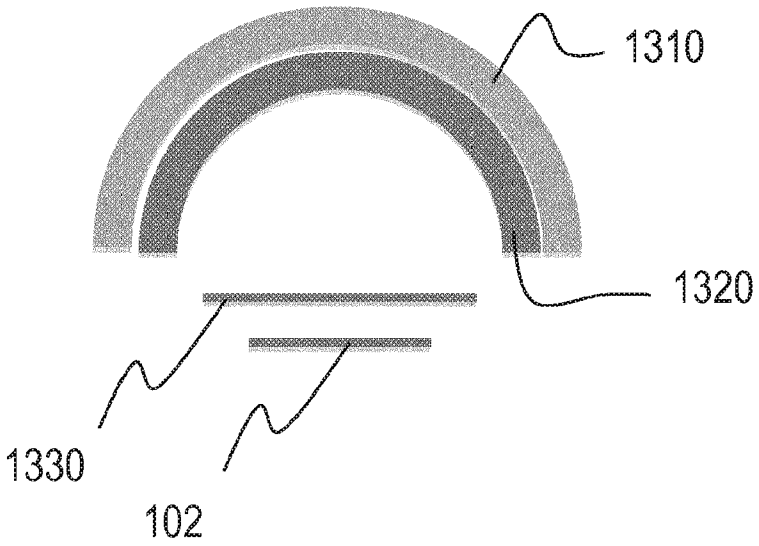


Fig. 13

HESAI EX1002, P.616

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EUROPEAN SEARCH REPORT

Application Number
EP 15 15 1031

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 040 116 A (EVANS JR JOHN M [US] ET AL) 13 August 1991 (1991-08-13) * abstract; figure 1b * * column 2, line 15 - line 57 * * column 3, line 55 * * column 4, line 29 - line 40 * * column 7, line 35 - line 39 *	1-14	INV. G01S17/46 G01S17/89 G01S7/481
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	25 June 2015	Beer, Mark

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 15 15 1031

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 316 000 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.05.2018 Bulletin 2018/18

(51) Int Cl.:
G01S 17/93 *(2006.01)* ***G01S 7/481*** *(2006.01)*
G01S 17/46 *(2006.01)*

(21) Application number: **16196456.4**

(22) Date of filing: **28.10.2016**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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(54) VEHICULAR SYSTEM FOR MEASURING A DISTANCE TO AN OBJECT AND METHOD OF INSTALLING SAME

(57) The invention pertains to a system (100), in a vehicle (200) having a windshield (250), for measuring a distance to an object outside said vehicle (200). The system comprises: a light source (110) for projecting a light pattern in a first direction onto said object; a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection. It further comprises a transparent prism (140), shaped in such a way that it can be placed with a first side in contact with the windshield (250) and a second side directed to the light source (110) and the detector (120), whereby the second side presents a smaller angle of incidence towards the first and second direction than the windshield (250).

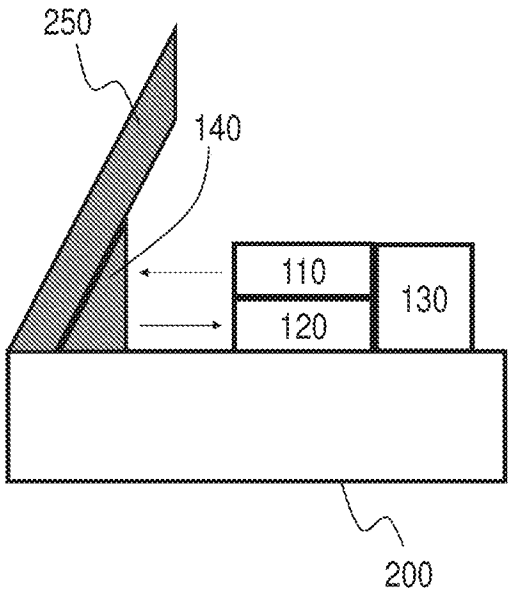


Figure 1

EP 3 316 000 A1

Description

Field of the Invention

[0001] The present invention pertains to the field of vehicular systems for determining a distance to an object in the vicinity or the path of a vehicle, including time-of-flight based sensing systems and triangulation-based sensing systems. The present invention also pertains to a method for installing such a system in a vehicle.

Background

[0002] Vehicular distance measurement systems are known and used in applications such as park assist, active suspension systems, advanced driver assistance systems, and self-driving cars.

[0003] A specific type of detection system is disclosed in detail in international patent application publication no. WO 2015/004213 A1 in the name of the present applicant.

[0004] Another specific type of detection system is described for example in the unpublished international patent application no. PCT/EP2016/075589 in the name of the present applicant.

[0005] It is clear from both cited applications, that it is extremely important to detect the largest possible proportion of the reflected light at the detector of such a system, to obtain the desired operating range and accuracy. The known systems have not been deployed inside vehicles, because the necessary passage of projected and reflected light beams through the vehicle's windshield is believed to attenuate the light beams to such an extent that sufficiently accurate detection would no longer be possible.

[0006] Hence, there is a need for systems of the above mentioned type that can be deployed inside vehicles.

Summary

[0007] According to an aspect of the present invention, there is provided a system, mountable in the interior of a vehicle having a windshield, the system being configured for measuring a distance to an object outside the vehicle, the system comprising: a light source for projecting a light pattern in a first direction onto the object; a detector for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means configured to determine a position and/or a distance of the object on the basis of the detected reflection; wherein the system further comprises a transparent prism which is shaped in such a way that it can be placed with a first side in contact with an inner surface of the windshield and a second side directed to the light source and the detector, whereby the second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield.

[0008] The present invention is based *inter alia* on the insight of the inventor that the range and accuracy of a vehicular ranging system, mounted inside a vehicle, can be improved by reducing the attenuation caused by the repeated traversal of the air/glass interfaces by the light beams. The present invention is further based on the insight of the inventor that such a reduction in attenuation can be obtained by modifying the angle of incidence at the interior interface. It is an advantage of the present invention that the angle of incidence at the interior interface is reduced by the presence of a judiciously shaped and positioned prism that modifies the angle of incidence at the air/glass interface on the internal side. It should be noted that the terms "internal side" and "external side" are used herein to designate the inside and the outside of the vehicle, and not of the prism.

[0009] The term "transparent prism" is used herein to denote a transparent solid body having at least two sides, forming non-parallel material/air interfaces.

[0010] The prism may be made of glass or a transparent polymer (e.g. polycarbonate or polymethylmethacrylate). Glass is preferred because it has a refractive index that is close to that of the windshield and excellent mechanical properties for the purposes of the present invention.

[0011] In an embodiment of the system according to the present invention, the second side is substantially perpendicular to the first direction and the second direction.

[0012] It is an advantage of this embodiment that the angle of incidence at the internal side is reduced to the maximum extent.

[0013] In an embodiment of the system according to the present invention, a refractive index of the prism is in the range of 1.48 to 1.52.

[0014] It is an advantage of this embodiment that the refractive index of the prism is close to that of a typical windshield, thus approaching the desired situation where the windshield and the prism form an optical continuum.

[0015] In an embodiment, the system according to the present invention further comprises a layer of adhesive arranged on the first side for attaching the prism to the windshield, the layer of adhesive having a refractive index in the range of 1.48 to 1.52.

[0016] It is an advantage of this embodiment that the refractive index of the adhesive layer is close to that of a typical windshield, thus approaching the desired situation where the windshield and the adhesive layer form an optical continuum.

[0017] According to an aspect of the present invention, there is provided a vehicle comprising a system as described above, the vehicle having a windshield, the prism being arranged with the first side in contact with an inner surface of the windshield, and the light source and the detector being arranged such that their optical paths pass through the first side and the second side of the prism, the optical paths having a smaller angle of incidence onto the second side than onto the windshield.

[0018] In an embodiment of the vehicle according to

the present invention, the windshield is provided with an anti-reflective coating, having a smaller refractive index than the windshield.

[0019] According to an aspect of the present invention, there is provided a method for installing a detection system in a vehicle having a windshield, the detection system comprising: a light source for projecting a light pattern in a first direction onto an object outside the vehicle; a detector for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means configured to determine a position and/or a distance of the object on the basis of the detected reflection; the method comprising: arranging a transparent prism with a first side in contact with an inner surface of a windshield of the vehicle; and arranging the light source and the detector such that their optical paths pass through the first side and the second side of the prism, whereby the second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield.

[0020] In an embodiment of the method according to the present invention, the arranging of the transparent prism comprises providing a layer of adhesive on the first side for attaching the prism to the windshield, the layer of adhesive having a refractive index in the range of 1.48 to 1.52.

[0021] The technical effects and advantages of embodiments of the vehicle and the method according to the present invention correspond, *mutatis mutandis*, to those of the corresponding embodiments of the system according to the present invention.

Brief Description of the Figures

[0022] These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

- Figure 1 schematically illustrates a system according to an embodiment of the present invention;
- Figure 2 schematically clarifies a principle of operation of the present invention; and
- Figure 3 provides a flow chart of a method according to an embodiment of the present invention.

Detailed Description of Embodiments

[0023] Figure 1 schematically illustrates a system **100** according to an embodiment of the present invention.

[0024] The system **100** is mountable in the interior of a vehicle **200** having a windshield **250**, and it is configured for measuring a distance to an object outside the vehicle **200**; in particular, the distance measurement is performed through the windshield **250**. The system **100** comprises a light source **110** for projecting a light pattern in a first direction onto the object, which may for example comprise a laser source arranged to project a pattern of spots (e.g., a VCSEL array, or a laser/grating combination). The system **100** further comprises a detector **120** for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction, which may for example comprise a CMOS sensor array. The system **100** further comprises processing means **130** configured to determine a position and/or a distance of the object on the basis of the detected reflection. The processing means **130** may be implemented in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA), programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component(s) may also include other functions.

[0025] The light source **110**, the detector **120**, and the processing means **130** may cooperate to obtain a distance measurement in a variety of ways that are known to the skilled person. Without limitation, the distance measurement may be obtained by analyzing in the processing means **130** the displacement of individual laser spots in a pattern projected by the light source **110** and detected by the detector **120**, as disclosed in detail in international patent application publication no. WO 2015/004213 A1 in the name of the present applicant. Still without limitation, the distance measurement may also be obtained by assessing in the processing means **130** the round-trip time-of-flight of a light (e.g., laser) pulse projected by the light source **110** and detected by the detector **120**, as described for example in the unpublished international patent application no. PCT/EP2016/075589 in the name of the present applicant. It is clear from both cited applications, that it is extremely important to detect the largest possible proportion of the reflected light at the detector **120**. The arrangements envisaged by the present invention have in common that the light is projected from inside the vehicle **200**, through the windshield **250**, onto a target scenery outside the vehicle **200**, and the reflections are again measured inside the vehicle **200** after passing once again through the windshield **250**. These systems may be used in automotive applications such as park assist, active suspension systems, advanced driver assistance systems, and self-driving cars.

[0026] The system **100** further comprises a transparent prism **140** which is shaped in such a way that it can be placed with a first side in contact with an inner surface of the windshield **250** and a second side directed to the light source **110** and the detector **120**. In other words, the transparent prim **140** is placed between the source/detector combination **110/120** and the windshield **250**, in the optical path of the projected and reflected light beams. The shape and the arrangement of the transparent prism **140** is such that its second side presents a smaller angle of incidence towards the first direction and the second direction than the windshield **250**. As a result, the projected and reflected beams pass through the prism/air interface at an angle that is closer to the per-

pendicular than the angle that they would present at the windshield/air interface in the absence of the prism. Accordingly, the beams undergo less refraction, and the amount of attenuation is reduced.

[0027] Thus, in a vehicle **200** equipped with the system **100** according to an embodiment of the present invention, the prism **140** is arranged with the first side in contact with an inner surface of the windshield **250**, and the light source **110** and the detector **120** are arranged such that their optical paths pass through the first side and the second side of the prism **140**, the optical paths having a smaller angle of incidence onto the second side than onto the windshield **250**. The windshield **250** may be provided with an anti-reflective coating **260**, having a smaller refractive index than the windshield. The refractive index and the thickness of the anti-reflective coating **260** may be selected by the skilled person to minimize the attenuation of a light beam having a given wavelength traversing the interface under a given angle.

[0028] Preferably, the second side - i.e. the side facing the source/detector combination **110/120** - is substantially perpendicular to the first direction and the second direction, so as to minimize the refraction effects.

[0029] The refractive index of the prism **140** is preferably in the range of 1.48 to 1.52. To optimize the system, the refractive index of the prism **140** may be chosen as close as possible to the refractive index of the windshield **250**, to approach the situation where the combination of the windshield **250** and the prism **140** form an optical continuum.

[0030] A layer of adhesive **150** may be arranged on the first side for attaching the prism **140** to the windshield **250**. The layer of adhesive **150** preferably has a refractive index in the range of 1.48 to 1.52. To optimize the system, the refractive index of the adhesive **150** may be chosen as close as possible to the refractive index of the windshield **250**, to approach the situation where the combination of the windshield **250** and the adhesive **150** form an optical continuum.

[0031] Figure 2 schematically clarifies a principle of operation of the present invention.

[0032] The top half of Figure 2 illustrates the situation of a light beam traversing the glass/air interfaces on the exterior side and the interior side of a windshield **250**. As the respective interfaces are parallel planes, and as the air on both sides has the same refractive index, identical angles of incidence can be observed on both sides. As the light typically travels to and from objects on the road in front of the vehicle, the angle of incidence on the exterior side will necessarily be very large - as a result, in this arrangement, the corresponding angle of incidence on the interior side will be equally large, which is undesirable.

[0033] Applying the Fresnel equations using standard values for the refractive indices of air (n = 1) and glass (n = 1.55), it may be calculated that the optical power of a light beam that travels a round-trip through the windshield (4 interface transitions) at angles of incidence of 65° will be reduced to 57%. At angles of incidence of 80°, the optical power of such a light beam will even be reduced to a mere 13%. Such a loss of optical power is detrimental to the range and accuracy of ranging systems as described above.

[0034] The bottom half of Figure 2 illustrates the situation of a light beam traversing the glass/air interfaces on the exterior side and the interior side of a windshield **250**, in the presence of a prism **140**, arranged in accordance with the present invention. The windshield/prism combination **250/140** is assumed to form an optical continuum. Hence, the respective interfaces traversed by the light beams are no longer parallel planes, such that different angles of incidence can be observed on both sides. By a judicious choice of the shape and arrangement of the prism **140**, the light that travels to and from objects on the road in front of the vehicle, is refracted in such a way that the angle of incidence on the interior side is small, preferably close to the perpendicular.

[0035] Applying the Fresnel equations again using the same values for the refractive indices of air (n = 1) and glass (n = 1.55), it may be calculated that the optical power of a light beam that travels a round-trip through the windshield (4 interface transitions) at angles of incidence of 65° (exterior) and 0° will be reduced to 69%. At angles of incidence of 80° (exterior) and 0° (interior), the optical power of such a light beam will be reduced to 33%. Hence, a much larger portion of the emitted light remains available for detection by the ranging systems thanks to the presence of the prism **140**, allowing a longer detection range and higher accuracy.

[0036] Figure 3 provides a flow chart of a method according to an embodiment of the present invention. While the steps of the method are illustrated as consecutive steps, this is done for clarification purposes only, and the illustrated order is not limiting. For consistency, reference numbers relating to elements illustrated in Figure 1 will also be included in the following description. Details and options of the system disclosed hereinabove in the context of Figure 1 apply to the following description as well, and will not be repeated.

[0037] The purpose and effect of the illustrated method is to install a detection system **100** in a vehicle **200** having a windshield **250**. The detection system **100** comprises a light source **110** for projecting a light pattern in a first direction onto an object outside the vehicle **200**, a detector **120** for detecting at least a partial reflection of the light pattern, arriving from the object in a second direction; and processing means **130** configured to determine a position and/or a distance of the object on the basis of the detected reflection. The method comprises arranging **310** a transparent prism **140** with a first side in contact with an inner surface of a windshield **250** of the vehicle **200**, and arranging **320** the light source **110** and the detector **120** such that their optical paths pass through the first side and the second side of the prism **140**. This is done in such a way that the second side of the prism **140** presents a smaller angle of incidence towards the first

direction and the second direction than the windshield **250.**

[0038] The arranging **310** of the transparent prism **140** may comprise providing a layer of adhesive **150** on the first side for attaching the prism to the windshield **250,** the layer of adhesive **150** having a refractive index in the range of 1.48 to 1.52.

[0039] While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (100), mountable in the interior of a vehicle (200) having a windshield (250), the system (100) being configured for measuring a distance to an object outside said vehicle (200), said system comprising:

   - a light source (110) for projecting a light pattern in a first direction onto said object;
   - a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and
   - processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection;

   characterized in that said system (100) further comprises a transparent prism (140) which is shaped in such a way that it can be placed with a first side in contact with an inner surface of said windshield (250) and a second side directed to said light source (110) and said detector (120), whereby said second side presents a smaller angle of incidence towards said first direction and said second direction than said windshield (250).

2. The system (100) according to claim 1, whereby said second side is substantially perpendicular to said first direction and said second direction.

3. The system (100) according to claim 1 or claim 2, wherein a refractive index of said prism (140) is in the range of 1.48 to 1.52.

4. The system (100) according to any of the preceding claims, further comprising a layer of adhesive (150) arranged on said first side for attaching said prism (140) to said windshield (250), said layer of adhesive (150) having a refractive index in the range of 1.48 to 1.52.

5. A vehicle (200) comprising a system (100) according to any of the preceding claims, said vehicle (200) having a windshield (250), said prism (140) being arranged with said first side in contact with an inner surface of said windshield (250), and said light source (110) and said detector (120) being arranged such that their optical paths pass through said first side and said second side of said prism (140), said optical paths having a smaller angle of incidence onto said second side than onto said windshield (250).

6. The vehicle (200) according to claim 5, wherein said windshield (250) is provided with an anti-reflective coating (260), having a smaller refractive index than said windshield.

7. A method for installing a detection system (100) in a vehicle (200) having a windshield (250), said detection system (100) comprising:

   - a light source (110) for projecting a light pattern in a first direction onto an object outside said vehicle (200);
   - a detector (120) for detecting at least a partial reflection of said light pattern, arriving from said object in a second direction; and
   - processing means (130) configured to determine a position and/or a distance of said object on the basis of said detected reflection;

   said method comprising:

   - arranging (310) a transparent prism (140) with a first side in contact with an inner surface of a windshield of said vehicle; and
   - arranging (320) said light source (110) and said detector (120) such that their optical paths pass through said first side and said second side of said prism (140),

   whereby said second side presents a smaller angle of incidence towards said first direction and said second direction than said windshield (250).

8. The method according to claim 7, wherein said arranging (310) of said transparent prism (140) comprises providing a layer of adhesive (150) on said first side for attaching said prism to said windshield (250), said layer of adhesive (150) having a refractive index in the range of 1.48 to 1.52.

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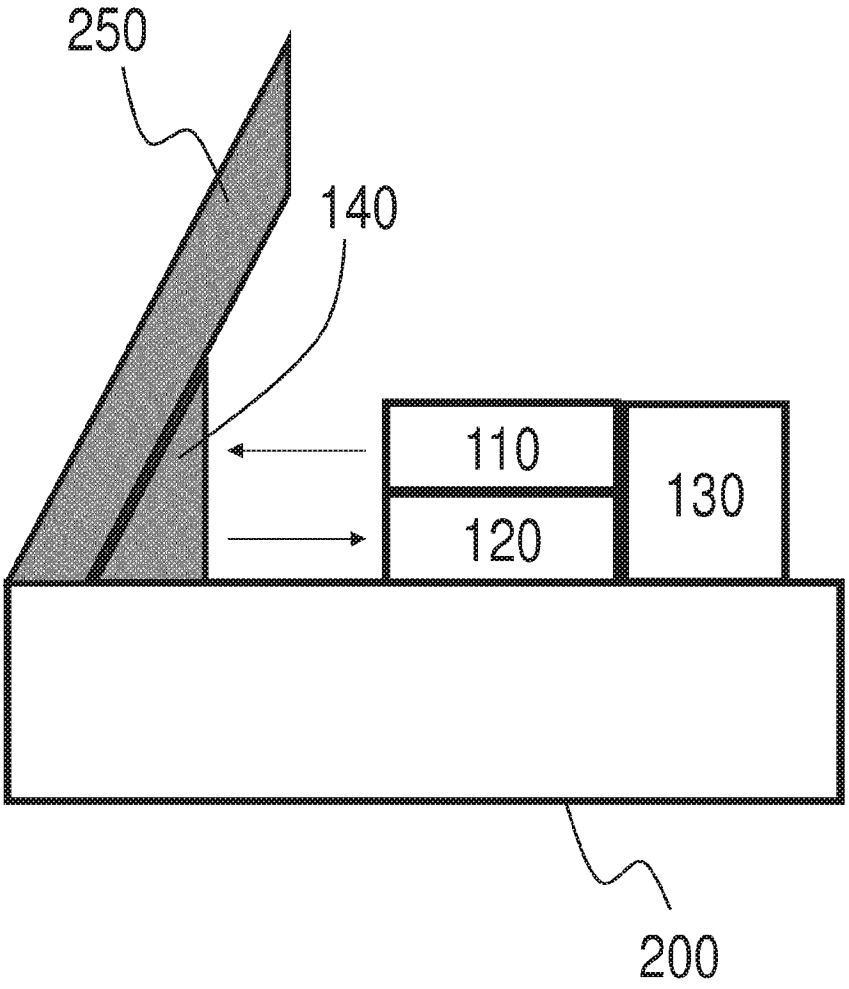
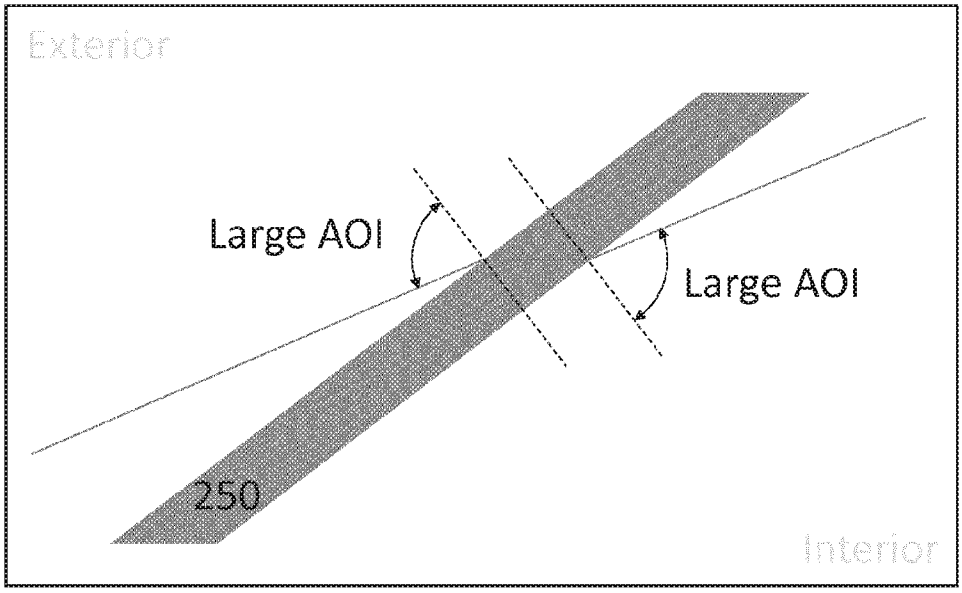


Figure 1

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Exterior
Large AOI
Large AOI
250
Interior

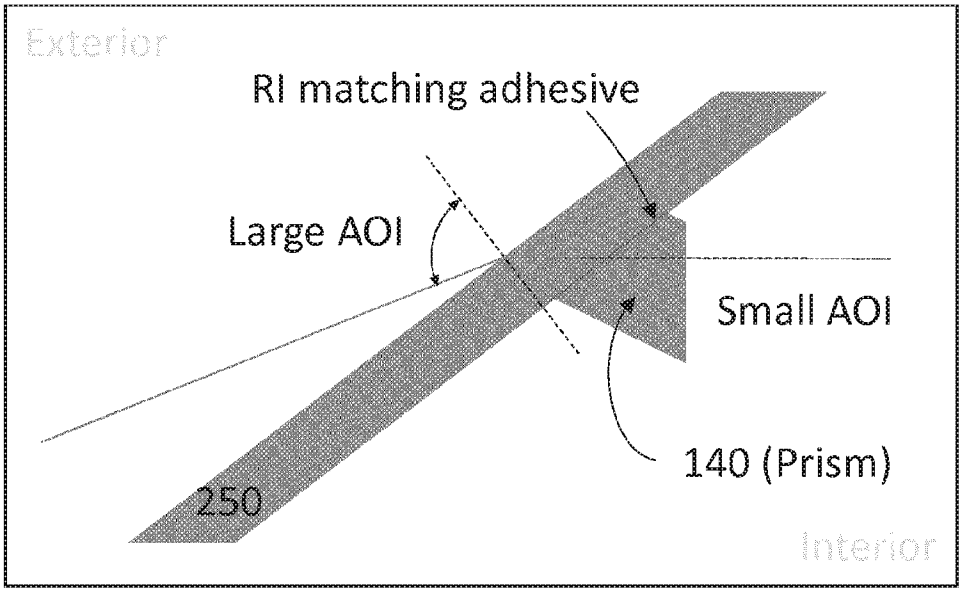

Exterior
RI matching adhesive
Large AOI
Small AOI
140 (Prism)
250
Interior

Figure 2

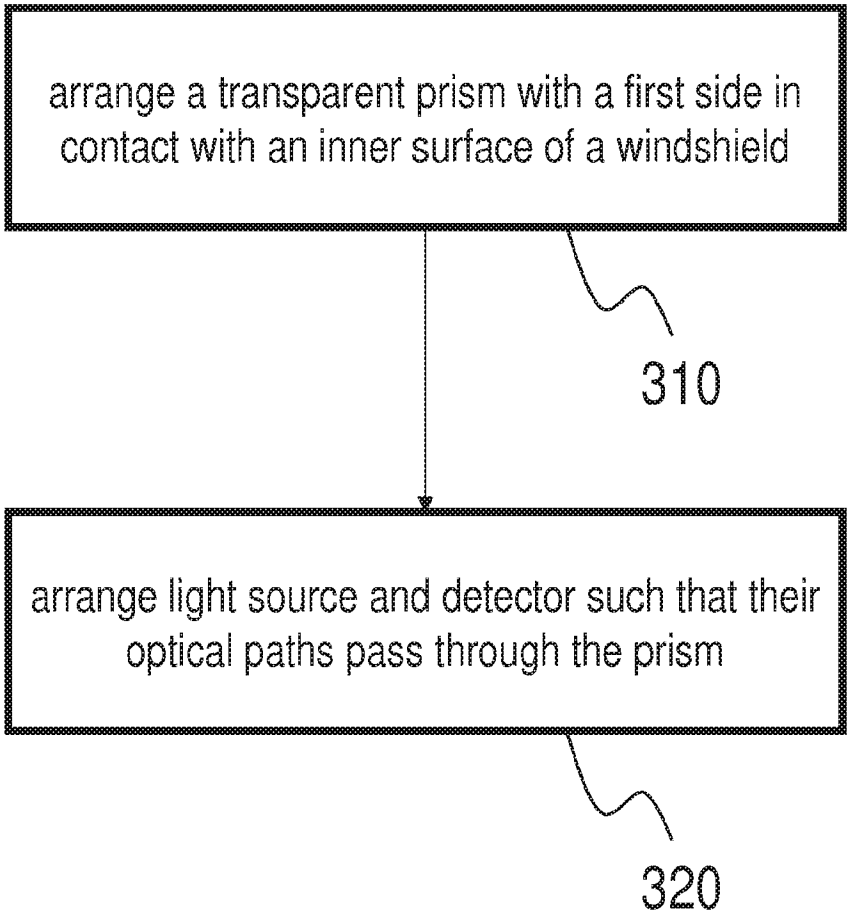


Figure 3

HESAI EX1002, P.627

Europäisches Patentamt
European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 16 19 6456

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 94/19705 A1 (SHACHTER ISRAEL [IL]; SILICON HEIGHTS LTD [IL]; YAVNAYI AMOTZ [IL]; GA) 1 September 1994 (1994-09-01) * abstract; figures 1,2a,16-18 * * page 11, lines 8-28 * * page 26, line 12 - page 27, line 15 * * claims 24-26 *	1-8	INV. G01S17/93 G01S7/481 ADD. G01S17/46
A	US 2011/128525 A1 (MIZUNO TAMOTSU [JP] ET AL) 2 June 2011 (2011-06-02) * abstract; figures 1-3 * * paragraphs [0043] - [0048], [0059] - [0077] *	1-8	
A	US 2003/156291 A1 (TSUNETOMO KEIJI [JP] ET AL) 21 August 2003 (2003-08-21) * abstract; figures 1,9,17 *	1-8	
			TECHNICAL FIELDS SEARCHED (IPC) G01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	27 April 2017	Lupo, Emanuela

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 16 19 6456

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27-04-2017

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- WO 2015004213 A1 **[0003] [0025]**
- EP 2016075589 W **[0004] [0025]**

HESAI EX1002, P.630

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2018 (12.04.2018)

W I P O I PCT

(10) International Publication Number
WO 2018/065426 A1

(51) International Patent Classification:
G01S 17/10 (2006.01) *G01S 7/487* (2006.01)
G01S 17/89 (2006.01) *G01S 17/93* (2006.01)
G01S 7/486 (2006.01) *G01S 7/481* (2006.01)

(21) International Application Number:
PCT/EP2017/075093

(22) International Filing Date:
03 October 2017 (03.10.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16192105.1 03 October 2016 (03.10.2016) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: METHOD FOR SUBTRACTING BACKGROUND LIGHT FROM AN EXPOSURE VALUE OF A PIXEL IN AN IMAGING ARRAY, AND PIXEL FOR USE IN SAME

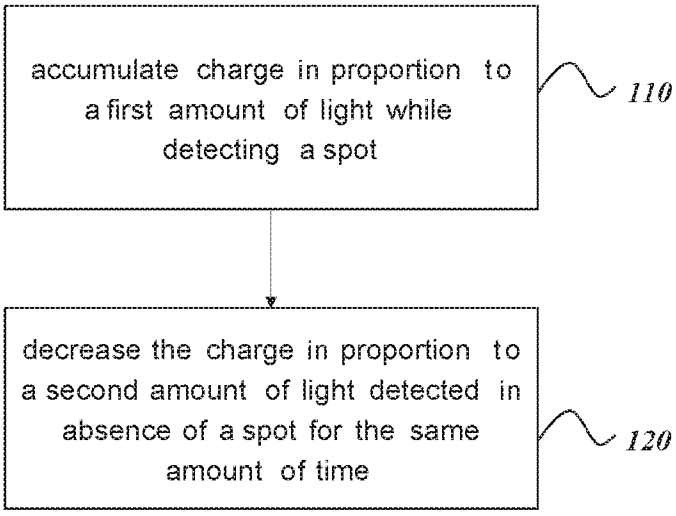


Fig. 1

(57) Abstract: The invention pertains to a method for subtracting background light from an exposure value of a pixel in an imaging array, and pixel for use in same The invention pertains to a method for subtracting background light from an exposure value of a first pixel in an imaging array, said first pixel receiving a reflection of a spot from a scenery illuminated by a periodically pulsed pattern of spots, said periodically pulsed pattern comprising in alternation an illuminated phase and a non-illuminated phase, the method comprising: accumulating in said first pixel a charge in proportion to a first quantity of incident light, received in said first pixel while detecting said spot during a predetermined amount of time; and decreasing said charge in proportion to a second quantity of incident light received during said predetermined amount of time in absence of said spot. The invention also pertains to a pixel and an imaging array.

WO 2018/065426 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Method for subtracting background light from an exposure value of a pixel in an imaging array, and pixel for use in same

Field of the Invention

The present invention pertains to the field of imaging systems, and in particular to a method for subtracting background light from an exposure value of a pixel in an imaging array, and to a pixel for use in such a method. The present invention may be used *inter alia* in systems for determining a distance to an object, in particular to time-of-flight based sensing systems to be used for the characterization of a scene or a part thereof.

Background

In the field of remote sensing technology, mainly in the usage of making high-resolution maps of the surroundings, to be used in many control and navigation applications such as but not limited to the automotive and industrial environment, gaming applications, and mapping applications, it is known to use time-of-flight based sensing to determine the distance of objects from a sensor. Time-of-flight based techniques include the use of RF modulated sources, range gated imagers, and direct time-of-flight (DToF) imagers. For the use of RF modulated sources and range gated imagers, it is necessary to illuminate the entire scene of interest with a modulated or pulsed source. Direct time-of-flight systems, such as most LIDARs, mechanically scan the area of interest with a pulsed beam, the reflection of which is sensed with a pulse detector.

In order to be able to correlate an emitted RF modulated signal with the detected reflected signal, the emitted signal must meet a number of constraints. In practice, these constraints turn out to make the RF modulated systems highly impractical for use in vehicular systems: the attainable range of detection is very limited for signal intensities that are within conventional safety limits and within the power budget of regular vehicles.

A direct TOF (DToF) imager, as used in most LIDAR systems, comprises a powerful pulsed laser (operating in a nanosecond pulse regime) , a mechanical scanning system to acquire from the ID point measurement a 3D map, and a pulse detector. Systems of this type are presently available from vendors including Velodyne Lidar of Morgan Hill, California. The Velodyne HDL-64E, as an example of state-of-the-art systems, uses 64 high-power lasers and 64 detectors (avalanche diodes) in a mechanically rotating structure at 5 to 15 rotations per second. The optical power required by these DToF LIDAR systems is too high to be obtained with semiconductor lasers, whose power is in the range of five to six orders of magnitude lower. In addition, the use of mechanically rotating elements for scanning purposes limits the prospects for miniaturization, reliability, and cost reduction of this type of system.

United States Patent application publication no. 2015/0063387 in the name of Trilumina discloses a VCSEL delivering a total energy of 50 mW in a pulse having a pulse width of 20 ns. The commercially available Optek OPV310 VCSEL delivers a total energy of 60 mW in a pulse having a duration of 10 ns and it can be estimated by extrapolation to have a maximum optical output power of 100 mW. This value is only realized under very stringent operating conditions, meaning optimal duty cycle and short pulse width so as to avoid instability due to thermal problems. Both the Trilumina disclosure and the Optek system illustrate that continuous-wave VCSEL systems are reaching their physical limits with respect to optical peak power output, due to thermal constraints inherently linked to the VCSEL design. At these pulse energy levels, and using ns pulses as presently used in DToF applications, the mere number of photons that can be expected to be usefully reflected by an object at a distance of 120 m is so low that it defeats detection by means of conventional semiconductor sensors such as CMOS or CCD or SPAD array. Thus, increasing the VCSEL power outputs by 5 or 6 orders of magnitude,

as would be required to extend the range of the known DToF systems, is physically impossible.

Even the use of avalanche diodes (AD or SPAD), which are theoretically sufficiently sensitive to capture the few returning photons, cannot be usefully deployed in the known LIDAR system architectures. A solid state implementation of an array of SPADs must be read out serially. A high number of SPADs is required to achieve the desired accuracy. The serial read-out constraints of the solid state implementation limit the bandwidth of the system turning it inappropriate for the desired accuracy. For accuracies such as that of the Velodyne system (0.02 m to 0.04 m, independent of distance), the required read-out data rate exceeds the practically achievable bandwidth in case of today's IC implementation. For operation at 120 m, a SPAD array of 500x500 pixels is required, which, in an IC-based implementation, must be read-out serially. For the same precision as the aforementioned Velodyne system, it would require 1000 pulses per millisecond and hence 1000 frames per millisecond, translating into a readout rate of 250 Gigapixels per second. This is believed to be technically unfeasible in the context of current SPAD IC technology.

The paper by Neil E. Newman et al., "High Peak Power VCSELs in Short Range LIDAR Applications", *Journal of Undergraduate Research in Physics*, 2013, http://www.jurp.org/2013/12017EXR.pdf, describes a VCSEL-based LIDAR application. The paper states that the maximum output power of the described prototype system was not great enough to do wide-field LIDAR at a range greater than 0.75 m. With a relatively focused beam (0.02 m spot size at 1 m distance), the authors were able to range a target object at a distance of up to 1 m.

The above examples clearly indicate that the optical power emitted by present semiconductor lasers cannot meet the power requirements necessary for operations in the known LIDAR systems to be of practical use in automotive applications (e.g. for ranges up to 120 m).

United States patent no. 7,544,945 in the name of Avago Technologies General IP (Singapore) Pte. Ltd., discloses vehicle-based LIDAR systems and methods using multiple lasers to provide more compact and cost-effective LIDAR functionality. Each laser in an array of lasers can be sequentially activated so that a corresponding optical element mounted with respect to the array of lasers produces respective interrogation beams in substantially different directions. Light from these beams is reflected by objects in a vehicle's environment, and detected so as to provide information about the objects to vehicle operators and/or passengers. The patent provides a solid state projector in which the individual lasers are consecutively activated in order to replace the known mechanical scanning in the known DToF LIDAR systems.

A high-accuracy medium-range surround sensing system for vehicles that does not use time-of-flight detection, is known from international patent application publication WO 2015/004213 A1 in the name of the present applicant. In that publication, the localization of objects is based on the projection of pulsed radiation spots and the analysis of the displacement of detected spots with reference to predetermined reference spot positions. More in particular, the system of the cited publication uses triangulation. However, the accuracy that can be achieved correlates with the triangulation base, which limits the further miniaturization that can be achieved.

US patent application publication no. US 2012/0038903 A1 discloses methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More

particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal .

European patent application publication no. EP 2 322 953 A1 discloses a distance image sensor capable of enlarging the distance measurement range without reducing the distance resolution. A radiation source provides first to fifth pulse trains which are irradiated to the object as radiation pulses in the first to fifth frames arranged in order on a time axis. In each of the frames, imaging times are prescribed at points of predetermined time from the start point of each frame, also the pulses are shifted respectively by shift amounts different from each other from the start point of the first to fifth frames. A pixel array generates element image signals each of which has distance information of an object in distance ranges different from each other using imaging windows A and B in each of five frames. A processing unit generates an image signal by combining the element image signals. Since five times-of-flight measurement are used, the width of the radiation pulse does not have to be increased to obtain distance information of the object in a wide distance range, and the distance resolution is not reduced.

European patent application publication no. EP 2 290 402 A1 discloses a range image sensor which is provided on a semiconductor substrate with an imaging region composed of a plurality of two-dimensionally arranged units, thereby obtaining a range image on the basis of charge quantities output from the units. One of the units is provided with a charge generating region (region outside a transfer electrode) where charges are generated in response to incident light, at least two semiconductor regions which are arranged spatially apart to collect charges from the charge generating region, and a transfer electrode which is installed at each periphery of the semiconductor region, given a charge transfer signal different in phase, and surrounding the semiconductor region.

The article by Shoji Kawahito et al., "A CMOS Time-of-Flight Range Image Sensor With Gates-on-Field-Oxide Structure", *IEEE Sensors Journal*, Vol. 7, no. 12, p. 1578-1586, discloses a type of CMOS time-of-flight (TOS) range image sensor using single-layer gates on field oxide structure for photo conversion and charge transfer. This structure allows the realization of a dense TOF range imaging array with 15 x 15 μm^2 pixels in a standard CMOS process. Only an additional process step to create an n-type buried layer which is necessary for high-speed charge transfer is added to the fabrication process. The sensor operates based on time-delay dependent modulation of photocharge induced by back reflected infrared light pulses from an active illumination light source. To reduce the influence of background light, a small duty cycle light pulse is used and charge draining structures are included in the pixel. The TOF sensor chip fabricated measures a range resolution of 2.35 cm at 30 frames per second an improvement to 0.74 cm at three frames per second with a pulse width of 100 ns.

All systems that rely on the detection of structured light emitted onto the scenery to be sensed, require a way to distinguish illuminated portions of the scenery from non-illuminated portions, despite the presence of ambient light. Hence, there is a continuing need to obtain methods and pixels that allow reliable removal of the background illumination component from an exposure value.

Summary of the Invention

According to an aspect of the present invention, there is provided a method for subtracting background light from an exposure value of a first pixel in an imaging array, said first pixel receiving a reflection of a spot from a scenery illuminated by a periodically pulsed pattern of spots, said periodically pulsed pattern comprising in alternation an illuminated phase and a non-illuminated phase, the method comprising: accumulating in said first pixel a charge in proportion to a first quantity of incident light, received in said first pixel while detecting said spot

during a predetermined amount of time; and decreasing said charge in proportion to a second quantity of incident light received during said predetermined amount of time in absence of said spot.

It is an advantage of the present invention that the background illumination is detected with components that are virtually identical to the components that detect the useful signal, and that both the background illumination and the useful signal are integrated over the same amount of time. In this way, an optimal pair of signals is obtained for subtraction.

In an embodiment of the method according to the present invention, the second quantity of incident light comprises light received in said first pixel during said predetermined amount of time in the non-illuminated phase.

It is an advantage of this embodiment that the background illumination is detected with components that are exactly the same as the components that detect the useful signal, which detect light originating from a single location in the scenery (apart from possibly a slight shift due to movement of the sensor) , such that the comparison between the illuminated phase and the non-illuminated phase provides a subtraction of the background illumination at that very location.

In another embodiment of the method according to the present invention, the second quantity of incident light comprises light received, during said accumulating, in a second pixel of the pixel array, the second pixel being at a sufficient distance from the first pixel so as not to be illuminated by said spot.

It is an advantage of this embodiment that the background illumination is detected at the same time as the useful signal, such that the subtraction of the background illumination is not sensitive to changes in the level of background illumination over time .

According to an aspect of the present invention, there is provided a pixel adapted for use as said first pixel in the method described above.

In an embodiment, the pixel comprises a capacitor for storing said charge, said capacitor having a first side and a second side, wherein said accumulating comprises transferring charges to said first side, and wherein said decreasing comprises transferring charges to said second side.

It is an advantage of this embodiment of the pixel according to the invention that it implements the inventive method of background subtraction in a very compact and reliable way, and without relying on additional digital computations.

According to an aspect of the present invention, there is provided an imaging array comprising a plurality of pixels as described above .

According to an aspect of the present invention, there is provided a system for determining a distance to an object comprising: a solid-state light source arranged for projecting a pattern of spots of laser light towards the object in a sequence of pulses; a detector comprising the imaging array as described above, the detector being configured for detecting light representing the pattern of spots as reflected by the object in synchronization with the sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by the pixels in response to the detected light; wherein the pixels are configured to generate the exposure values by accumulating, for each pulse of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window.

The inventors have found that the improved background subtraction method of the present invention can contribute to achieving the demanding power/performance requirements of automotive applications with a compact, semiconductor based time-of-flight based ranging system.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 represents a flow chart of an embodiment of the method according to the present invention;

Figure 2 schematically represents an embodiment of the pixel according to the present invention;

Figure 3 represents a flow chart of an embodiment of the method according to the present invention;

Figure 4 schematically represents an embodiment of the system according to the present invention;

Figure 5 represents a timing diagram for light projection and detection in embodiments of the present invention.

Detailed Description of Embodiments

Figure 1 represents a flow chart of an embodiment of the method for subtracting background light from an exposure value of a first pixel in an imaging array according to the present invention. The first pixel receives a reflection of a spot from a scenery illuminated by a periodically pulsed pattern of spots, the periodically pulsed pattern comprising in alternation an illuminated phase and a non-illuminated phase.

The method comprises accumulating **110** in the first pixel a charge in proportion to a first quantity of incident light, received in the first pixel while detecting the spot during a predetermined amount of time. The term "accumulating" is used herein to designate both an operation of an electronic circuit capable of collecting cumulative amounts of charge, and a mathematical operation carried out by digital computation means.

To remove the infuence of the ambient light from the exposure value, the method further comrpises decreasing **120** the accumulated charge in proportion to a second quantity of incident light received during the same predetermined amount of time, but in absence of a spot.

The second quantity of incident light may be obtained by receiving light the same pixel during an equal amount of time in the non-illuminated phase of the pulsed pattern. Alternatively, the second quantity of incident light may be obtained by receiving light simultaneously with the receiving of the spot, but in a different pixel of the pixel array. This variant relies on the fact that the projected pattern consists of distinct spots, and requires that the second pixel be at a sufficient distance from the first pixel so as not to be illuminated by the same spot.

Figure 2 schematically represents an embodiment of the pixel according to the present invention. The pixel is suitable for use in the method described above, and may be part of an imaging array .

The pixel comprises a capacitor **130** for storing the charge, said capacitor having a first side **130a** and a second side **130b.** The accumulating **110** comprises transferring charges to the first side **130a,** and the decreasing **120** comprises transferring charges to said second side **130b.** Subsequently, the voltage over the capacity **130** is measured, which represents the difference between the laser spot induced charges and the background charges.

The reaons for the presence of a second capacitor and a second pair of wells at the opposite side of the light sensitive element (righthand side of Figure 2, leading to "B signal") will become apparent from the following description of the range-gating method.

The inventors have found that the pixel array according to the present invention can advantageously be applied in a novel type of ranging system which aims to achieve the same power/performance characteristics with a compact, semiconductor based time-of-flight based system. Accordingly, an aspect of the present invention concerns a ranging system comprising the pixel array described above.

In this aspect of the invention, the limitations of the existing LIDAR-based systems are overcome by changing the way the time-of-flight based system operates. The total amount of light energy emitted for each time-of-flight measurement (and thus, the number of photons available for detection at the detector for each time-of-flight measurement) may be increased by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power VCSELs.

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the presently described systems benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 µs (this is one possible value, chosen here to keep the description clear and simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500 ns or more, preferably 750 ns or more, most preferably 900 ns or more). In an exemplary

system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 µs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically .

The ranging system of the present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 3 represents a flow chart of an applicable ranging method. Without loss of generality, the ranging method is described with reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular or an irregular spatial pattern of spots)

from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally, even at long ranges and with high levels of ambient light (e.g., in daylight) , a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20**, a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20**, the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from

the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 5.

The detector comprises a pixel array as described above, which is configured to perform background light subtraction as described in connection with Figures 1 and 2, with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element.

The term "picture element" as used herein may refer to an individual light-sensitive area or well of a pixel, or to an entire pixel (which may comprise multiple wells, see below). For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221, 222,** such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221, 222** of the same pixel or pixel group.

Figure 4 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99**. A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the object **99** and back to the detector **220**. It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230**, which may include a conventional clock circuit or oscillator, is configured to operate the solid-state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99**, during respective subsequent second predetermined time windows **20**. Appropriate processing means **240** are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 5 represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of the pulse sequence which is repeated periodically of Figure 3 is illustrated, which consists of a first time window **10** and a second time window **20**.

As can be seen in Figure 5a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first well **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part

representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second well **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first well **221** and the larger the proportion of the pulse that will be detected in the second well **222**.

If the leading edge of the reflected pulse arrives after the closing of the first well **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second well **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge A, B in each of the respective wells **221**, **222** for varying distances of the object **99** are shown in Figure 5b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of A and B:

- For time of flight delays up to the duration of the first time window **10**, B is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value B/(B+A) may be used,

removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.

- For time of flight delays exceeding the duration of the first time window **10**, **A** consists of daylight and noise contributions only (not illustrated) , and **C−B** is substantially proportional (after correcting for the inverse square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 5a and 5b illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 5c schematically illustrates exemplary timing characteristics of such a sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

Reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first well (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first well is increased, and the photon capacity represented by the second well is decreased. If the increase and decrease are

balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost .

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant well and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise") . To this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reSet}) and the signal voltage (V_{Signal}), for example by measuring V_{reSet} at the beginning of the frame and measuring V_{Signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals ($V_{Signal} - V_{reSet}$) in a processor .

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements .

The ranging system according to the present invention may be integrated with a triangulation-based system in accordance with WO 2015/004213 A1. If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately.

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical

arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

While various techniques known from WO 2015/004213 A1 may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly. Additionally or alternatively, background light or ambient light may be subtracted from the detected signal at pixel level. This requires two exposures, one during the arrival of the laser pulse and one in the absence of a pulse.

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However, this non-linear

compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention .

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoir or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination or 90% in case of back illumination, also known as back thinning) , or by a special design, or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning) . Preferably, the pixel design implements an anti-blooming mechanism.

European patent application no. EP15191288.8 in the name of the present applicant, which has not been published at the filing date of the present application, describes further aspects of a system and method for determining a distance to an object, which may be combined with the present disclosure.

In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of

the spot pattern is advantageously directed downwards, i.e. towards the road.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA), programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component(s) may also include other functions. The present invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view).

It should be noted that the method, the pixel, and the pixel array according to the present invention may also be used in triangulation-based systems such as the system of WO 2015/004213 A1, and in existing LIDAR systems, to improve the quality of the measurements in the presence of ambient light.

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system,

respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A method for subtracting background light from an exposure value of a first pixel in an imaging array, said first pixel receiving a reflection of a spot from a scenery illuminated by a periodically pulsed pattern of spots, said periodically pulsed pattern comprising in alternation an illuminated phase and a non-illuminated phase, the method comprising:

- accumulating (110) in said first pixel a charge in proportion to a first quantity of incident light, received in said first pixel while detecting said spot during a predetermined amount of time; and
- decreasing (120) said charge in proportion to a second quantity of incident light received during said predetermined amount of time in absence of said spot.

2. The method according to claim 1, wherein said second quantity of incident light comprises light received in said first pixel during said predetermined amount of time in said non-illuminated phase.

3. The method according to claim 1, wherein said second quantity of incident light comprises light received, during said accumulating, in a second pixel of said pixel array, said second pixel being at a sufficient distance from said first pixel so as not to be illuminated by said spot.

4. A pixel adapted for use as said first pixel in the method according to any of the preceding claims.

5. The pixel according to claim 4, comprising a capacitor (130) for storing said charge, said capacitor (130) having a first side (130a) and a second side (130b), wherein said accumulating (110) comprises transferring charges to said first side (130a), and wherein said decreasing (120) comprises transferring charges to said second side (130b).

6. An imaging array comprising a plurality of pixels according to claim 4 or claim 5.

7. A system (200) for determining a distance to an object comprising:

- a solid-state light source (210) arranged for projecting a pattern of spots of laser light towards said object in a sequence of pulses;
- a detector (220) comprising the imaging array according to claim 6, said detector (220) being configured for detecting light representing said pattern of spots as reflected by said object in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate said distance to said object as a function of exposure values generated by said pixels in response to said detected light;

wherein said pixels (220) are configured to generate said exposure values by accumulating, for each pulse of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10).

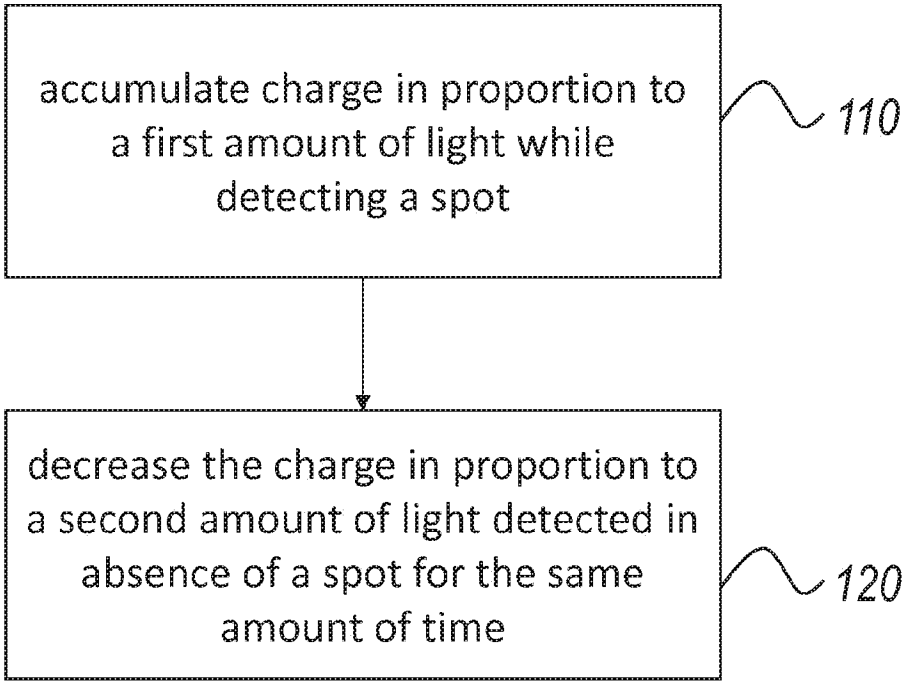

accumulate charge in proportion to a first amount of light while detecting a spot
110
decrease the charge in proportion to a second amount of light detected in absence of a spot for the same amount of time
120

Fig. 1

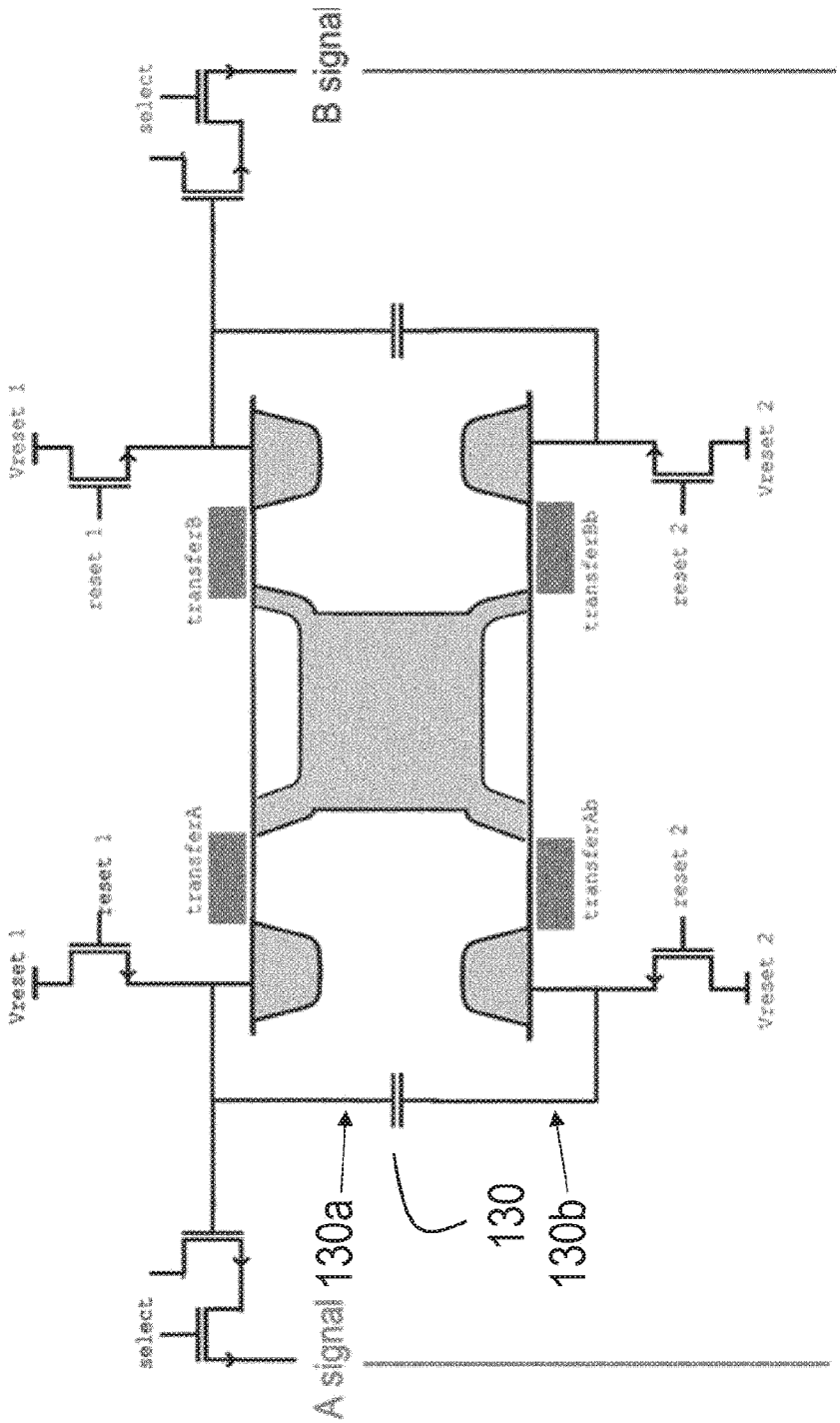

B signal
select
Vreset 1
reset 1
transferB
transferBb
reset 2
Vreset 2
transferA
transferAb
Vreset 1
treset 1
reset 2
Vreset 2
A signal
130a
130
130b
select

Fig. 2

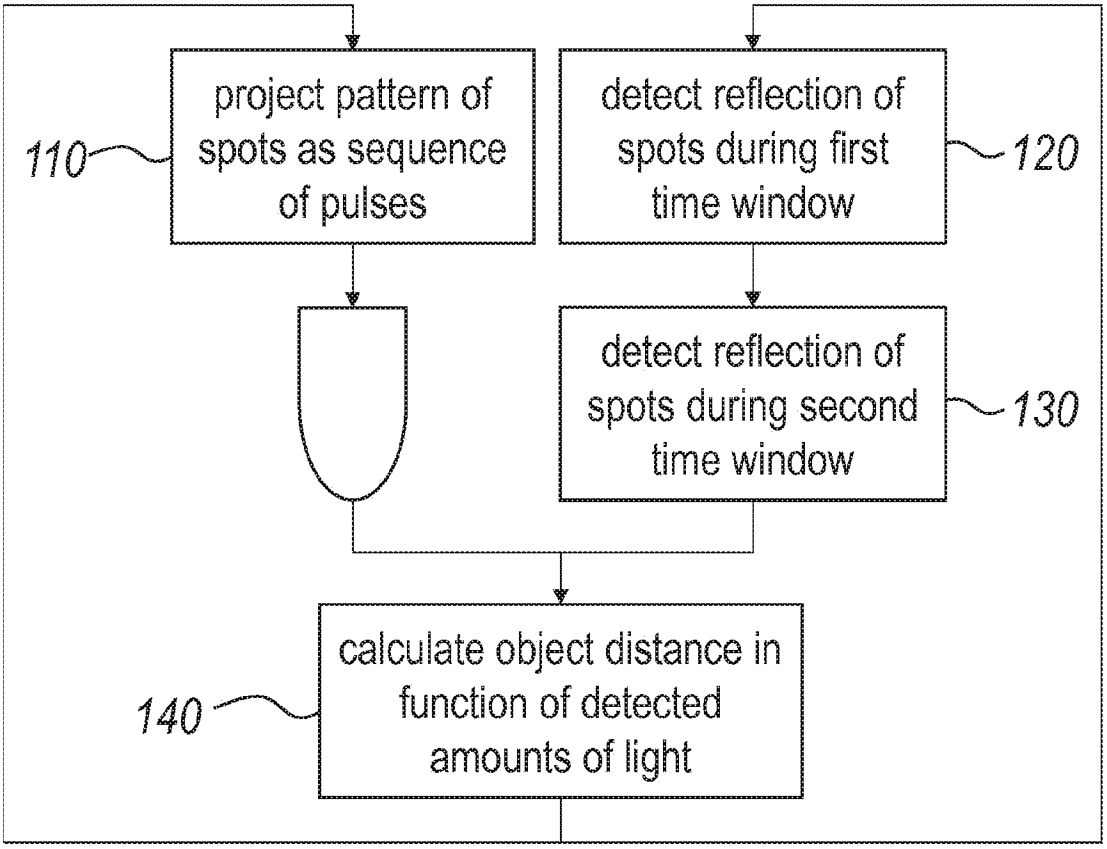

project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 3

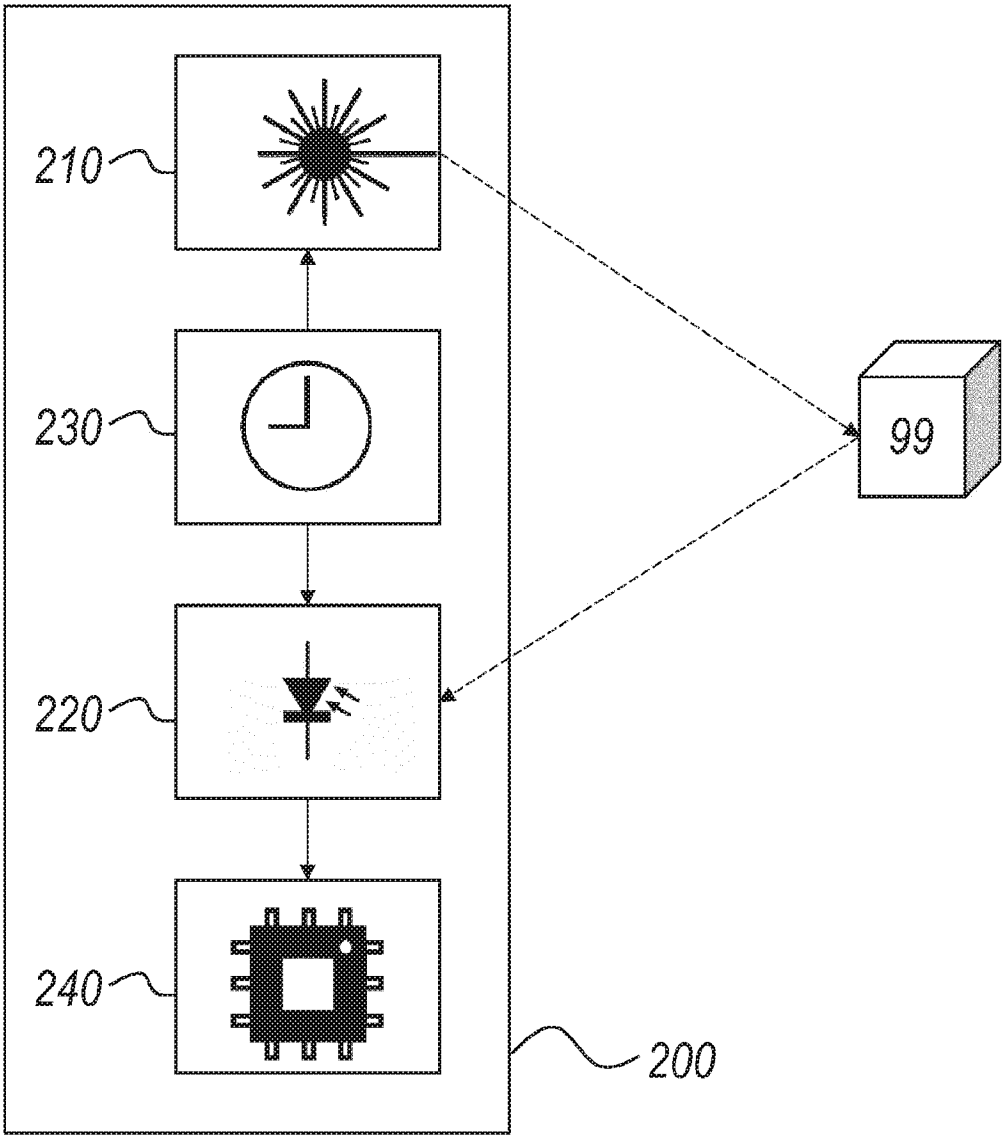


Fig. 4

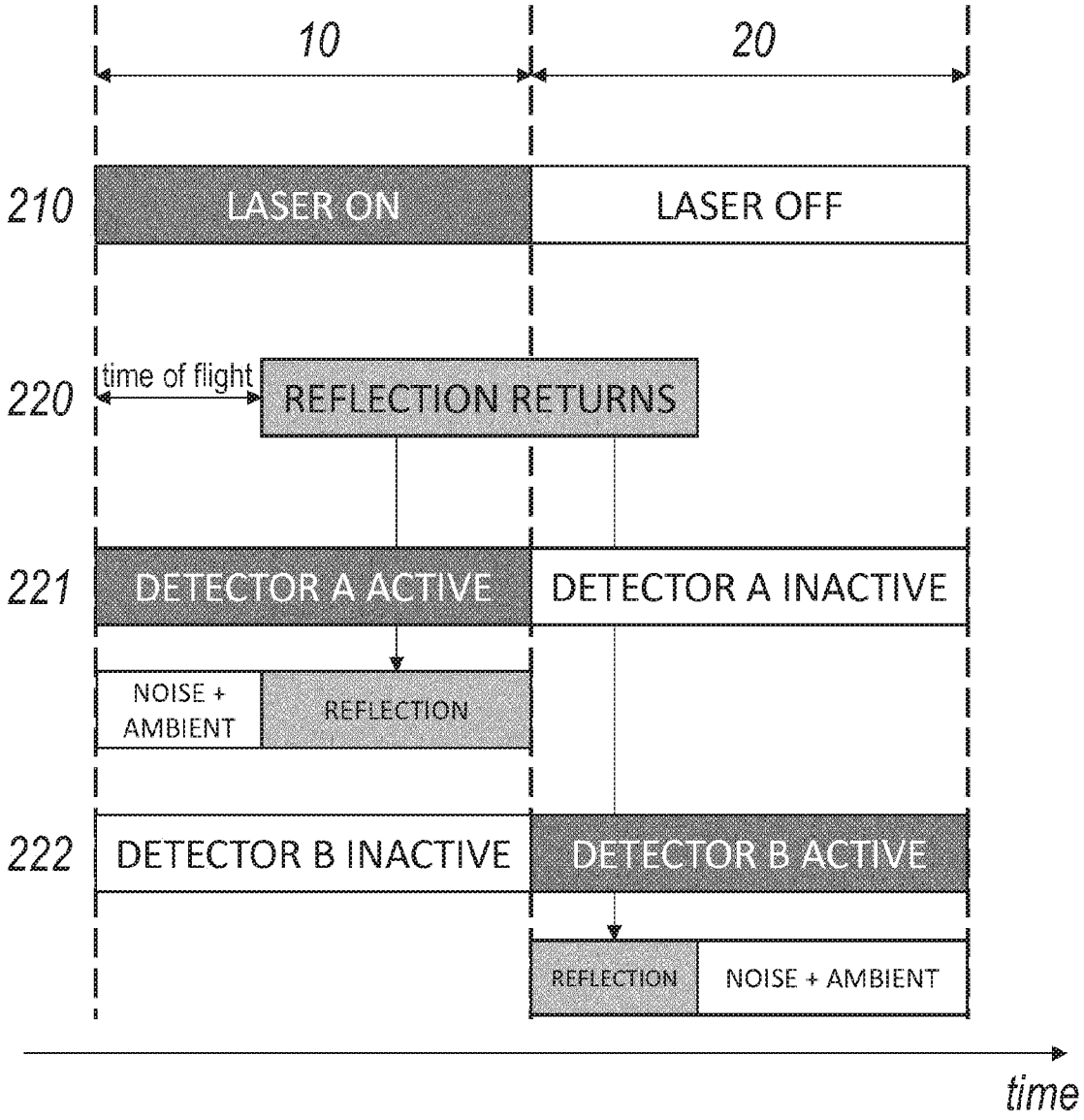

10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 5a

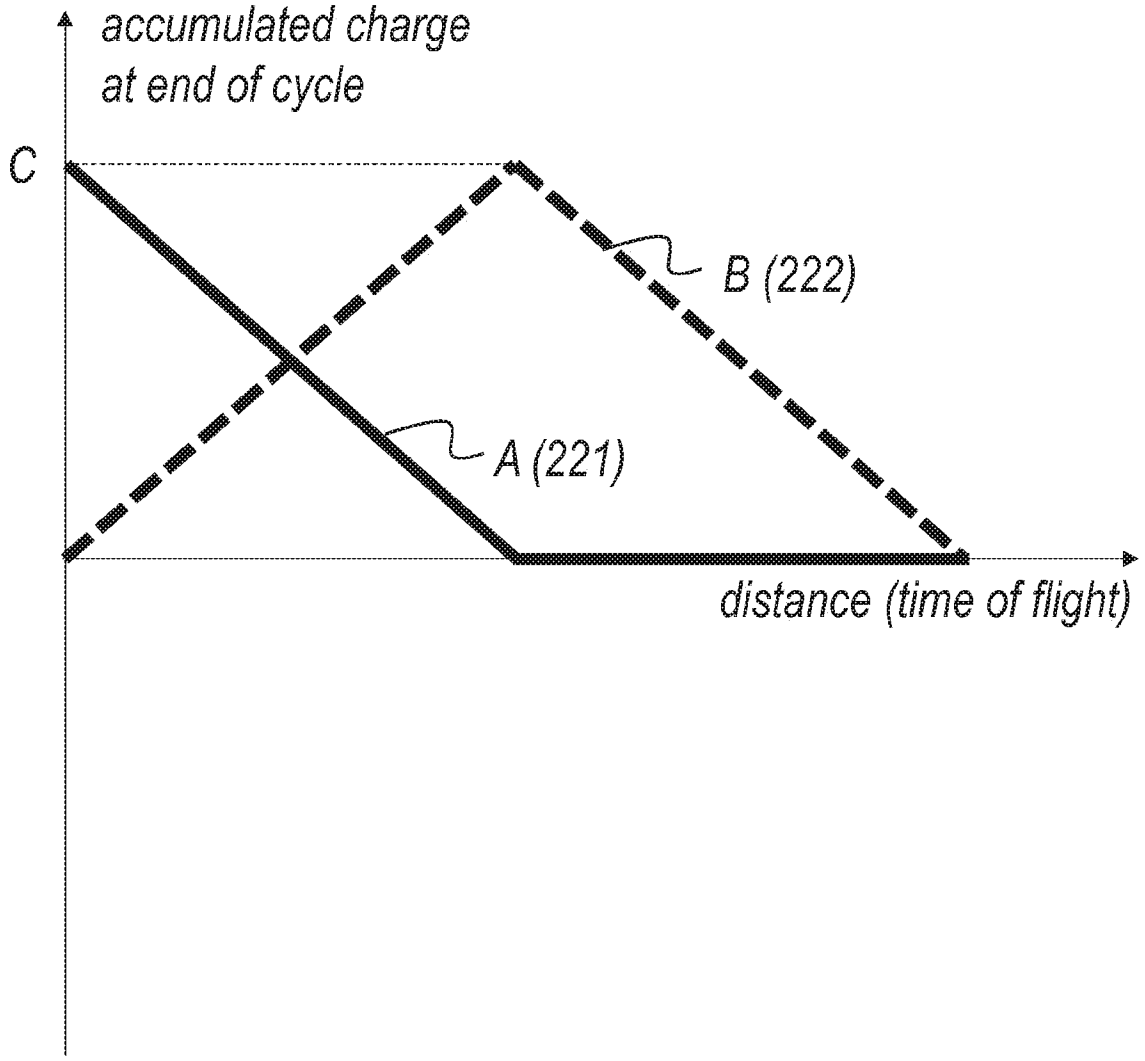

accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 5b

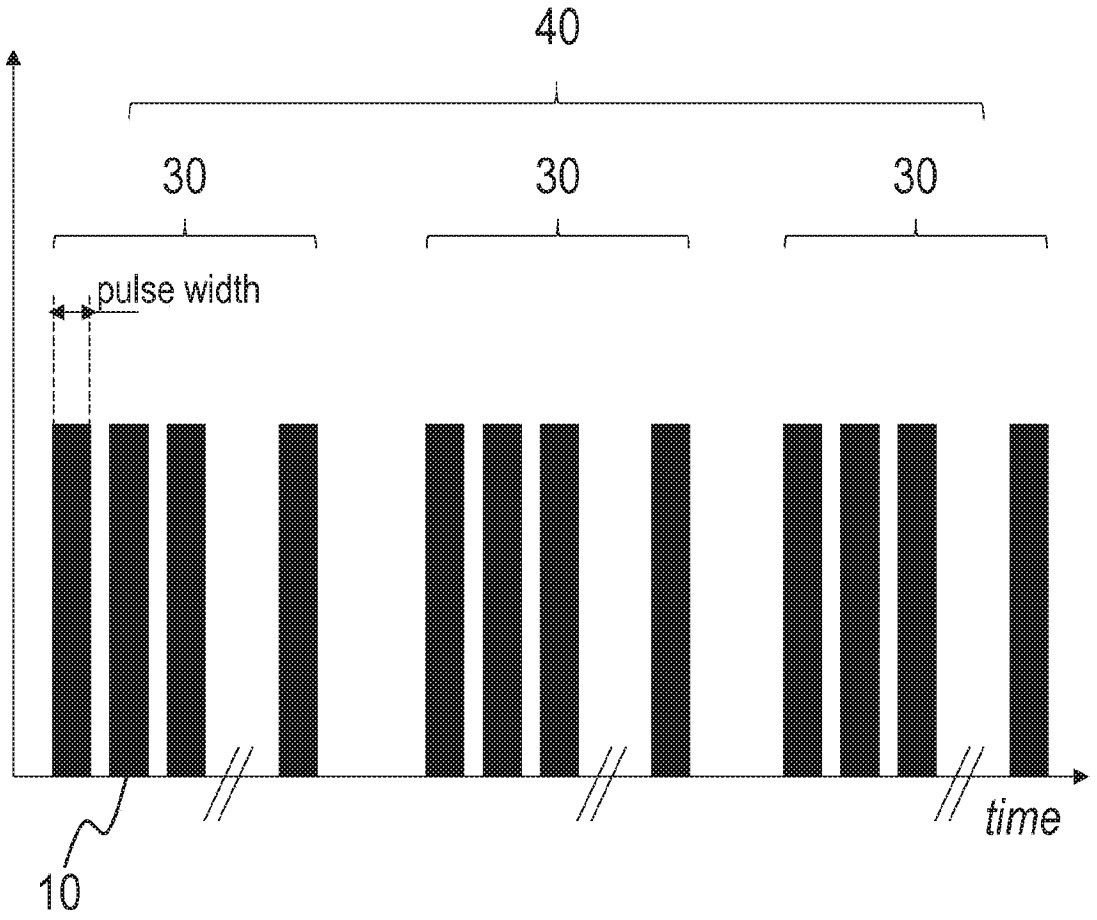


Fig. 5c

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075093

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S7/486 G01S7/487 G01S17/93
G01S7/481
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/008394 A1 (LANGE ROBERT [CH] ET AL) 15 January 2004 (2004-01-15)	1-6
Y	paragraphs [0018], [0030] - [0031], [0043], [0095], [0019], [0086], [0039], [0085], [0025], [0042], [0035], [0060]; figures 8,4	7
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13)	7
A	paragraphs [0002], [0008], [0014], [0016] - [0028], [0031], [0033], [0035], [0039]; figures 1,5b, 7b, 2	1-6

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2018	06/02/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Metz, Carsten

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075093

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004008394 A1	15-01-2004	EP 1152261 A1	07-11-2001
		JP 2003532122 A	28-10-2003
		US 2004008394 A1	15-01-2004
		WO 0184182 A1	08-11-2001
US 2013148102 A1	13-06-2013	NONE	

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2018 (12.04.2018)

W!P O | PCT

(10) International Publication Number
WO 2018/065427 A1

(51) International Patent Classification:
G01S 17/10 (2006.01) *G01S 7/481* (2006.01)
G01S 17/89 (2006.01) *G01S 7/486* (2006.01)
G01S 17/93 (2006.01)

(21) International Application Number:
PCT/EP2017/075094

(22) International Filing Date:
03 October 2017 (03.10.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16192104.4 03 October 2016 (03.10.2016) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: SYSTEM FOR DETERMINING A DISTANCE TO AN OBJECT

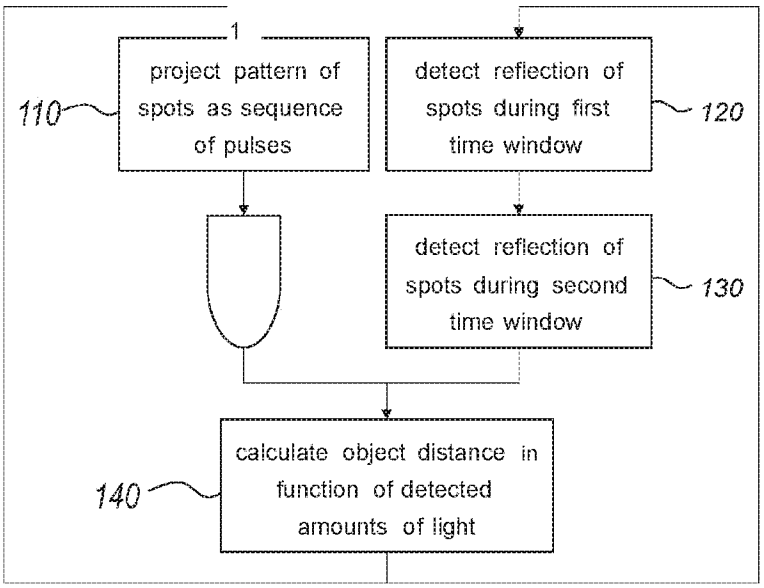


Fig. 1

(57) **Abstract:** The invention pertains to a system for determining a distance, comprising: a light source for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising picture elements, for detecting light representing the pattern as reflected by the object in synchronization with the sequence of pulses; and processing means to calculate the distance to the object as a function of exposure values generated by said picture elements. The picture elements generate the exposure values by accumulating a first amount of electrical charge representative of a first amount of light reflected during a first time window and a second electrical charge representative of a second amount of light reflected during a second time window, the second time window occurring after the first time window. The picture elements comprise at least two sets of charge storage wells, each configured as a cascade.

WO 2018/065427 A1

[Continued on next page]

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

System for determining a distance to an object

Field of the Invention

The present invention pertains to the field of systems for determining a distance to an object, in particular to time-of-flight based sensing systems to be used for the characterization of a scene or a part thereof.

Background

In the field of remote sensing technology, mainly in the usage of making high-resolution maps of the surroundings, to be used in many control and navigation applications such as but not limited to the automotive and industrial environment, gaming applications, and mapping applications, it is known to use time-of-f light based sensing to determine the distance of objects from a sensor. Time-of-flight based techniques include the use of RF modulated sources, range gated imagers, and direct time-of-f light (DToF) imagers. For the use of RF modulated sources and range gated imagers, it is necessary to illuminate the entire scene of interest with a modulated or pulsed source. Direct time-of-f light systems, such as most LIDARs, mechanically scan the area of interest with a pulsed beam, the reflection of which is sensed with a pulse detector.

In order to be able to correlate an emitted RF modulated signal with the detected reflected signal, the emitted signal must meet a number of constraints. In practice, these constraints turn out to make the RF modulated systems highly impractical for use in vehicular systems: the attainable range of detection is very limited for signal intensities that are within conventional safety limits and within the power budget of regular vehicles.

A direct TOF (DToF) imager, as used in most LIDAR systems, comprises a powerful pulsed laser (operating in a nanosecond pulse regime) , a mechanical scanning system to acquire from the ID point

measurement a 3D map, and a pulse detector. Systems of this type are presently available from vendors including Velodyne Lidar of Morgan Hill, California. The Velodyne HDL-64E, as an example of state-of-the-art systems, uses 64 high-power lasers and 64 detectors (avalanche diodes) in a mechanically rotating structure at 5 to 15 rotations per second. The optical power required by these DToF LIDAR systems is too high to be obtained with semiconductor lasers, whose power is in the range of five to six orders of magnitude lower. In addition, the use of mechanically rotating elements for scanning purposes limits the prospects for miniaturization, reliability, and cost reduction of this type of system.

United States Patent application publication no. 2015/0063387 in the name of Trilumina discloses a VCSEL delivering a total energy of 50 mW in a pulse having a pulse width of 20 ns. The commercially available Optek OPV310 VCSEL delivers a total energy of 60 mW in a pulse having a duration of 10 ns and it can be estimated by extrapolation to have a maximum optical output power of 100 mW. This value is only realized under very stringent operating conditions, meaning optimal duty cycle and short pulse width so as to avoid instability due to thermal problems. Both the Trilumina disclosure and the Optek system illustrate that continuous-wave VCSEL systems are reaching their physical limits with respect to optical peak power output, due to thermal constraints inherently linked to the VCSEL design. At these pulse energy levels, and using ns pulses as presently used in DToF applications, the mere number of photons that can be expected to be usefully reflected by an object at a distance of 120 m is so low that it defeats detection by means of conventional semiconductor sensors such as CMOS or CCD or SPAD array. Thus, increasing the VCSEL power outputs by 5 or 6 orders of magnitude, as would be required to extend the range of the known DToF systems, is physically impossible.

Even the use of avalanche diodes (AD or SPAD), which are theoretically sufficiently sensitive to capture the few returning

photons, cannot be usefully deployed in the known LIDAR system architectures. A solid state implementation of an array of SPADs must be read out serially. A high number of SPADs is required to achieve the desired accuracy. The serial read-out constraints of the solid state implementation limit the bandwidth of the system turning it inappropriate for the desired accuracy. For accuracies such as that of the Velodyne system (0.02 m to 0.04 m, independent of distance), the required read-out data rate exceeds the practically achievable bandwidth in case of today's IC implementation. For operation at 120 m, a SPAD array of 500x500 pixels is required, which, in an IC-based implementation, must be read-out serially. For the same precision as the aforementioned Velodyne system, it would require 1000 pulses per millisecond and hence 1000 frames per millisecond, translating into a readout rate of 250 Gigapixels per second. This is believed to be technically unfeasible in the context of current SPAD IC technology.

The paper by Neil E. Newman et al., "High Peak Power VCSELs in Short Range LIDAR Applications", *Journal of Undergraduate Research in Physics*, 2013, http://www.jurp.org/2 013/12 017EXR.pdf, describes a VCSEL-based LIDAR application. The paper states that the maximum output power of the described prototype system was not great enough to do wide-field LIDAR at a range greater than 0.75 m. With a relatively focused beam (0.02 m spot size at 1 m distance), the authors were able to range a target object at a distance of up to 1 m.

The above examples clearly indicate that the optical power emitted by present semiconductor lasers cannot meet the power requirements necessary for operations in the known LIDAR systems to be of practical use in automotive applications (e.g. for ranges up to 120 m).

United States patent no. 7,544,945 in the name of Avago Technologies General IP (Singapore) Pte. Ltd., discloses vehicle-based LIDAR systems and methods using multiple lasers to provide more compact and cost-effective LIDAR functionality. Each laser in

an array of lasers can be sequentially activated so that a corresponding optical element mounted with respect to the array of lasers produces respective interrogation beams in substantially different directions. Light from these beams is reflected by objects in a vehicle's environment, and detected so as to provide information about the objects to vehicle operators and/or passengers. The patent provides a solid state projector in which the individual lasers are consecutively activated in order to replace the known mechanical scanning in the known DToF LIDAR systems.

A high-accuracy medium-range surround sensing system for vehicles that does not use time-of-flight detection, is known from international patent application publication WO 2015/004213 A1 in the name of the present applicant. In that publication, the localization of objects is based on the projection of pulsed radiation spots and the analysis of the displacement of detected spots with reference to predetermined reference spot positions. More in particular, the system of the cited publication uses triangulation . However, the accuracy that can be achieved correlates with the triangulation base, which limits the further miniaturization that can be achieved.

US patent application publication no. US 2012/0038903 A1 discloses methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal.

European patent application publication no. EP 2 322 953 A1 discloses a distance image sensor capable of enlarging the distance measurement range without reducing the distance resolution. A radiation source provides first to fifth pulse trains which are irradiated to the object as radiation pulses in the first to fifth frames arranged in order on a time axis. In each of the frames, imaging times are prescribed at points of predetermined time from the start point of each frame, also the pulses are shifted respectively by shift amounts different from each other from the start point of the first to fifth frames. A pixel array generates element image signals each of which has distance information of an object in distance ranges different from each other using imaging windows A and B in each of five frames. A processing unit generates an image signal by combining the element image signals. Since five times-of-flight measurement are used, the width of the radiation pulse does not have to be increased to obtain distance information of the object in a wide distance range, and the distance resolution is not reduced.

European patent application publication no. EP 2 290 402 A1 discloses a range image sensor which is provided on a semiconductor substrate with an imaging region composed of a plurality of two-dimensionally arranged units, thereby obtaining a range image on the basis of charge quantities output from the units. One of the units is provided with a charge generating region (region outside a transfer electrode) where charges are generated in response to incident light, at least two semiconductor regions which are arranged spatially apart to collect charges from the charge generating region, and a transfer electrode which is installed at each periphery of the semiconductor region, given a charge transfer signal different in phase, and surrounding the semiconductor region.

The article by Shoji Kawahito et al., "A CMOS Time-of-Flight Range Image Sensor With Gates-on-Field-Oxide Structure", *IEEE Sensors Journal*, Vol. 7, no. 12, p. 1578-1586, discloses a type of CMOS time-of-flight (TOS) range image sensor using single-layer gates

on field oxide structure for photo conversion and charge transfer. This structure allows the realization of a dense TOF range imaging array with 15 x 15 μm^2 pixels in a standard CMOS process. Only an additional process step to create an n-type buried layer which is necessary for high-speed charge transfer is added to the fabrication process. The sensor operates based on time-delay dependent modulation of photocharge induced by back reflected infrared light pulses from an active illumination light source. To reduce the influence of background light, a small duty cycle light pulse is used and charge draining structures are included in the pixel. The TOF sensor chip fabricated measures a range resolution of 2.35 cm at 30 frames per second an improvement to 0.74 cm at three frames per second with a pulse width of 100 ns.

European patent application no. EP15191288.8 in the name of the present applicant, which has not been published at the filing date of the present application, describes some aspects of a system and method for determining a distance to an object.

There is a continuing need to obtain extreme miniaturization and/or longer-range in complex vehicular surround sensing applications, such as ADAS (autonomous driving assistance system) applications and autonomous driving applications, and this at a reasonable cost and in a compact, semiconductor-integrated form factor.

Summary of the Invention

It is an objective of embodiments of the present invention to provide a further miniaturized and longer-range alternative for displacement-based vehicular surround sensing systems. Furthermore, it is an objective of embodiments of the present invention to provide a full solid-state alternative for the known LIDAR systems.

According to an aspect of the present invention, there is provided a system for determining a distance to an object comprising: a

solid-state light source arranged for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising a plurality of picture elements, the detector being configured for detecting light representing the pattern of discrete spots as reflected by the object in synchronization with the sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by the picture elements in response to the detected light; wherein the picture elements are configured to generate the exposure values by accumulating, for all of the pulses of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window; wherein each of the plurality of picture elements comprises at least two sets of charge storage wells, the detecting of said first amount of light and the detecting of the second amount of light occurring at respective ones of the at least two sets of charge storage wells; and wherein each of the sets of charge storage wells is configured as a cascade.

The term "charge storage well" designates a storage provided in the semiconductor substrate, e.g. a capacitor, that stores electrical charges generated by the conversion of photons impinging on the pixel.

The present invention relies on the same physical principles as direct time-of-f light based ranging systems, viz. the fact that light always takes a certain amount of time to travel a given distance. However, the present invention uses range gating to determine the distance travelled by a light pulse that has been transmitted and subsequently reflected by a target object. The present invention is *inter alia* based on the insight of the inventors that by combining range gating, an at least partially simultaneous spot pattern projection (based on a novel

illumination scheme) and a low-power semiconductor light source, a substantially miniaturized, full solid state and energy-efficient long-range distance detection method can be obtained. The term "pattern" as used herein refers to a spatial distribution of simultaneously projected spots. In order to determine the position of the detected spot reflection in three-dimensional space, it is necessary to combine the distance information obtained from the ranging step with angular information to fix the remaining two spatial coordinates. A camera comprising a pixel array and suitably arranged optics can be used to provide the additional angular information, by identifying the pixel in which the reflection is detected.

Embodiments of the present invention are based on the further insight of the inventors that in order to be able to use spot patterns generated by solid-state light sources in a LIDAR system at the desired ranges, a way to circumvent the optical power limitations is needed. The inventors have found that by prolonging the pulse duration and by integrating the reflected energy of multiple VCSEL-generated light pulses within at least two sets of semiconductor sensor wells, followed by a single read-out of the integrated charge, a solid-state LIDAR system can be obtained with a significantly greater operating range than is currently possible with solid-state implementations. Hereinafter, the term "storage" will be used to designate the well or the pixel in which charge is accumulated in response to the detection of photons.

It is an advantage of the present invention that the solid-state light source and the solid-state sensor (such as a CMOS sensor, a CCD sensor, SPAD array or the like) may be integrated on the same semiconductor substrate. The solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern.

Moreover, by assessing the reflected light energy detected in two consecutive time windows, and normalizing for the total accumulated charge in the two consecutive windows, the impact of

varying reflectivity of the object under study and the contribution of ambient light can adequately be accounted for in the distance calculation algorithm.

The transmission and detection of the sequence of pulses may be repeated periodically.

In the picture elements, charge representative of the impinging light is accumulated at well level. An advantage of charge accumulation at the well level is that read-out noise is minimized, leading to a better signal-to-noise ratio.

It is an advantage of the cascade-based arrangement that the total amount of charge to be accumulated is distributed over multiple wells, which allows for a greater total charge storage capacity while maintaining an accurate reading of the total charge level.

The increase in the total charge storage capacity is of particular importance at the end of the operating range where large number of photons - and hence, large amounts of charge - are received by the system; this is the case at short range (because the intensity of the light in function of distance follows an inverse-square law) or when surfaces with an unusually high reflectance are present in the field of view of the sensor. In conditions where a single well would tend to be saturated, a cascade-based arrangement allows the excess charge to be stored in a subsequent storage well, without losing the possibility of accurately determining the total amount of charge.

The total number of capacities in the cascade can be selected in function of the desired operating range and accuracy, and the general requirement to keep the Poisson noise as low as possible. The latter condition is inherently linked to the application of range gating, where Poisson noise is detrimental to the accuracy of the distance determination. A low level of Poisson noise allows a continuous photon-charge response, regardless of whether the charge is stored in one or more capacities of the cascade.

In an embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a serially arranged cascade. In another embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a parallelly arranged cascade.

It is an advantage of these embodiments that they provide easy to implement arrangements to obtain the desired cascade effect of the storage wells.

In an embodiment of the system according to the present invention, the first predetermined time window and the second predetermined time window are of substantially equal duration and occur back-to-back, and a total storage capacity of the set of charge storage wells configured to detect the first amount of light is larger than a total storage capacity of the set of charge storage wells configured to detect the second amount of light.

It is an advantage of this embodiment that it helps to avoid saturation of the charge storage elements due to an overload of reflected photons. This problem is most prominent at nearby distances. At short ranges, the total number of reflected photons will be higher, due to the inverse square law, while most of the reflected signal will arrive within the first time window and thus be stored in the corresponding set of charge storage wells. Hence, it is useful to dimension the set of charge storage wells corresponding to the first time window so as to be able to deal with a larger amount of charge.

According to an aspect of the present invention, there is provided a vehicle, comprising: a system as described above arranged to operatively cover at least a part of an area surrounding said vehicle .

The system according to the present invention is particularly advantageous in a vehicle with ADAS or autonomous driving control

unit such as but not limited to ECU (electrical control unit) . The vehicle may further comprise a vehicle control unit, adapted for receiving measurement information from the system and for using the information for ADAS control or autonomous driving decision taking. The part of an area surrounding the vehicle may include a road surface ahead of, beside, or behind the vehicle. Accordingly, the system may provide road profile information of the surface ahead of the car, to be used for active suspension or semi-active suspension .

According to an aspect of the present invention, there is provided a camera, the camera comprising a system as described above, whereby the system is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

The technical effects and advantages of embodiments of the camera and the vehicle according to the present invention correspond, *mutatis mutandis*, to those of the corresponding embodiments of the system according to the present invention.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings , in which:

Figure 1 represents a flow chart of an embodiment of the method according to the present invention;

Figure 2 schematically represents an embodiment of the system according to the present invention;

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention;

Figure 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom) ;

Figure 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel;

Figure 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention;

Figure 7 schematically illustrates an embodiment of a pixel architecture with two charge wells (bins) with each a separate transfer gate for use in embodiments of the present invention;

Figure 8 schematically illustrates a first exemplary optical arrangement for use in embodiments of the present invention;

Figure 9 schematically illustrates a second exemplary optical arrangement for use in embodiments of the present invention;

Figure 10 schematically illustrates a third exemplary optical arrangement for use in embodiments of the present invention;

Figure 11 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention;

Figure 12 schematically illustrates a fifth exemplary optical arrangement for use in embodiments of the present invention; and

Figure 13 schematically illustrates a sixth exemplary optical arrangement .

Detailed Description of Embodiments

The surround sensing systems of the type disclosed in international patent application publication WO 2015/004213 A1, in

the name of the present applicant, have the advantage of observing an extensive scene while illuminating that scene simultaneously or partially simultaneously only in a number of discrete and well-defined spots, in particular a predefined spot pattern. By using VCSEL lasers with an outstanding bundle quality and a very narrow output spectrum, it is possible to obtain a detection range with a limited amount of output power, even in the presence of daylight. The actual ranging performed in the system of WO 2015/004213 A1 relies on displacement detection, in particular triangulation, which was understood to be the only method practically available in the context of the long (quasi-stationary) pulse durations that were necessary in view of the power budget. To date, it had not been possible to achieve the same power/performance characteristics with a compact, semiconductor based time-of-flight based system.

The present invention overcomes this limitation by radically changing the way the time-of-flight based system operates. The invention increases the total amount of light energy emitted for each time-of-flight measurement (and thus, the number of photons available for detection at the detector for each time-of-flight measurement) by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power VCSELs.

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the systems according to the present invention benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 µs (this is one possible value, chosen here to keep the description clear and simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500

ns or more, preferably 750 ns or more, most preferably 900 ns or more) . In an exemplary system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 µs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically.

The present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 1 represents a flow chart of an embodiment of the method according to the present invention. Without loss of generality, the ranging method is described with reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular

or an irregular spatial pattern of spots) from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally, even at long ranges and with high levels of ambient light (e.g., in daylight) , a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20**, a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20**, the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from

the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 3.

The detector comprises a plurality of picture elements, i.e. it consists of a picture element array with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element. The term "picture element" as used herein may refer to an individual light-sensitive area or well of a pixel, or to an entire pixel (which may comprise multiple wells, see below). For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221, 222,** such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221, 222** of the same pixel or pixel group.

Figure 2 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99.** A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the object **99** and back to the detector **220.** It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230,** which may include a conventional clock circuit or oscillator, is configured to operate the solid-

state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99**, during respective subsequent second predetermined time windows **20**. Appropriate processing means **240** are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of the pulse sequence which is repeated periodically of Figure 1 is illustrated, which consists of a first time window **10** and a second time window **20**.

As can be seen in Figure 3a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first set of wells **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second set of wells **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first set of wells **221** and the larger the proportion of the pulse that will be detected in the second set of wells **222**.

If the leading edge of the reflected pulse arrives after the closing of the first set of wells **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second set of wells **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge A, B in each of the respective sets of wells **221**, **222** for varying distances of the object **99** is shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of A and B:

- For time of flight delays up to the duration of the first time window **10**, B is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value B/(B+A) may be used,

removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.

- For time of flight delays exceeding the duration of the first time window **10**, **A** consists of daylight and noise contributions only (not illustrated) , and **C–B** is substantially proportional (after correcting for the inverse square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 3a and 3b illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 3c schematically illustrates exemplary timing characteristics of such a sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

The sets of wells **221**, **222** each consist of a cascade of charge storage wells. A judicious design of the cascades ensures a smooth transition between the capacities to assure extremely high accuracy levels.

The storage capacities are preferably designed around each pixel, to ensure that there is sufficient space for the cascade while optimizing the charge transfer from the area where the impinging photons are converted to electrical charges .

The capacities are preferably dimensioned so as to provide an accurate read-out of the lowest level of light that must be detectable (e.g. 1000 photons) . It is advantageous to design the cascade in such a way that the maximum amount of charge n_{max} that can be stored in any given stage of the cascade equals the minimum amount of charge $\mathbf{n_m i_n}$ that can be reliably read out from the next stage .

Reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first set of wells (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first set of wells is increased, and the photon capacity represented by the second set of wells is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost.

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant set of wells and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise") . To

this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reset}) and the signal voltage (V_{signal}), for example by measuring V_{reset} at the beginning of the frame and measuring V_{signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals ($V_{signal} - V_{reset}$) in a processor .

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements .

The ranging system according to the present invention may be integrated with a triangulation-based system in accordance with WO 2015/004213 A1. If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately .

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal

stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

While various techniques known from WO 2015/004213 A1 may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly. Additionally or alternatively, background light or ambient light may be subtracted from the detected signal at pixel level. This requires two exposures, one during the arrival of the laser pulse and one in the absence of a pulse.

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However, this non-linear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoir or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination

or 90% in case of back illumination, also known as back thinning), or by a special design such as shown in Figure 6 (see below), or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning). Preferably, the pixel design implements an anti-blooming mechanism.

Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both Vgate1 and Vgate2 gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage Vgate2 is set low. The electrons reflow towards capacitor 7, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on Vgate1. The electrons reflow towards the floating diffusion 2.

Figure 7 represents a possible dual-well or dual-bin implementation of an envisaged pixel to be used in CMOS technology. The impinging signal is distributed over two charge storages. Each reservoir has a separate transfer gate controlled by an external pulse which is synchronized with the pulse of the laser sources.

The charge storage elements shown in the designs of Figure 6 and Figure 7 may be replicated to obtain a cascade of charge storage wells as required by the present invention.

Figures 8-10 illustrate cameras that may be used in embodiments of the invention, where the light radiation source emits monochromatic light and the at least one detector is equipped with

a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter) . In particular, in Figure 9, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

The correction of the angle of incidence is of particular importance in embodiments of the present invention where the entire space around a vehicle is to be monitored with a limited number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad. Figure 8 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length f, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds

to a cone angle of 9.3° (half cone angle) . The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102**, would thus be 9.3°.

As illustrated in Figure 9, the preferred design consists of a tandem of two lenses **1130**, **1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150**, a spectral filter **1160** and a CMOS detector **102**. Since the center 0 of the first lens **1130** is in the focus of the second lens **1140**, every ray that crosses 0 will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130**. Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140**. The light rays that are emitted from the spot S **1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140**. The central axis of this light cone crosses the point 0 and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens **1150**. In this way all the imaging rays of the spot S **1110** are bent in a direction nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the aperture can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150**. In this way the

sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

For the first and second lenses **1130**, **1140**, commercially available lenses may be used. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 μm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the aperture.

Figure 10 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous embodiment, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250.** The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones) . A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102**, to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240**, **1250**,

1260, 1270, 102 has its own function to meet the requirements imposed by the present invention.

As the minimal angle of a cone generated by a lens of diameter d is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter d = 8.5 µm and λ = 850 nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

In the arrangements of Figures 8-10, the characteristics of the optics will result in a non-planar focal plane. To compensate this effect, the picture elements of the detector may be arranged on a substrate having a curvature that follows the focal plane of the optics. As a result, the reflected and filtered spots will be in focus, regardless of where they reach the detector. The desired curvature of the substrate of the detector can be obtained by using flex-chip technology, or by composing the substrate by combining differently oriented tiles. This solution is schematically illustrated in Figure 11, which shows telecentric optics **1330**, followed by a narrow band-pass filter **1360**, and a curved pixel layer **102**, the curvature of which is adapted to follow the shape of the focal plane of the telecentric optics **1330**.

When it is not possible (or not desirable) to arrange the optics in such a way as to ensure that light rays following different paths all pass through the narrow bandpass filter under the same (perpendicular) angle, the problem of having different filter characteristics with different angles of incidence may be resolved at the source. In particular, the VCSEL array may be configured such that different spots have different respective wavelengths. This configuration may be obtained by using a tiled laser array, or by providing means for modulating the wavelength of individual VCSELs in the VCSEL array. This solution is schematically illustrated in Figure 12, which shows a narrow band-pass filter **1460** arranged before the optics **1430** and the sensor array **102**. For clarity purposes and without loss of generality, two different

angles of incidence with different respective wavelengths (λ_1, λ_2) have been indicated on the Figure. The different wavelengths (λ_1, λ_2) of the light sources are chosen to correspond to the maximum of the passband of the narrow bandpass filter under their respective angles of incidence.

Figure 13 illustrates an alternative optical arrangement, comprising a dome **1510** (e.g., a bent glass plate) with the narrow bandpass filter **1520** disposed on its inside (as illustrated) or outside (not illustrated) . The advantage of disposing the filter **1520** on the inside of the dome **1510,** is that the dome **1510** protects the filter **1520** from outside forces. The dome **1510** and the filter **1520** optically cooperate to ensure that incident light passes through the filter **1520** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1530** are provided between the dome-filter assembly and the sensor **102,** which may be a CMOS or a CCD sensor or SPAD array. The fish-eye optics **1530** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor.

Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realized over a spatial angle of m x 1 rad in height and n x 1 rad in width.

In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop. The different VCSELs within the array can be controlled individually for intensity, varying the intensity of the individual VCSELs in the pattern while projected simultaneously.

In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageou sly directed downwards, i.e. towards the road.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA) , programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component (s) may also include other functions. The present invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view).

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (200) for determining a distance to an object comprising :

- a solid-state light source (210) arranged for projecting a pattern of discrete spots of laser light towards said object in a sequence of pulses;
- a detector (220) comprising a plurality of picture elements, said detector (220) being configured for detecting light representing said pattern of discrete spots as reflected by said object in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate said distance to said object as a function of exposure values generated by said picture elements in response to said detected light;

wherein said picture elements (220) are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10);

wherein each of said plurality of picture elements comprises at least two sets of charge storage wells, each set of charge storage wells being configured as a cascade so as to form a greater total charge storage capacity, said detecting of said first amount of light and said detecting of said second amount of light occurring at respective ones of said cascades.

2. The system according to claim 1, wherein each of said sets of charge storage wells is configured as a serially arranged cascade.

3. The system according to claim 1, wherein each of said sets of charge storage wells is configured as a parallelly arranged cascade .

4. The system according to any of the preceding claims, wherein said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and wherein a total storage capacity of said set of charge storage wells configured to detect said first amount of light is larger than a total storage capacity of said set of charge storage wells configured to detect said second amount of light.

5. A vehicle comprising a system (100) according to any of the previous claims arranged to operatively cover at least a part of an area surrounding said vehicle.

6. A camera, the camera comprising a system (100) according to any of claims 1 to 4, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

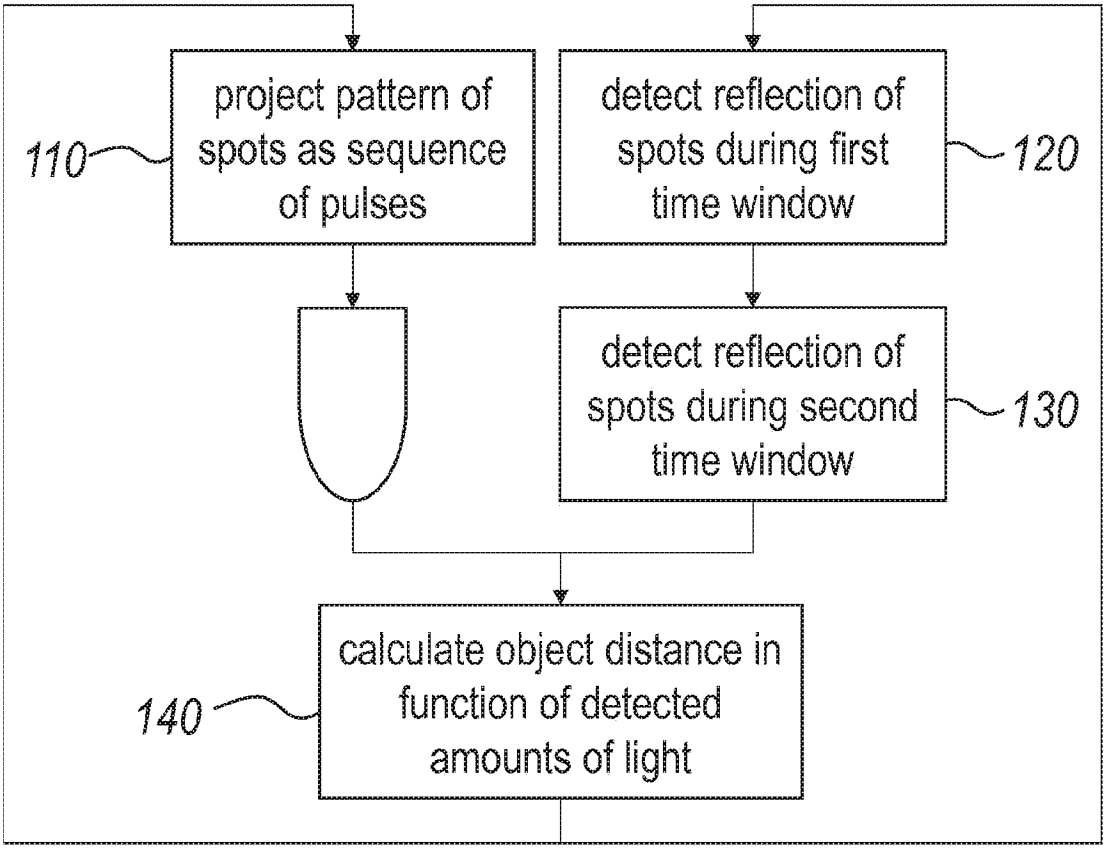

project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 1

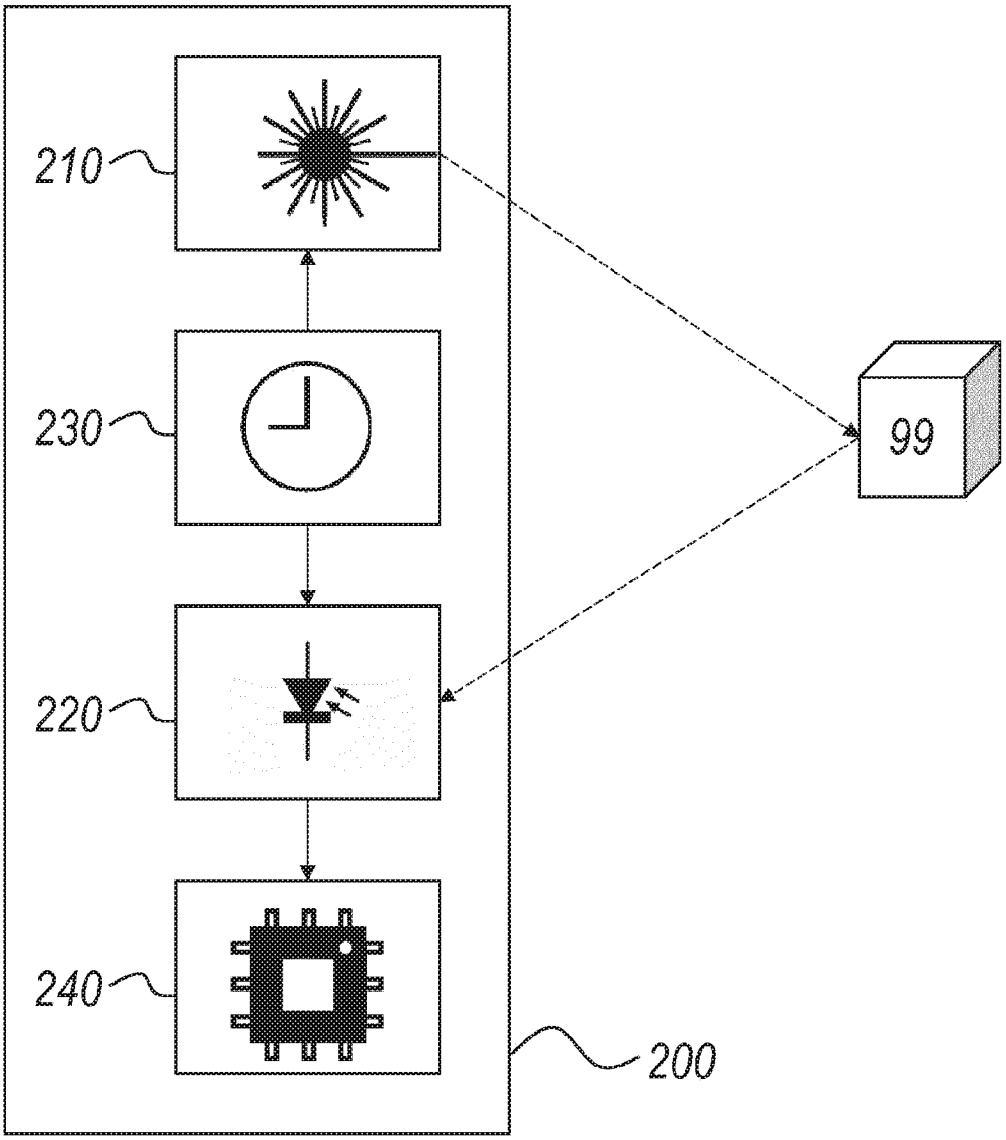


Fig. 2

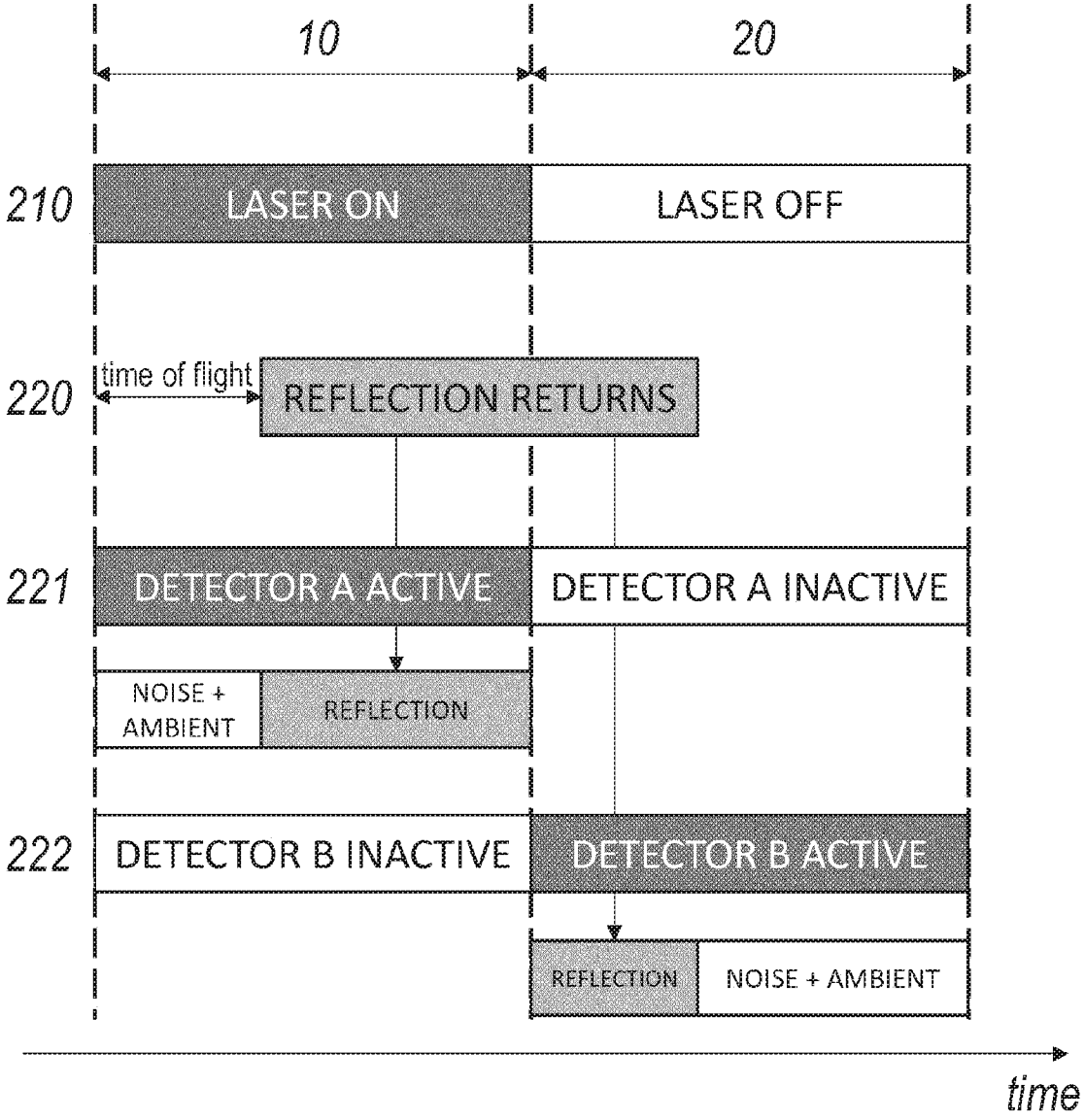

10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 3a

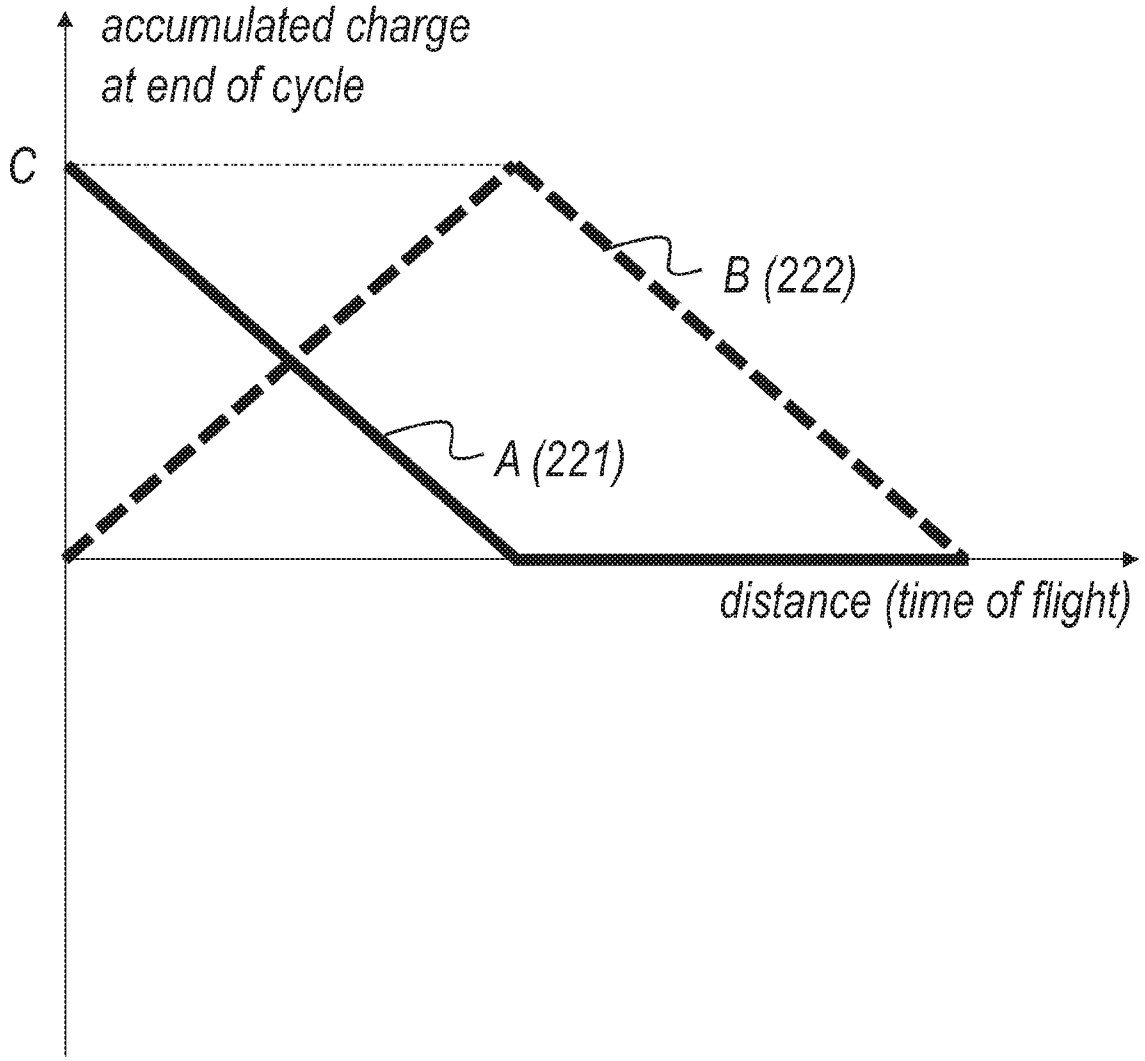

accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3b

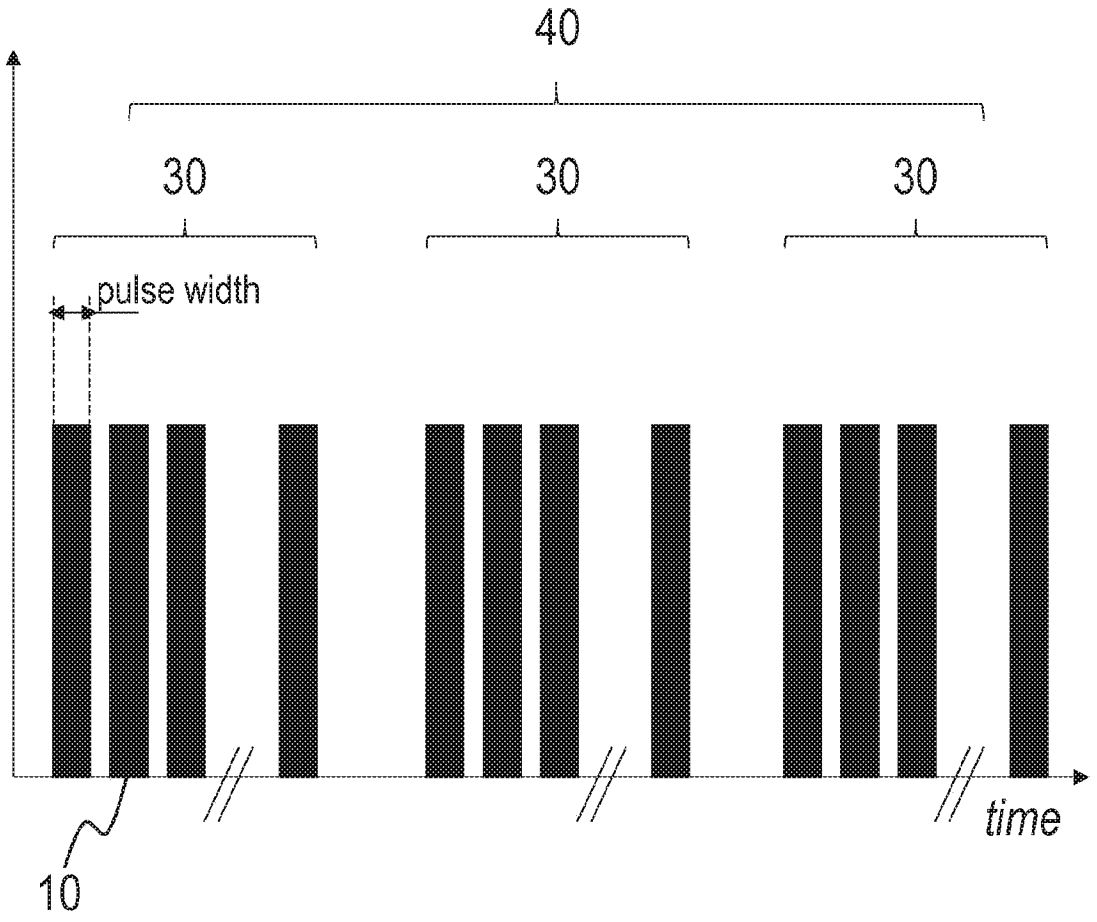


Fig. 3c

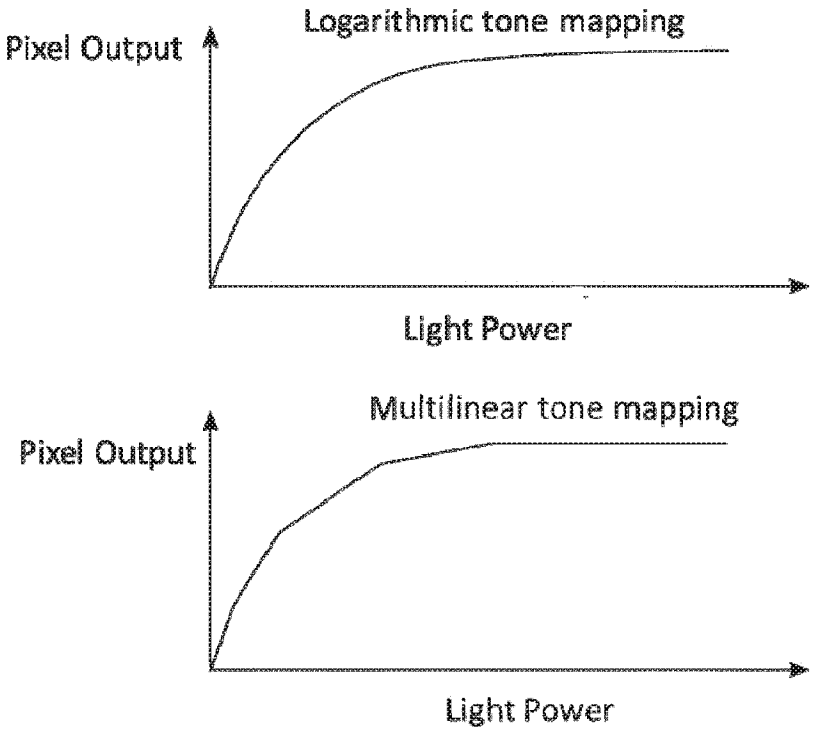

Logarithmic tone mapping
Pixel Output
Light Power
Multilinear tone mapping
Pixel Output
Light Power

Fig. 4

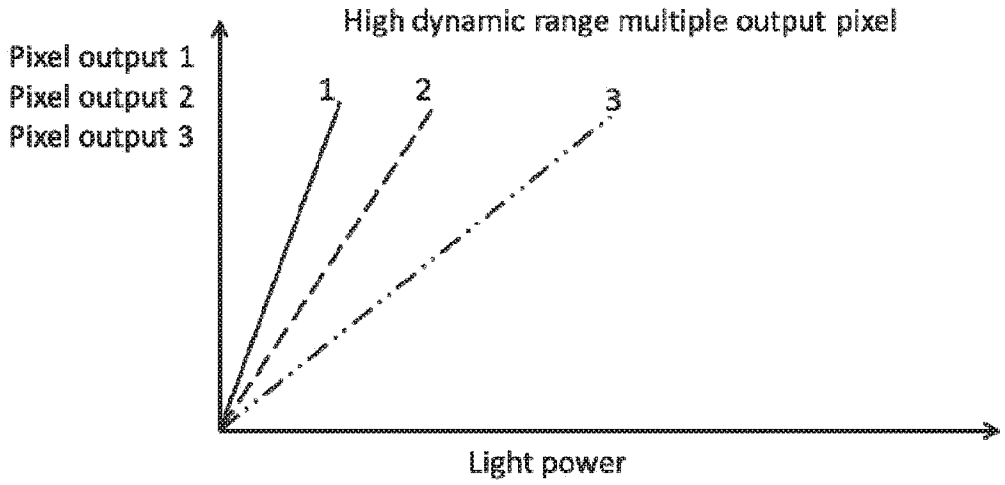

High dynamic range multiple output pixel
Pixel output 1
Pixel output 2
Pixel output 3
1
2
3
Light power

Fig. 5

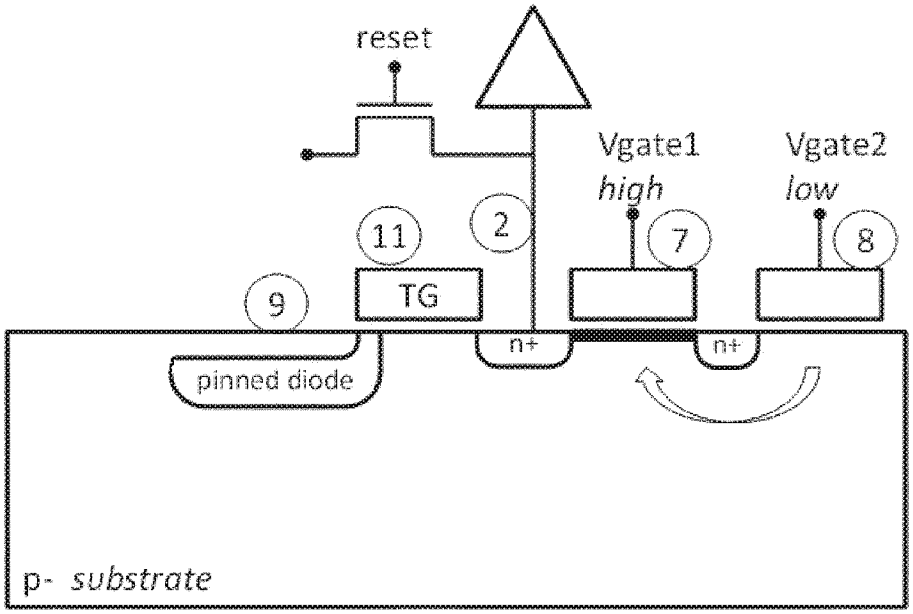

reset
Vgate1
high
Vgate2
low
11
2
7
8
9
TG
n+
n+
pinned diode
p- substrate

Fig. 6

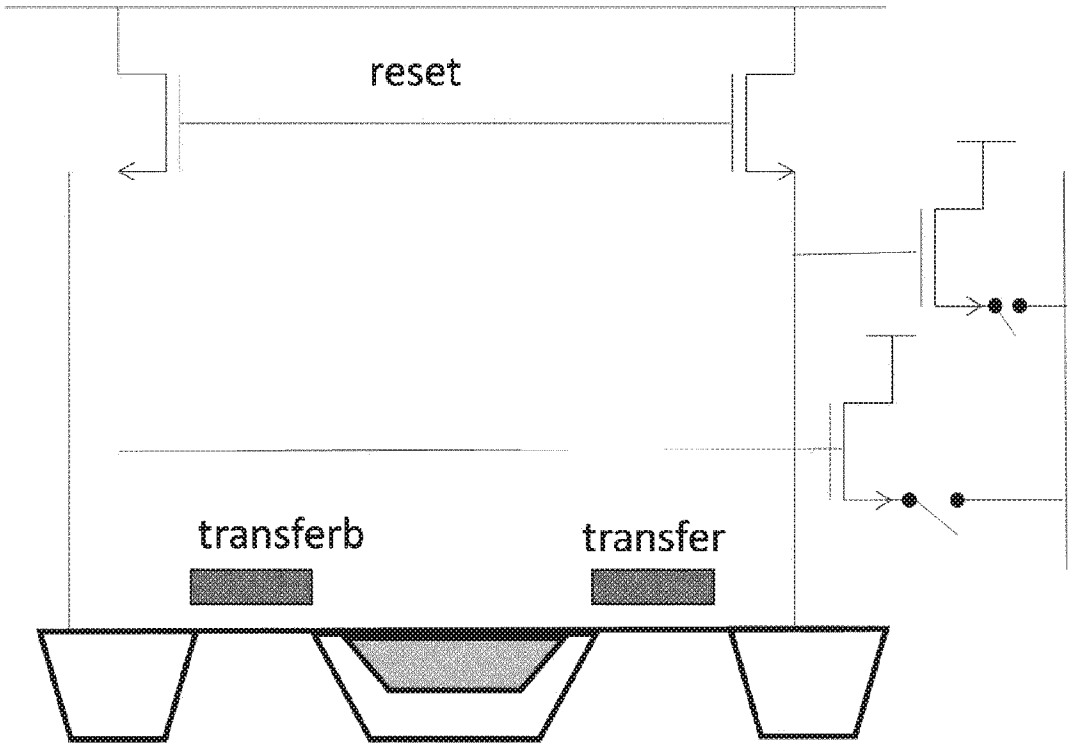


Fig. 7

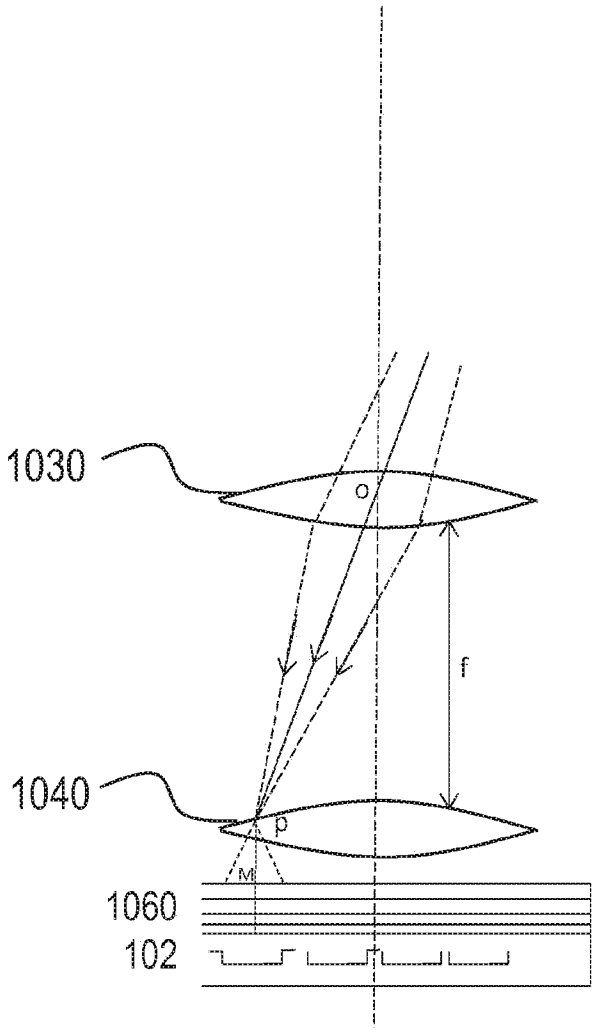


Fig. 8

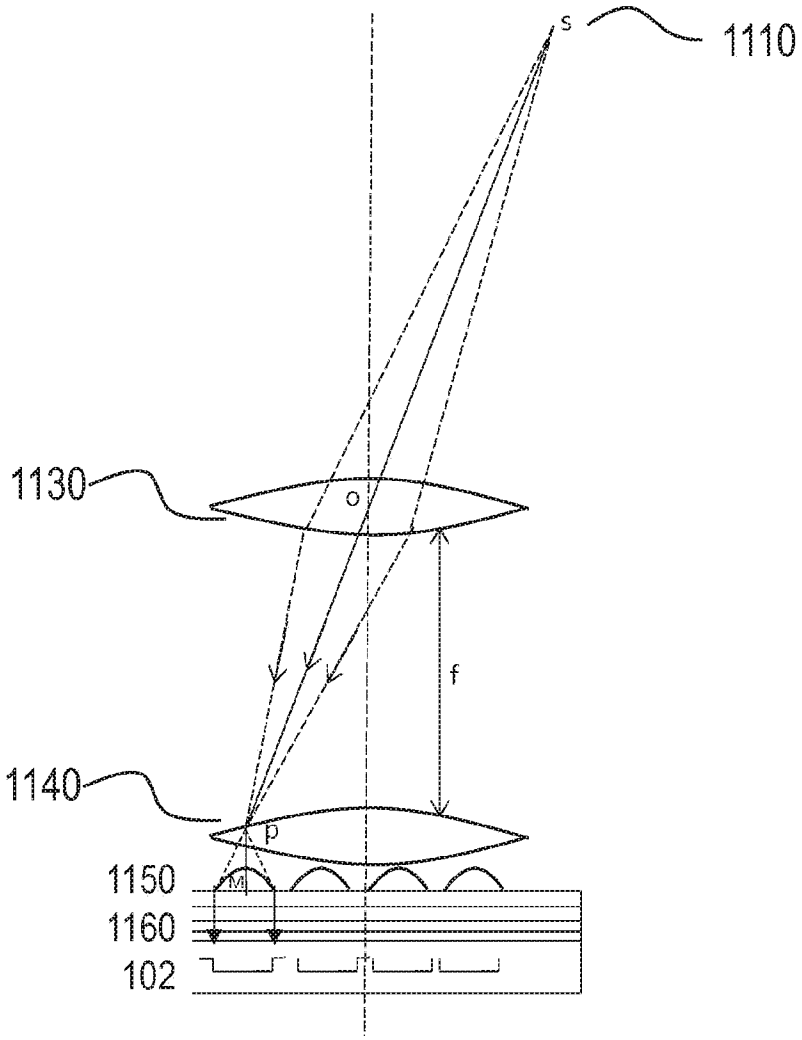


Fig. 9

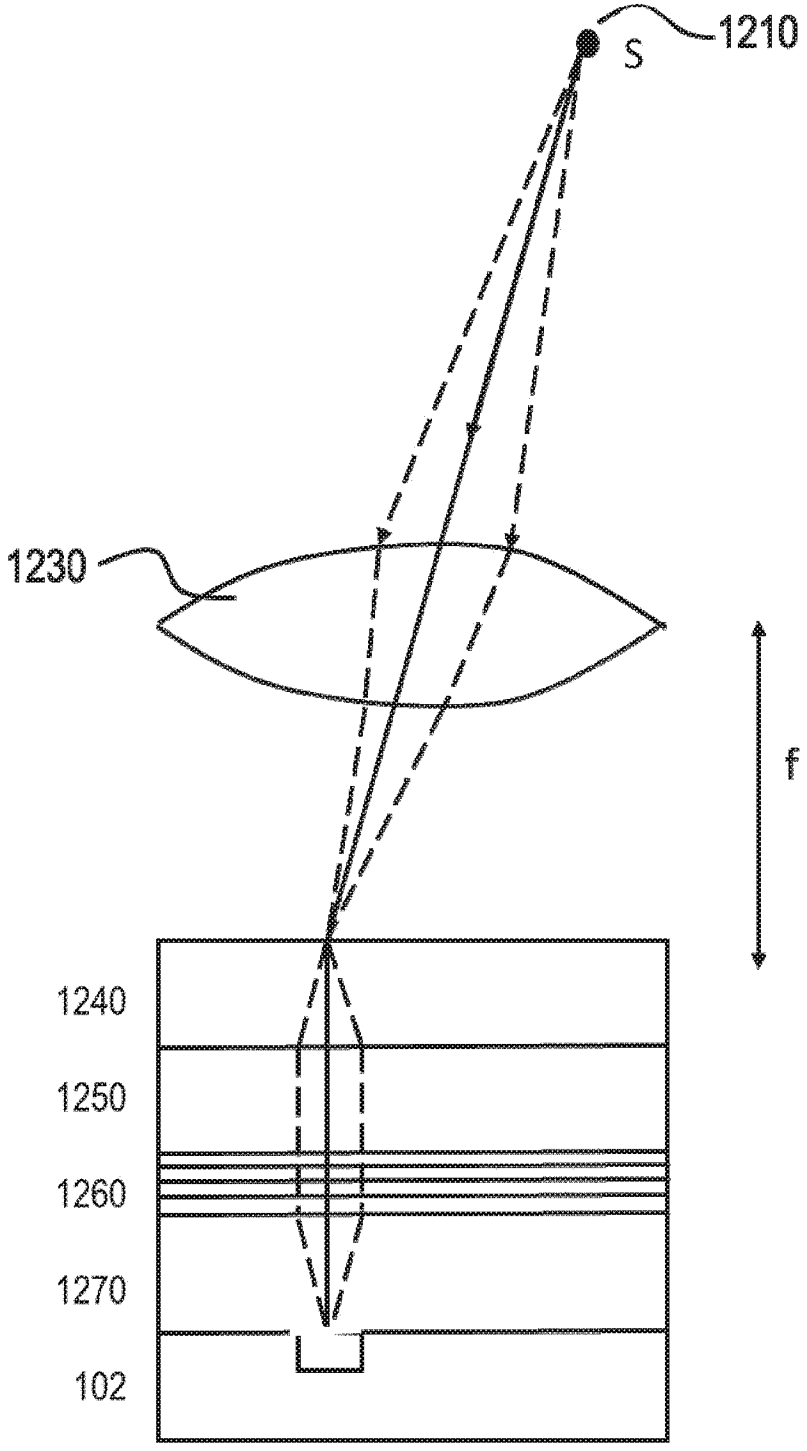


Fig. 10

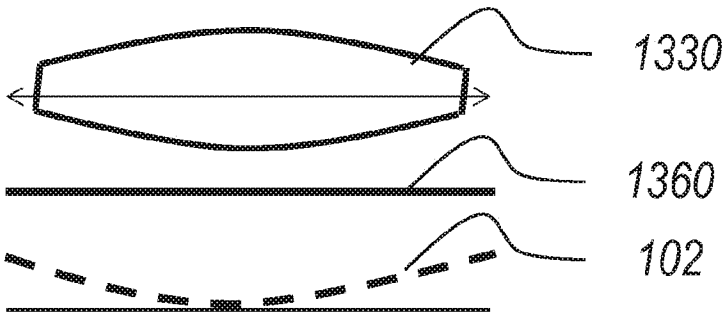


Fig. 11

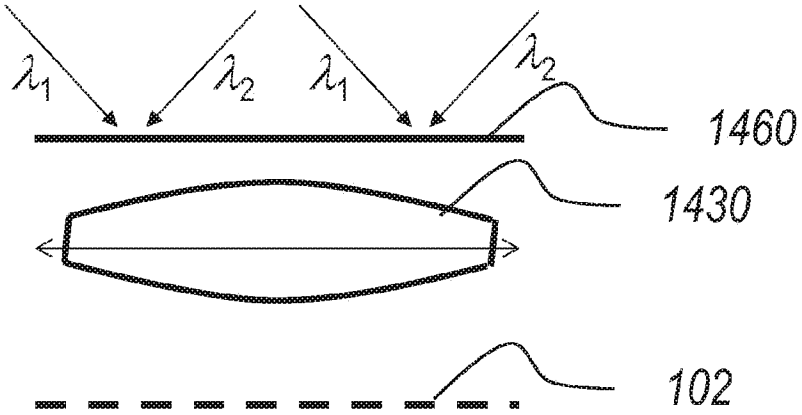


Fig. 12

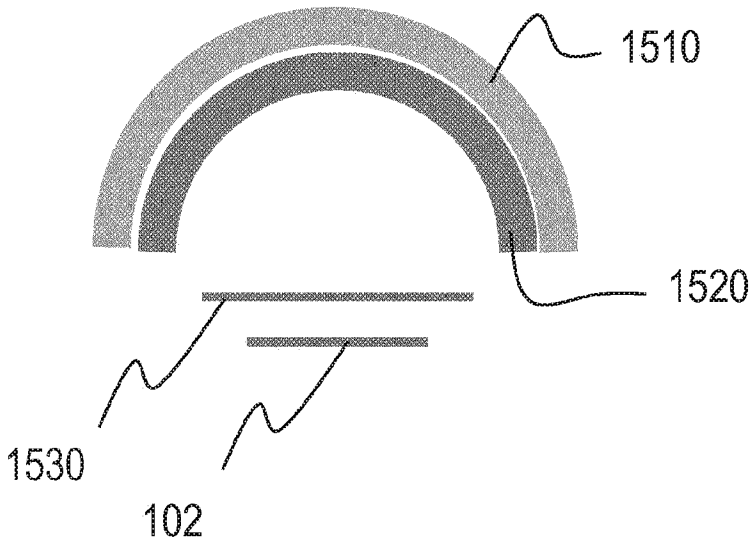


Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075094

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S17/93 G01S7/481 G01S7/486
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002], [0008], [0016] - [0028], [0014], [0031], [0033], [0035], [0039]; figures 1,2,5b,7	1-6
Y	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101], [0129] - [0135], [0198] - [0211], [0125] - [0128], [0069]; figures 6,9,10,24	1-6

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" documentwhich may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2018	29/01/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Metz, Carsten

2

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075094

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013148102 A1	13-06-2013	NONE	
US 2010231891 A1	16-09-2010	CN 101784911 A	21-07-2010
		EP 2187237 A1	19-05-2010
		JP 5171158 B2	27-03-2013
		JP 2009047662 A	05-03-2009
		KR 20100062975 A	10-06-2010
		US 2010231891 A1	16-09-2010
		WO 2009025373 A1	26-02-2009

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2018 (12.04.2018)

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(10) International Publication Number
WO 2018/065428 A3

(51) International Patent Classification:
G01S 17/10 (2006.01) *G01S 17/93* (2006.01)
G01S 17/89 (2006.01) *G01S 7/481* (2006.01)

(21) International Application Number:
PCT/EP2017/075095

(22) International Filing Date:
03 October 2017 (03.10.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16192102.8 03 October 2016 (03.10.2016) EP

(71) Applicant: **XENOMATIX NV** [BE/BE]; Esperantolaan 4, B-3001 Leuven (BE).

(72) Inventors: **PAESEN, Rik;** Helstraat 82, B-3590 Diepenbeek (BE). **VAN DYCK, Dirk;** Kleine Grippe 37, B-2630 Aartselaar (BE).

(74) Agent: **IPLODGE BVBA;** Technologielaan 9, B-3001 Heverlee (BE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: SYSTEM FOR DETERMINING A DISTANCE TO AN OBJECT

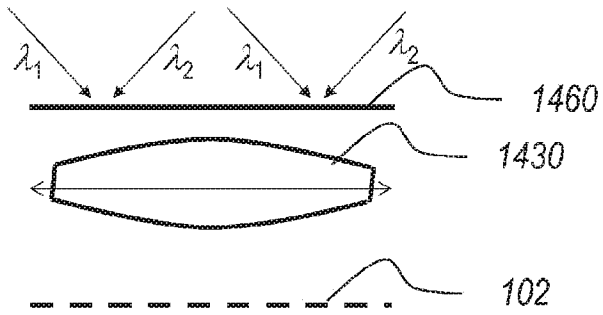


Fig. 12

(57) Abstract: The invention pertains to a system for determining a distance, comprising: a light source for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising picture elements, for detecting light representing the pattern as reflected by the object in synchronization with the sequence of pulses; and processing means to calculate the distance to the object as a function of exposure values generated by said picture elements. The picture elements generate exposure values by accumulating a first amount of electrical charge representing a first amount of light reflected during a first time window and a second electrical charge representating a second amount of light reflected during a second time window. The solid-state radiation source emits substantially monochromatic light having a wavelength spread of less than ±20 nm and the detector is equipped with a corresponding narrow bandpass filter.

WO 2018/065428 A3

[Continued on next page]

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(88) Date of publication of the international search report:

17 May 2018 (17.05.2018)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075095

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S17/93 G01S7/481
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002], [0008], [0017] - [0028], [0014], [0016], [0031], [0033], [0035], [0039]; figures 1,5b, 7,2	1-13
Y	WO 2015/004213 A1 (XENOMATIX BVBA [BE]) 15 January 2015 (2015-01-15) page 5, line 28-page 6, line 24 and page 4, line 26 - page 5, line 5	1-3, 11- 13
Y	US 2007/177841 A1 (DANZIGER YOCHAY [IL]) 2 August 2007 (2007-08-02)	2
A	paragraph [0084]; figure 13	1,3, 11-13

-/- .

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 April 2018	16/04/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Metz, Carsten

2

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HESAI EX1002, P.719

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2007/177011 A1 (LEWIN ANDREW C [GB] ET AL) 2 August 2007 (2007-08-02) paragraphs [0081] , [0109] , [0115] , [0116] , [0148] , [0158] ; figure 2	2 1,3, 11-13
Y A	US 2015/260830 A1 (GHOSH CHUNI LAL [US] ET AL) 17 September 2015 (2015-09-17) paragraphs [0019] , [0078] , [0087] , [0089] , [0108] ; figures 8,13	2,3 1,11-13
Y A	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101] , [0129] - [0135] , [0198] - [0211] ; figures 6,10,24	12 1-3 ,11, 13
Y	MICHAEL C Y HUANG ET AL: "Monolithic Integrated Piezoelectric MEMS-Tunable VCSEL" , IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, IEEE SERVICE CENTER, PISCATAWAY, NJ , US, vol . 13, no. 2, 1 March 2007 (2007-03-01) , pages 374-380, XP011179412 , ISSN: 1077-260X, DOI: 10.1109/JSTQE.2007.894056 pages 374-378, paragraph III; figures 1-2	4,5
Y	US 8 742 325 B1 (DROZ PIERRE-YVES [US] ET AL) 3 June 2014 (2014-06-03) col . 2, line 13-col . 8, line 4; claim 1; figures 1-4	6-10
Y	EP 3 045 936 A1 (XENOMATIX BVBA [BE]) 20 July 2016 (2016-07-20) paragraph [0037]	9,10
A	Anonymous : "Laser linewidth - Wikipedia, the free encyclopedia" , , 14 November 2011 (2011-11-14) , XP055426729 , Retrieved from the Internet: URL: https://web.archive.org/web/20111114232732/https://en.wikipedia.org/wiki/Laser_linewidth [retrieved on 2017-11-20] the whole document	1-3 , 11-13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2017/075095

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 11-13

An optical wavelength division multiplex system illuminating different spots by individually different respective wavelengths, which are selectively received by the detector.
Solved technical problem underlying the claimed invention (see page 11, lines 9-18): Projecting spots as monochromatic light, and filtering the light to be detected to a narrow band around the wavelength of the projected spots, thus reducing the amount of sunlight to be dealt with to the light present in the relevant band.

---

2. claims: 4, 5

Means to adapt the emission wavelength of individual VCSELs within the a VCSEL array light source for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 10, lines 1-7): The emission wavelength is tuned to the detector such that is at the maximum of the passband of the detectors narrow bandpass filter under different angles of incidence.

---

3. claims: 6-8

The implementation of an image-space telecentric optics and an angle of incident changing optics for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 12, lines 29- page 12, line 5): To allow the narrowband filter to obtain satisfactory results over a wider field of view.

---

4. claims: 9, 10

A minilens array optics for an optical distance determining system.
Solved technical problem underlying the claimed invention (see page 29, lines 3-4): To improve the sensitivity of the sensor assembly.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075095

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 2013148102 A1	13-06-2013	NONE		
WO 2015004213 A1	15-01-2015	CN 105393083	A	09-03-2016
		EP 3019824	A1	18-05-2016
		JP 2016530503	A	29-09-2016
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		WO 2005085904	A2	15-09-2005
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		US 2015260830	A1	17-09-2015
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		EP 2187237	A1	19-05-2010
		JP 5171158	B2	27-03-2013
		JP 2009047662	A	05-03-2009
		KR 20100062975	A	10-06-2010
		US 2010231891	A1	16-09-2010
		WO 2009025373	A1	26-02-2009
US 8742325 B1	03-06-2014	CN 105408769	A	16-03-2016
		EP 3028067	A1	08-06-2016
		JP 2016535269	A	10-11-2016
		KR 20160035055	A	30-03-2016
		US 8742325	B1	03-06-2014
		US 2015034809	A1	05-02-2015
		WO 2015017213	A1	05-02-2015
EP 3045936 A1	20-07-2016	EP 3045936	A1	20-07-2016
		US 2016200161	A1	14-07-2016

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2018 (12.04.2018)

W!P O | PCT

(10) International Publication Number
WO 2018/065429 A1

(51) International Patent Classification:
G01S 17/89 (2006.01) *G01S 7/481* (2006.01)
G01S 17/93 (2006.01) *G01S 7/486* (2006.01)
G01S 17/10 (2006.01)

(21) International Application Number:
PCT/EP2017/075096

(22) International Filing Date:
03 October 2017 (03.10.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16192103.6 03 October 2016 (03.10.2016) EP

(71) Applicant: **XENOMATIX NV** [BE/BE]; Esperantolaan 4, B-3001 Leuven (BE).

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: SYSTEM AND METHOD FOR DETERMINING A DISTANCE TO AN OBJECT

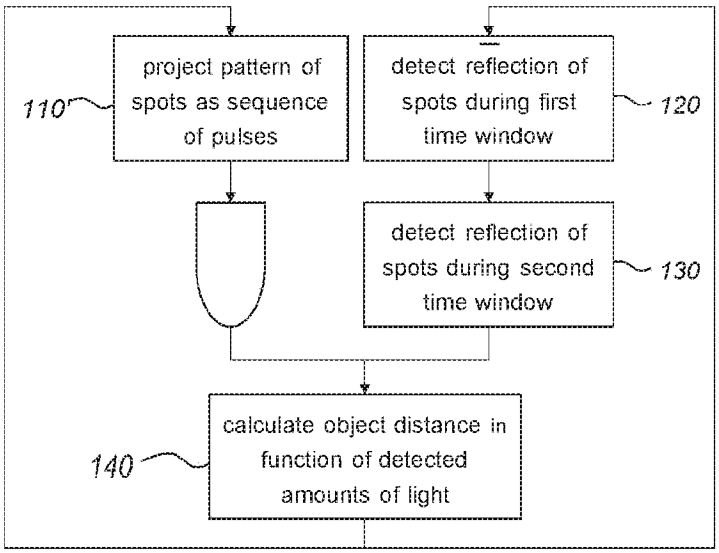


Fig. 1

(57) Abstract: The invention pertains to a system for determining a distance, comprising: a light source for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising picture elements, for detecting light representing the pattern as reflected by the object in synchronization with the sequence of pulses, and processing means to calculate the distance to the object as a function of exposure values generated by said picture elements. The picture elements generate exposure values by accumulating a first amount of electrical charge representing a first amount of light reflected during a first time window and a second electrical charge representating a second amount of light reflected during a second time window. The system projects and detects for at least two consecutive sequences of pulses, each being operated with a different duration of said first time window and said second time window.

WO 2018/065429 A1

[Continued on next page]

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

System and Method for determining a distance to an object

Field of the Invention

The present invention pertains to the field of systems for determining a distance to an object, in particular to time-of-flight based sensing systems to be used for the characterization of a scene or a part thereof.

Background

In the field of remote sensing technology, mainly in the usage of making high-resolution maps of the surroundings, to be used in many control and navigation applications such as but not limited to the automotive and industrial environment, gaming applications, and mapping applications, it is known to use time-of-f light based sensing to determine the distance of objects from a sensor. Time-of-flight based techniques include the use of RF modulated sources, range gated imagers, and direct time-of-f light (DToF) imagers. For the use of RF modulated sources and range gated imagers, it is necessary to illuminate the entire scene of interest with a modulated or pulsed source. Direct time-of-f light systems, such as most LIDARs, mechanically scan the area of interest with a pulsed beam, the reflection of which is sensed with a pulse detector.

In order to be able to correlate an emitted RF modulated signal with the detected reflected signal, the emitted signal must meet a number of constraints. In practice, these constraints turn out to make the RF modulated systems highly impractical for use in vehicular systems: the attainable range of detection is very limited for signal intensities that are within conventional safety limits and within the power budget of regular vehicles.

A direct TOF (DToF) imager, as used in most LIDAR systems, comprises a powerful pulsed laser (operating in a nanosecond pulse regime) , a mechanical scanning system to acquire from the ID point

measurement a 3D map, and a pulse detector. Systems of this type are presently available from vendors including Velodyne Lidar of Morgan Hill, California. The Velodyne HDL-64E, as an example of state-of-the-art systems, uses 64 high-power lasers and 64 detectors (avalanche diodes) in a mechanically rotating structure at 5 to 15 rotations per second. The optical power required by these DToF LIDAR systems is too high to be obtained with semiconductor lasers, whose power is in the range of five to six orders of magnitude lower. In addition, the use of mechanically rotating elements for scanning purposes limits the prospects for miniaturization, reliability, and cost reduction of this type of system.

United States Patent application publication no. 2015/0063387 in the name of Trilumina discloses a VCSEL delivering a total energy of 50 mW in a pulse having a pulse width of 20 ns. The commercially available Optek OPV310 VCSEL delivers a total energy of 60 mW in a pulse having a duration of 10 ns and it can be estimated by extrapolation to have a maximum optical output power of 100 mW. This value is only realized under very stringent operating conditions, meaning optimal duty cycle and short pulse width so as to avoid instability due to thermal problems. Both the Trilumina disclosure and the Optek system illustrate that continuous-wave VCSEL systems are reaching their physical limits with respect to optical peak power output, due to thermal constraints inherently linked to the VCSEL design. At these pulse energy levels, and using ns pulses as presently used in DToF applications, the mere number of photons that can be expected to be usefully reflected by an object at a distance of 120 m is so low that it defeats detection by means of conventional semiconductor sensors such as CMOS or CCD or SPAD array. Thus, increasing the VCSEL power outputs by 5 or 6 orders of magnitude, as would be required to extend the range of the known DToF systems, is physically impossible.

Even the use of avalanche diodes (AD or SPAD), which are theoretically sufficiently sensitive to capture the few returning

photons, cannot be usefully deployed in the known LIDAR system architectures. A solid state implementation of an array of SPADs must be read out serially. A high number of SPADs is required to achieve the desired accuracy. The serial read-out constraints of the solid state implementation limit the bandwidth of the system turning it inappropriate for the desired accuracy. For accuracies such as that of the Velodyne system (0.02 m to 0.04 m, independent of distance), the required read-out data rate exceeds the practically achievable bandwidth in case of today's IC implementation. For operation at 120 m, a SPAD array of 500x500 pixels is required, which, in an IC-based implementation, must be read-out serially. For the same precision as the aforementioned Velodyne system, it would require 1000 pulses per millisecond and hence 1000 frames per millisecond, translating into a readout rate of 250 Gigapixels per second. This is believed to be technically unfeasible in the context of current SPAD IC technology.

The paper by Neil E. Newman et al., "High Peak Power VCSELs in Short Range LIDAR Applications", *Journal of Undergraduate Research in Physics*, 2013, http://www.jurp.org/2 013/12 017EXR.pdf, describes a VCSEL-based LIDAR application. The paper states that the maximum output power of the described prototype system was not great enough to do wide-field LIDAR at a range greater than 0.75 m. With a relatively focused beam (0.02 m spot size at 1 m distance), the authors were able to range a target object at a distance of up to 1 m.

The above examples clearly indicate that the optical power emitted by present semiconductor lasers cannot meet the power requirements necessary for operations in the known LIDAR systems to be of practical use in automotive applications (e.g. for ranges up to 120 m).

United States patent no. 7,544,945 in the name of Avago Technologies General IP (Singapore) Pte. Ltd., discloses vehicle-based LIDAR systems and methods using multiple lasers to provide more compact and cost-effective LIDAR functionality. Each laser in

an array of lasers can be sequentially activated so that a corresponding optical element mounted with respect to the array of lasers produces respective interrogation beams in substantially different directions. Light from these beams is reflected by objects in a vehicle's environment, and detected so as to provide information about the objects to vehicle operators and/or passengers. The patent provides a solid state projector in which the individual lasers are consecutively activated in order to replace the known mechanical scanning in the known DToF LIDAR systems.

A high-accuracy medium-range surround sensing system for vehicles that does not use time-of-flight detection, is known from international patent application publication WO 2015/004213 A1 in the name of the present applicant. In that publication, the localization of objects is based on the projection of pulsed radiation spots and the analysis of the displacement of detected spots with reference to predetermined reference spot positions. More in particular, the system of the cited publication uses triangulation . However, the accuracy that can be achieved correlates with the triangulation base, which limits the further miniaturization that can be achieved.

US patent application publication no. US 2012/0038903 A1 discloses methods and systems for adaptively controlling the illumination of a scene. In particular, a scene is illuminated, and light reflected from the scene is detected. Information regarding levels of light intensity received by different pixels of a multiple pixel detector, corresponding to different areas within a scene, and/or information regarding a range to an area within a scene, is received. That information is then used as a feedback signal to control levels of illumination within the scene. More particularly, different areas of the scene can be provided with different levels of illumination in response to the feedback signal.

European patent application publication no. EP 2 322 953 A1 discloses a distance image sensor capable of enlarging the distance measurement range without reducing the distance resolution. A radiation source provides first to fifth pulse trains which are irradiated to the object as radiation pulses in the first to fifth frames arranged in order on a time axis. In each of the frames, imaging times are prescribed at points of predetermined time from the start point of each frame, also the pulses are shifted respectively by shift amounts different from each other from the start point of the first to fifth frames. A pixel array generates element image signals each of which has distance information of an object in distance ranges different from each other using imaging windows A and B in each of five frames. A processing unit generates an image signal by combining the element image signals. Since five times-of-flight measurement are used, the width of the radiation pulse does not have to be increased to obtain distance information of the object in a wide distance range, and the distance resolution is not reduced.

European patent application publication no. EP 2 290 402 A1 discloses a range image sensor which is provided on a semiconductor substrate with an imaging region composed of a plurality of two-dimensionally arranged units, thereby obtaining a range image on the basis of charge quantities output from the units. One of the units is provided with a charge generating region (region outside a transfer electrode) where charges are generated in response to incident light, at least two semiconductor regions which are arranged spatially apart to collect charges from the charge generating region, and a transfer electrode which is installed at each periphery of the semiconductor region, given a charge transfer signal different in phase, and surrounding the semiconductor region.

The article by Shoji Kawahito et al., "A CMOS Time-of-Flight Range Image Sensor With Gates-on-Field-Oxide Structure", *IEEE Sensors Journal*, Vol. 7, no. 12, p. 1578-1586, discloses a type of CMOS time-of-flight (TOS) range image sensor using single-layer gates

on field oxide structure for photo conversion and charge transfer. This structure allows the realization of a dense TOF range imaging array with 15 x 15 μm^2 pixels in a standard CMOS process. Only an additional process step to create an n-type buried layer which is necessary for high-speed charge transfer is added to the fabrication process. The sensor operates based on time-delay dependent modulation of photocharge induced by back reflected infrared light pulses from an active illumination light source. To reduce the influence of background light, a small duty cycle light pulse is used and charge draining structures are included in the pixel. The TOF sensor chip fabricated measures a range resolution of 2.35 cm at 30 frames per second an improvement to 0.74 cm at three frames per second with a pulse width of 100 ns.

European patent application no. EP15191288.8 in the name of the present applicant, which has not been published at the filing date of the present application, describes some aspects of a system and method for determining a distance to an object.

There is a continuing need to obtain extreme miniaturization and/or longer-range in complex vehicular surround sensing applications, such as ADAS (autonomous driving assistance system) applications and autonomous driving applications, and this at a reasonable cost and in a compact, semiconductor-integrated form factor.

Summary of the Invention

It is an objective of embodiments of the present invention to provide a further miniaturized and longer-range alternative for displacement-based vehicular surround sensing systems. Furthermore, it is an objective of embodiments of the present invention to provide a full solid-state alternative for the known LIDAR systems.

According to an aspect of the present invention, there is provided a system for determining a distance to an object comprising: a

solid-state light source arranged for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising a plurality of picture elements, the detector being configured for detecting light representing the pattern of discrete spots as reflected by the object in synchronization with the sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by the picture elements in response to the detected light; wherein the picture elements are configured to generate the exposure values by accumulating, for all of the pulses of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window; wherein the system is configured to perform the projecting and the detecting for at least two consecutive sequences of pulses, each of the sequences being operated with a different duration of the first predetermined time window and the second predetermined time window.

The present invention relies on the same physical principles as direct time-of-f light based ranging systems, viz. the fact that light always takes a certain amount of time to travel a given distance. However, the present invention uses range gating to determine the distance travelled by a light pulse that has been transmitted and subsequently reflected by a target object. The present invention is *inter alia* based on the insight of the inventors that by combining range gating, an at least partially simultaneous spot pattern projection (based on a novel illumination scheme) and a low-power semiconductor light source, a substantially miniaturized, full solid state and energy-efficient long-range distance detection method can be obtained. The term "pattern" as used herein refers to a spatial distribution of simultaneously projected spots. In order to determine the position of the detected spot reflection in three-dimensional space, it is

necessary to combine the distance information obtained from the ranging step with angular information to fix the remaining two spatial coordinates. A camera comprising a pixel array and suitably arranged optics can be used to provide the additional angular information, by identifying the pixel in which the reflection is detected.

Embodiments of the present invention are based on the further insight of the inventors that in order to be able to use spot patterns generated by solid-state light sources in a LIDAR system at the desired ranges, a way to circumvent the optical power limitations is needed. The inventors have found that by prolonging the pulse duration and by integrating the reflected energy of multiple VCSEL-generated light pulses within at least two semiconductor sensor wells or within at least two pixels, followed by a single read-out of the integrated charge, a solid-state LIDAR system can be obtained with a significantly greater operating range than is currently possible with solid-state implementations. Hereinafter, the term "storage" will be used to designate the well or the pixel in which charge is accumulated in response to the detection of photons.

It is an advantage of the present invention that the solid-state light source and the solid-state sensor (such as a CMOS sensor, a CCD sensor, SPAD array or the like) may be integrated on the same semiconductor substrate. The solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern.

Moreover, by assessing the reflected light energy detected in two consecutive time windows, and normalizing for the total accumulated charge in the two consecutive windows, the impact of varying reflectivity of the object under study and the contribution of ambient light can adequately be accounted for in the distance calculation algorithm.

The present invention is further based on the insight of the inventors that the range of the system can be improved by splitting up the sensing of the full range over multiple frames (i.e., multiple sequences of pulses), each of which "sees" a different range by virtue of operating with different timing parameters (the first predetermined time window and the second predetermined time window) .

A judicious choice of these operating parameters can ensure that in each frame, the number of reflected photons expected to be detected for the maximal distance of the desired range corresponds to an amount of charge that can be reliably read out from the charge storage well. On the other hand, the nearest point at which accurate measurements can be carried out is determined by the number of photons that will saturate the capactity of the pixels. The ratio between the minimal detectable number of photons and the maximal number of photons that can be received without saturation determines the distance range that can be spanned in a single frame .

In an embodiment of the system according to the present invention, each of the plurality of picture elements comprises at least two sets of charge storage wells, the detecting of said first amount of light and the detecting of the second amount of light occurring at respective ones of the at least two sets of charge storage wells; and each of the sets of charge storage wells is configured as a cascade.

The term "charge storage well" designates a storage provided in the semiconductor substrate, e.g. a capacitor, that stores electrical charges generated by the conversion of photons impinging on the pixel.

In the picture elements, charge representative of the impinging light is accumulated at well level. An advantage of charge accumulation at the well level is that read-out noise is minimized, leading to a better signal-to-noise ratio.

It is an advantage of the cascade-based arrangement that the total amount of charge to be accumulated is distributed over multiple wells, which allows for a greater total charge storage capacity while maintaining an accurate reading of the total charge level.

The increase in the total charge storage capacity is of particular importance at the end of the operating range where large number of photons - and hence, large amounts of charge - are received by the system; this is the case at short range (because the intensity of the light in function of distance follows an inverse-square law) or when surfaces with an unusually high reflectance are present in the field of view of the sensor. In conditions where a single well would tend to be saturated, a cascade-based arrangement allows the excess charge to be stored in a subsequent storage well, without losing the possibility of accurately determining the total amount of charge.

The total number of capacities in the cascade can be selected in function of the desired operating range and accuracy, and the general requirement to keep the Poisson noise as low as possible. The latter condition is inherently linked to the application of range gating, where Poisson noise is detrimental to the accuracy of the distance determination. A low level of Poisson noise allows a continuous photon-charge response, regardless of whether the charge is stored in one or more capacities of the cascade.

In an embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a serially arranged cascade. In another embodiment of the system according to the present invention, each of the sets of charge storage wells is configured as a parallelly arranged cascade.

It is an advantage of these embodiments that they provide easy to implement arrangements to obtain the desired cascade effect of the storage wells.

In an embodiment of the system according to the present invention, for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and a total storage capacity of said picture elements configured to detect said first amount of light is larger than a total storage capacity of said picture elements configured to detect said second amount of light.

It is an advantage of this embodiment that it helps to avoid saturation of the charge storage elements due to an overload of reflected photons. This problem is most prominent at nearby distances. At short ranges, the total number of reflected photons will be higher, due to the inverse square law, while most of the reflected signal will arrive within the first time window and thus be stored in the corresponding set of charge storage wells. Hence, it is useful to dimension the set of charge storage wells corresponding to the first time window so as to be able to deal with a larger amount of charge.

According to an aspect of the present invention, there is provided a vehicle, comprising: a system as described above arranged to operatively cover at least a part of an area surrounding said vehicle .

The system according to the present invention is particularly advantageous in a vehicle with ADAS or autonomous driving control unit such as but not limited to ECU (electrical control unit) . The vehicle may further comprise a vehicle control unit, adapted for receiving measurement information from the system and for using the information for ADAS control or autonomous driving decision taking. The part of an area surrounding the vehicle may include a road surface ahead of, beside, or behind the vehicle. Accordingly, the system may provide road profile information of the surface ahead of the car, to be used for active suspension or semi-active suspension .

According to an aspect of the present invention, there is provided a camera, the camera comprising a system as described above, whereby the system is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

According to an aspect of the present invention, there is provided a method for determining a distance to an object, the method comprising: using a solid-state light source to project a pattern of spots of laser light towards the object in a sequence of pulses; using a detector comprising a plurality of picture elements to detect light representing the pattern of spots as reflected by the object in synchronization with the sequence of pulses; and calculating the distance to the object as a function of exposure values generated by the pixels in response to the detected light; wherein the picture elements generate the exposure values by accumulating, for each pulse of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the object during a first predetermined time window and a second amount of electrical charge representative of a second amount of light reflected by the object during a second predetermined time window, the second predetermined time window occurring after the first predetermined time window; and wherein the projecting and the detecting are repeated for at least two consecutive sequences of pulses, each of the sequences being operated with a different duration of the first predetermined time window and the second predetermined time window.

In an embodiment of the method according to the present invention, for each of the at least two consecutive sequences of pulses the first predetermined time window and the second predetermined time window are of substantially equal duration and occur back-to-back.

In an embodiment of the method according to the present invention, each of the plurality of picture elements comprises at least two charge storage wells, and the detecting of the first amount of

light and the detecting of the second amount of light occurs at respective ones of the at least two charge storage wells.

According to an aspect of the present invention, there is provided a computer program product comprising code means configured to cause a processor to carry out the method as described above.

The technical effects and advantages of embodiments of the camera, the vehicle, the method, and the computer program product according to the present invention correspond, *mutatis mutandis*, to those of the corresponding embodiments of the system according to the present invention.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 represents a flow chart of an embodiment of the method according to the present invention;

Figure 2 schematically represents an embodiment of the system according to the present invention;

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention;

Figure 4 provides diagrams of exemplary pixel output in function of incident light power as obtained by logarithmic tone mapping (top) and multilinear tone mapping (bottom);

Figure 5 provides a diagram of exemplary pixel outputs in function of incident light power as obtained by a high dynamic range multiple output pixel;

Figure 6 schematically illustrates the structure of a high-dynamic range pixel for use in embodiments of the present invention;

Figure 7 schematically illustrates an embodiment of a pixel architecture with two charge wells (bins) with each a separate transfer gate for use in embodiments of the present invention;

Figure 8 schematically illustrates a first exemplary optical arrangement for use in embodiments of the present invention;

Figure 9 schematically illustrates a second exemplary optical arrangement for use in embodiments of the present invention;

Figure 10 schematically illustrates a third exemplary optical arrangement for use in embodiments of the present invention;

Figure 11 schematically illustrates a fourth exemplary optical arrangement for use in embodiments of the present invention;

Figure 12 schematically illustrates a fifth exemplary optical arrangement for use in embodiments of the present invention; and

Figure 13 schematically illustrates a sixth exemplary optical arrangement .

Detailed Description of Embodiments

The surround sensing systems of the type disclosed in international patent application publication WO 2015/004213 A1, in the name of the present applicant, have the advantage of observing an extensive scene while illuminating that scene simultaneously or partially simultaneously only in a number of discrete and well-defined spots, in particular a predefined spot pattern. By using VCSEL lasers with an outstanding bundle quality and a very narrow output spectrum, it is possible to obtain a detection range with a limited amount of output power, even in the presence of daylight. The actual ranging performed in the system of WO 2015/004213 A1

relies on displacement detection, in particular triangulation, which was understood to be the only method practically available in the context of the long (quasi-stationary) pulse durations that were necessary in view of the power budget. To date, it had not been possible to achieve the same power/performance characteristics with a compact, semiconductor based time-of-f light based system.

The present invention overcomes this limitation by radically changing the way the time-of-f light based system operates. The invention increases the total amount of light energy emitted for each time-of-f light measurement (and thus, the number of photons available for detection at the detector for each time-of-f light measurement) by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power VCSELs.

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the systems according to the present invention benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 µs (this is one possible value, chosen here to keep the description clear and simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500 ns or more, preferably 750 ns or more, most preferably 900 ns or more) . In an exemplary system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 µs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required

number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically.

The present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 1 represents a flow chart of an embodiment of the method according to the present invention. Without loss of generality, the ranging method is described with reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular or an irregular spatial pattern of spots) from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally,

even at long ranges and with high levels of ambient light (e.g., in daylight), a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20**, a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20**, the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 3.

The detector comprises a plurality of picture elements, i.e. it consists of a picture element array with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element. The term "picture element" as used herein may refer to an individual light-sensitive area or

well of a pixel, or to an entire pixel (which may comprise multiple wells, see below) . For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221**, **222**, such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221**, **222** of the same pixel or pixel group.

Figure 2 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99**. A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the object **99** and back to the detector **220**. It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230**, which may include a conventional clock circuit or oscillator, is configured to operate the solid-state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99**, during respective subsequent second predetermined time windows **20**. Appropriate processing means **240**

are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 3 represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of a single pulse sequence of Figure 1 is illustrated, which consists of a first time window **10** and a second time window **20**. According to the present invention, at least two sequences are transmitted consecutively, using different durations of the first time window **10** and the second time window **20** in the first sequence than in the second sequence.

As can be seen in Figure 3a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first well or cascaded set of wells **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second well or cascaded set of wells **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part

representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first well or cascaded set of wells **221** and the larger the proportion of the pulse that will be detected in the second well or cascaded set of wells **222**.

If the leading edge of the reflected pulse arrives after the closing of the first well or cascaded set of wells **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second well or cascaded set of wells **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge A, B in each of the respective wells or cascaded sets of wells **221**, **222** for varying distances of the object **99** is shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of A and B:

- For time of flight delays up to the duration of the first time window **10**, B is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value B/(B+A) may be used, removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.
- For time of flight delays exceeding the duration of the first time window **10**, A consists of daylight and noise contributions only (not illustrated), and C–B is substantially proportional (after correcting for the inverse

square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 3a and 3b illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 3c schematically illustrates exemplary timing characteristics of a single sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

Figure 3d schematically illustrates how the individual frames in the sequence of Figure 3c, which may fail to cover the entire targeted range of distances $[z_{min}, z_{max}]$ as a result of the constraints imposed by N_{max} (maximal number of electrons that can be stored without saturating the pixel) and N_{min} (minimum number of pixels required for accurate read-out), can be broken down into sequences with different timing parameters, each covering a portion of the targeted range $[z_{min}(i), z_{max}(i)]$ that can more easily be covered within the same constraints on the number of photons.

With reference to the symbols introduced above and used in Figure 3d, the corresponding electron amounts $n_{min}(i)$ and $n_{max}(i)$ of the subranges are defined by:

- The maximum allowable number of electrons (using "FPC" for the full pixel capacity, which corresponds to full well capacity in case there are no additional capacities):

$$n_{max} = N_{min} \times \left(\frac{z(i)}{z(i+1)}\right) \leq FPC, \text{ with } z(0) = z_{max}$$

- The minimum required accuracy level: $n_{min} = N_{min}$

~ $z_{max}(i) = z_{min}(i-1)$

Additionally, the pulse characteristics can be determined as follows:

- the pulsewidth $\tau(i) = \frac{z_{max}(i)}{c}$
- the total "on" time is reduced proportionally to $\frac{N_{max}}{N_{min}}$ to respect the limits imposed by the full pixel capacity and the accuracy level.

The above principles may be further clarified by the following non-limiting numerical example.

A Lambertian reflecting surface with 10% reflectivity at a distance of 150m must provide 1000 electrons to obtain an accuracy of 1,6%. At the same distance, a 100% reflecting surface will generate 10000 electrons. With a full well capacity of 200000 electrons, the following multi-frame solution is proposed:

	Sub-range	Pulse Width	Total "on" time
Frame 1	150m - 33m	1 µs	1 ms
Frame 2	7.4m - 33m	22 ns	50 µs
Frame 3	1.65m - 7.4m	4.9 ns	2.5 µs
Frame 4	0.37m - 1.65m	1.1 ns	0.125 µs

It should be noted that for robustness reasons, it may be advantageous to provide an overlap in the subranges .

For assuring the same 3D resolution, it may be advantageous to use a faster camera: e.g., a camera operating at 180Hz with 3-frame interleaving gives the same data speed as a 60Hz with single frame operation .

As indicated in the text above, the charge storage elements **221, 222** may each consist of a cascade of charge storage wells. A judicious design of the cascades ensures a smooth transition between the capacities to assure extremely high accuracy levels. The storage capacities are preferably designed around each pixel, to ensure that there is sufficient space for the cascade while to optimizing the charge transfer from the area where the impinging

photons are converted to electrical charges . The capacities are preferably dimensioned so as to provide an accurate read-out of the lowest level of light that must be detectable (e.g. 1000 photons), for the specific subrange applicable to each sequence of pulses and the corresponding timing parameters.

Reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first set of wells (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first set of wells is increased, and the photon capacity represented by the second set of wells is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost.

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant set of wells and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is

obtained independently (and without contamination from) neighboring pixels.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise") . To this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reset}) and the signal voltage (V_{signal}) , for example by measuring V_{reset} at the beginning of the frame and measuring V_{signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals (V_{signal} - V_{reset}) in a processor .

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements .

The ranging system according to the present invention may be integrated with a triangulation-based system in accordance with WO 2015/004213 A1 . If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately .

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that

require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

While various techniques known from WO 2015/004213 A1 may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the

ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly. Additionally or alternatively, background light or ambient light may be subtracted from the detected signal at pixel level. This requires two exposures, one during the arrival of the laser pulse and one in the absence of a pulse.

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a true high dynamic range sensor is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression (see Figure 4). However, this non-linear compression necessitates relinearisation of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor as presented in Figure 5. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US 2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention.

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoir or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination or 90% in case of back illumination, also known as back thinning), or by a special design such as shown in Figure 6 (see below), or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning). Preferably, the pixel design implements an anti-blooming mechanism.

Figure 6 presents a schematic illustration of an advantageous implementation of a pixel with high dynamic range. The example in this figure makes use of two storage gates 7, 8, connected to the floating diffusion. After exposure, the electron generated by the scene AND the laser pulse, is transferred on the floating diffusion using the transfer gate 11. Both Vgate1 and Vgate2 gate voltages are set high. The charges are then spread over both capacitors, realizing a significant Full Well. Once this high full-well data is read via connection to the amplifier, the voltage Vgate2 is set low. The electrons reflow towards capacitor 7, increasing the total pixel gain. The data can be read through the amplifier. It is further possible to achieve an even higher gain by applying later a low voltage on Vgate1. The electrons reflow towards the floating diffusion 2.

Figure 7 represents a possible dual-well or dual-bin implementation of an envisaged pixel to be used in CMOS technology. The impinging signal is distributed over two charge storages. Each reservoir has a separate transfer gate controlled by an external pulse which is synchronized with the pulse of the laser sources.

The charge storage elements shown in the designs of Figure 6 and Figure 7 may be replicated to obtain a cascade of charge storage in embodiments of the present invention.

Figures 8-10 illustrate cameras that may be used in embodiments of the invention, where the light radiation source emits monochromatic light and the at least one detector is equipped with a corresponding narrow bandpass filter and optics arranged so as to modify an angle of incidence onto said narrow bandpass filter, to confine said angle of incidence to a predetermined range around a normal of a main surface of said narrow bandpass filter, said optics comprising an image-space telecentric lens. The term "camera" is used herein as a combination of a sensor and associated optics (lenses, lens arrays, filter) . In particular, in Figure 9, the optics further comprise a minilens array arranged between the image-space telecentric lens and the at least one detector, such that individual minilenses of the minilens array focus incident light on respective light-sensitive areas of individual pixels of the at least one detector. It is an advantage of this one-minilens-per-pixel arrangement that the loss due to the fill factor of the underlying sensor can be reduced, by optically guiding all incident light to the light-sensitive portion of the pixels.

These examples all result in radiation travelling a substantially equal length through the filter medium or in other words in that the incident radiation is substantially orthogonal to the filter surface, i.e. it is confined to an angle of incidence within a predetermined range around the normal of the filter surface, thus allowing in accurate filtering within a narrow bandwidth to e.g. filter the daylight, the sunlight and in order to for the spots to surpass the daylight.

The correction of the angle of incidence is of particular importance in embodiments of the present invention where the entire space around a vehicle is to be monitored with a limited

number of sensors, for instance 8 sensors, such that the incident rays may extend over a solid angle of for example 1 x 1 rad. Figure 8 schematically illustrates a first optical arrangement of this type. It comprises a first lens **1030** and a second lens **1040**, with approximately the same focal length *f*, in an image space telecentric configuration. That means that all chief rays (rays passing through the center of the aperture stop) are normal to the image plane. An exemplary numerical aperture of 0.16 corresponds to a cone angle of 9.3° (half cone angle) . The maximum incidence angle on the narrow bandpass filter 1060, arranged between the lens system **1030-1040** and the sensor **102**, would thus be 9.3°.

As illustrated in Figure 9, the preferred design consists of a tandem of two lenses **1130**, **1140** with approximately the same focal length *f*, in an image-space telecentric configuration (the configuration is optionally also object-space telecentric), a planar stack of mini-lens array **1150**, a spectral filter **1160** and a CMOS detector **102**. Since the center 0 of the first lens **1130** is in the focus of the second lens **1140**, every ray that crosses 0 will be refracted by the second lens **1140** in a direction parallel to the optical axis. Consider now a particular laser spot S **1110** located at a very large distance as compared to the focal length of the first lens **1130**. Thus the image of this spot **1110** by the first lens **1130** is a point P located close to the focal plane of this lens, thus exactly in the middle plane of the second lens **1140**. The light rays that are emitted from the spot S **1110** and captured by the first lens **1130** form a light cone that converges towards the point P in the second lens **1140**. The central axis of this light cone crosses the point 0 and is refracted parallel the optical axis and thus perpendicular to the spectral filter **1160** so as to achieve optimal spectral sensitivity. Hence, the second lens **1140** acts as a correcting lens for the angle of the incident light beam. The other rays of the cone can also be bent in a bundle of rays parallel to the optical axis by using a small convex mini-lens **1150** behind the second lens **1140** in such a way that the point P is located in the focal point of the mini-lens **1150**. In this way all the imaging rays of the spot S **1110** are bent in a direction

nearly perpendicular to the spectral filter. This can now be done in front of every pixel of the CMOS detector separately by using an array of mini-lenses positioned in front of every pixel. In this configuration, the minilenses have an image-telecentric function. The main advantage is that the pupil of the first lens **1030** can be enlarged, or the aperture can be eliminated while compensating for the increase in spherical aberration by a local correction optics in the mini-lens **1150.** In this way the sensitivity of the sensor assembly can be improved. A second mini-lens array (not shown in Figure 11) may be added between the spectral filter **1160** and the CMOS pixels **102,** to focus the parallel rays back to the photodiodes of the pixels so as to maximize the fill factor.

For the first and second lenses **1130, 1140,** commercially available lenses may be used. The skilled person will appreciate that lenses typically used in other smart phone cameras or webcams of comparable quality can also be used. The aforementioned iSight camera has a 6 x 3 mm CMOS sensor with 8 megapixels, 1.5 µm pixel size, a very large aperture of f/2.2, an objective focal length of about f = 7 mm, and a pupil diameter about 3.2 mm. The viewing angle is of the order of 1 rad x 1 rad. If we assume that the resolution of the camera is roughly the pixel size (1.5 micron), we can conclude (from Abbe's law) that the aberrations of the lens are corrected for all the rays of the viewing angle selected by the aperture.

Figure 10 illustrates a variation of the arrangement of Figure 11, optimized for manufacturing in a single lithographic process. The first lens **1230** is similar to the first lens **1130** of the previous embodiment, but the angle-correcting second lens **1140** is replaced by a Fresnel lens **1240** with the same focal length f and the mini-lens arrays **1150** by Fresnel lens arrays **1250.** The advantage is that they are completely flat and can be produced by nano-electronics technology (with discrete phase zones) . A second mini-lens array **1270** may be added between the spectral filter **1260** and the CMOS pixels **102,** to focus the parallel rays back to the

photodiodes of the pixels so as to maximize the fill factor. Thus the camera is essentially a standard camera as the iSight but in which the CMOS sensor is replaced by a specially designed multi-layer sensor in which all the components are produced in one integrated block within the same lithographic process. This multilayer sensor is cheap in mass production, compact, robust and it need not be aligned. Each of these five layers **1240, 1250, 1260, 1270, 102** has its own function to meet the requirements imposed by the present invention.

As the minimal angle of a cone generated by a lens of diameter d is of the order of λ/d, with λ the wavelength of the light, the minimal cone angle is 1/10 radian for a mini-lens diameter d = 8.5 μm and λ = 850 nm. With a good quality spectral interference filter this corresponds to a spectral window of about 3 nm.

In the arrangements of Figures 8-10, the characteristics of the optics will result in a non-planar focal plane. To compensate this effect, the picture elements of the detector may be arranged on a substrate having a curvature that follows the focal plane of the optics. As a result, the reflected and filtered spots will be in focus, regardless of where they reach the detector. The desired curvature of the substrate of the detector can be obtained by using flex-chip technology, or by composing the substrate by combining differently oriented tiles. This solution is schematically illustrated in Figure 11, which shows telecentric optics **1330**, followed by a narrow band-pass filter **1360**, and a curved pixel layer **102**, the curvature of which is adapted to follow the shape of the focal plane of the telecentric optics **1330**.

When it is not possible (or not desirable) to arrange the optics in such a way as to ensure that light rays following different paths all pass through the narrow bandpass filter under the same (perpendicular) angle, the problem of having different filter characteristics with different angles of incidence may be resolved at the source. In particular, the VCSEL array may be configured

such that different spots have different respective wavelengths. This configuration may be obtained by using a tiled laser array, or by providing means for modulating the wavelength of individual VCSELs in the VCSEL array. This solution is schematically illustrated in Figure 12, which shows a narrow band-pass filter **1460** arranged before the optics **1430** and the sensor array **102**. For clarity purposes and without loss of generality, two different angles of incidence with different respective wavelengths (λ_1, λ_2) have been indicated on the Figure. The different wavelengths (λ_1, λ_2) of the light sources are chosen to correspond to the maximum of the passband of the narrow bandpass filter under their respective angles of incidence.

Figure 13 illustrates an alternative optical arrangement, comprising a dome **1510** (e.g., a bent glass plate) with the narrow bandpass filter **1520** disposed on its inside (as illustrated) or outside (not illustrated) . The advantage of disposing the filter **1520** on the inside of the dome **1510**, is that the dome **1510** protects the filter **1520** from outside forces. The dome **1510** and the filter **1520** optically cooperate to ensure that incident light passes through the filter **1520** along a direction that is substantially normal to the dome's surface. Fish-eye optics **1530** are provided between the dome-filter assembly and the sensor **102**, which may be a CMOS or a CCD sensor or SPAD array. The fish-eye optics **1530** are arranged to guide the light that has passed through the dome-filter assembly towards the sensitive area of the sensor .

Optionally, further fish-eye optics are provided at the projector. In a specific embodiment, a plurality of VCSELs are mounted in a 1 x n or a m x n configuration, whereby an exit angle of the laser beam can be realized over a spatial angle of m x 1 rad in height and n x 1 rad in width.

In some embodiments of the present invention, the intensity of the spots can be kept substantially constant over the full depth range, by applying a stepped or variable attenuation filter at the

detector. Alternatively or in addition, also a non-symmetrical lens pupil can be provided for weakening the intensity of spots closer to the detector, while the intensity of the spots further away from the detector are received at full intensity. In this way clipping of the detector is avoided and the average intensity can be made substantially the same for all spots.

In some embodiments, the radiation source can be a VCSEL that can be split in different zones, whereby the laser ON time is controlled for the different zones. The images of the spots can thus be controlled to have a constant intensity, e.g. 2/3rd of the A/D range. Alternatively the driving voltage can be driven over the array of spots as function of the height, again to obtain a constant intensity. Such controlling can be referred to as a saturation avoidance servoing loop. The different VCSELs within the array can be controlled individually for intensity, varying the intensity of the individual VCSELs in the pattern while projected simultaneously.

In some other embodiments of the present invention, a micro prism matrix can be used in front of the narrow bandwidth filter, such that the radiation is incident within an angle of incidence between +9° and -9° on the filter. This allows to obtain narrow bandwidth filtering. The prism matrix can for example be made by plastic moulding.

In embodiments of the present invention, e.g. where active suspension vehicle applications are envisaged, the projection of the spot pattern is advantageously directed downwards, i.e. towards the road.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA), programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component(s) may also include other functions. The present

invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view).

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system (200) for determining a distance to an object comprising :

- a solid-state light source (210) arranged for projecting a pattern of discrete spots of laser light towards said object in a sequence of pulses;
- a detector (220) comprising a plurality of picture elements, said detector (220) being configured for detecting light representing said pattern of discrete spots as reflected by said object in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate said distance to said object as a function of exposure values generated by said picture elements in response to said detected light;

wherein said picture elements (220) are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10);

wherein said system is configured to perform said projecting and said detecting for at least two consecutive sequences of pulses, each of said sequences being operated with a different duration of said first predetermined time window and said second predetermined time window.

2. The system according to claim 1, wherein each of said plurality of picture elements comprises at least two sets of charge storage wells, said detecting of said first amount of light and said detecting of said second amount of light occurring at respective ones of said at least two sets of charge storage wells; and wherein each of said sets of charge storage wells is configured as a cascade.

3. The system according to claim 2, wherein each of said sets of charge storage wells is configured as a serially arranged cascade.

4. The system according to claim 2, wherein each of said sets of charge storage wells is configured as a parallelly arranged cascade.

5. The system according to any of the preceding claims, wherein for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back, and wherein a total storage capacity of said picture elements configured to detect said first amount of light is larger than a total storage capacity of said picture elements configured to detect said second amount of light.

6. A vehicle comprising a system (100) according to any of the previous claims arranged to operatively cover at least a part of an area surrounding said vehicle.

7. A camera, the camera comprising a system (100) according to any of claims 1 to 5, whereby the system (100) is adapted to add 3D information to the camera image based on information obtained from the system, making it possible to create a 3D image.

8. A method for determining a distance to an object, the method comprising :

- using a solid-state light source (210) to project (110) a pattern of spots of laser light towards said object in a sequence of pulses;
- using a detector (220) comprising a plurality of picture elements to detect (120; 130) light representing said pattern of spots as reflected by said object in synchronization with said sequence of pulses; and

- calculating (140) said distance to said object as a function of exposure values generated by said pixels in response to said detected light;

wherein said picture elements (220) generate said exposure values by accumulating, for each pulse of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window (10) and a second amount of electrical charge representative of a second amount of light reflected by said object during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10); and

wherein said projecting (110) and said detecting (120; 130) are repeated for at least two consecutive sequences of pulses, each of said sequences being operated with a different duration of said first predetermined time window and said second predetermined time window .

9. The method according to claim 8, wherein for each of said at least two consecutive sequences of pulses said first predetermined time window and said second predetermined time window are of substantially equal duration and occur back-to-back.

10. The method according to claim 8 or claim 9, wherein each of said plurality of picture elements comprises at least two charge storage wells, and wherein said detecting of said first amount of light and said detecting of said second amount of light occurs at respective ones of said at least two charge storage wells.

11. A computer program product comprising code means configured to cause a processor to carry out the method according to any of claims 8-10 .

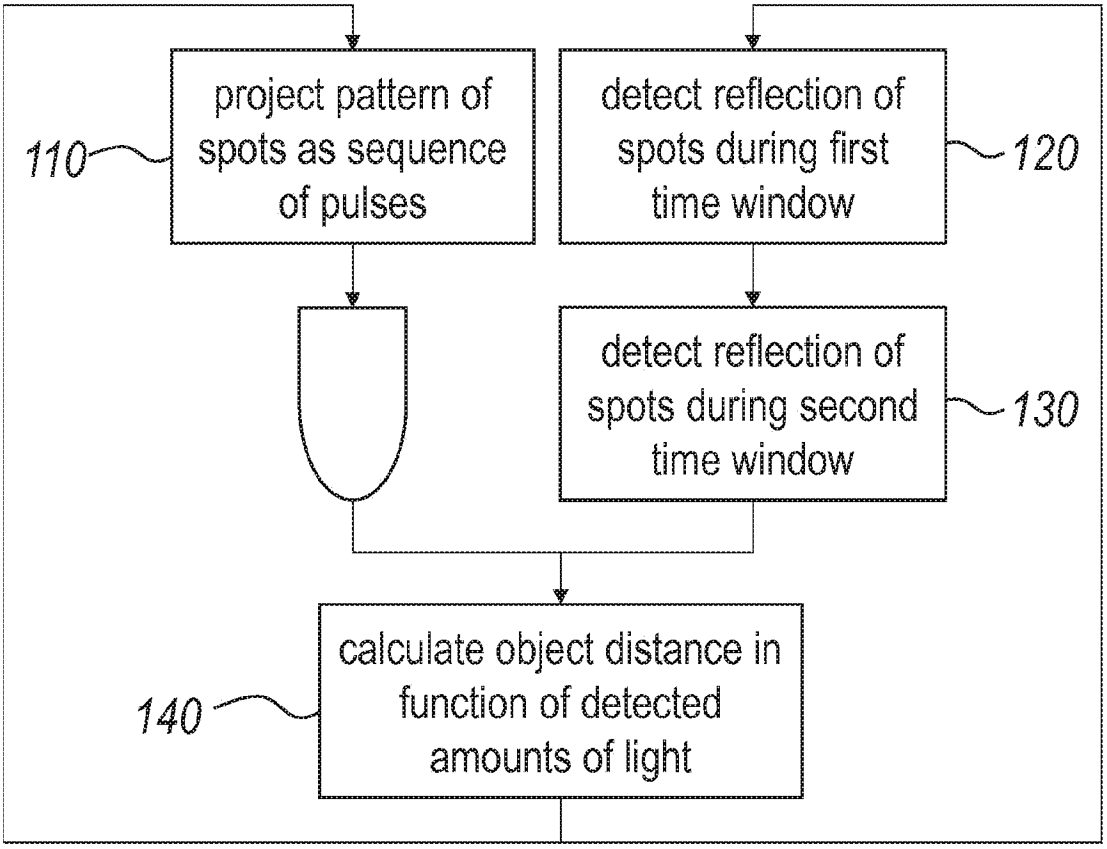

project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 1

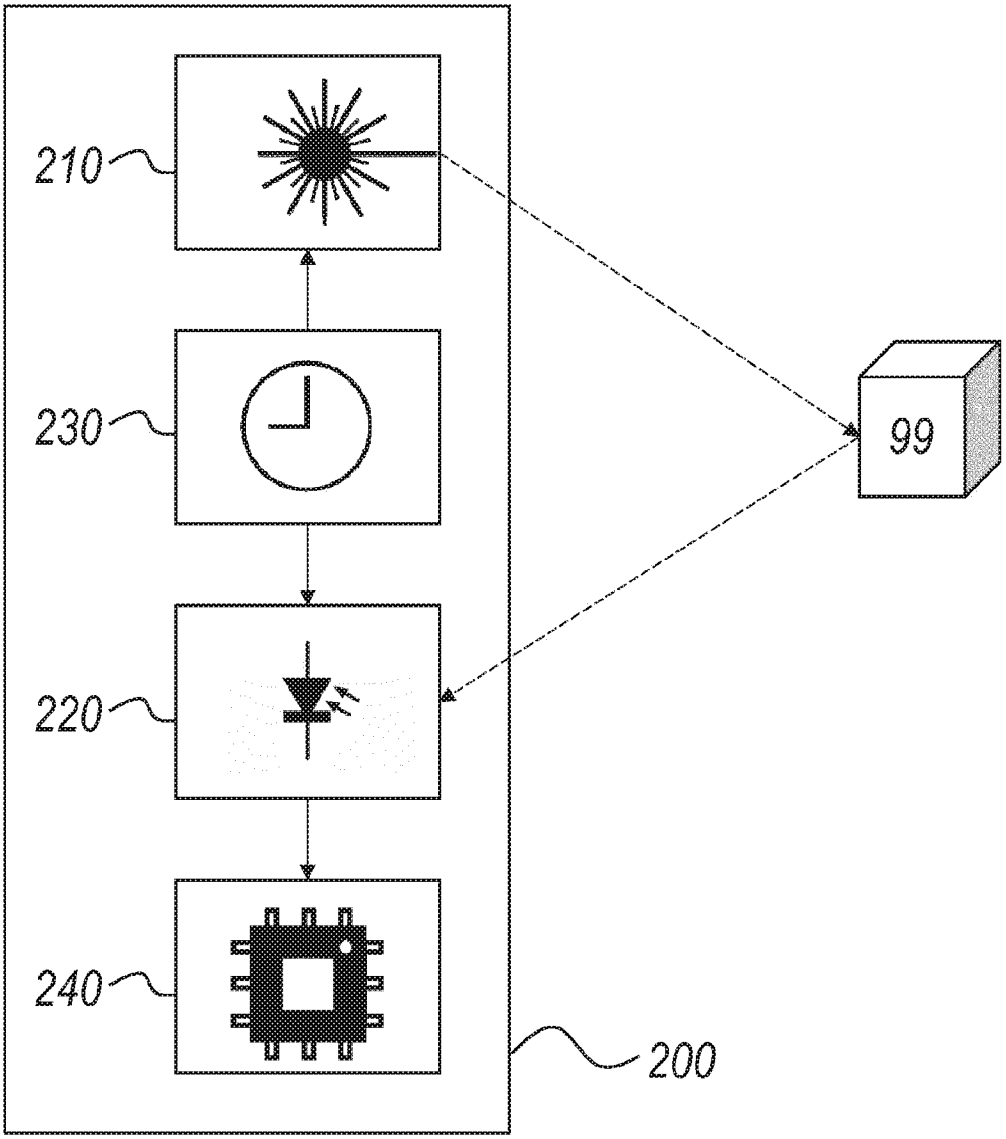


Fig. 2

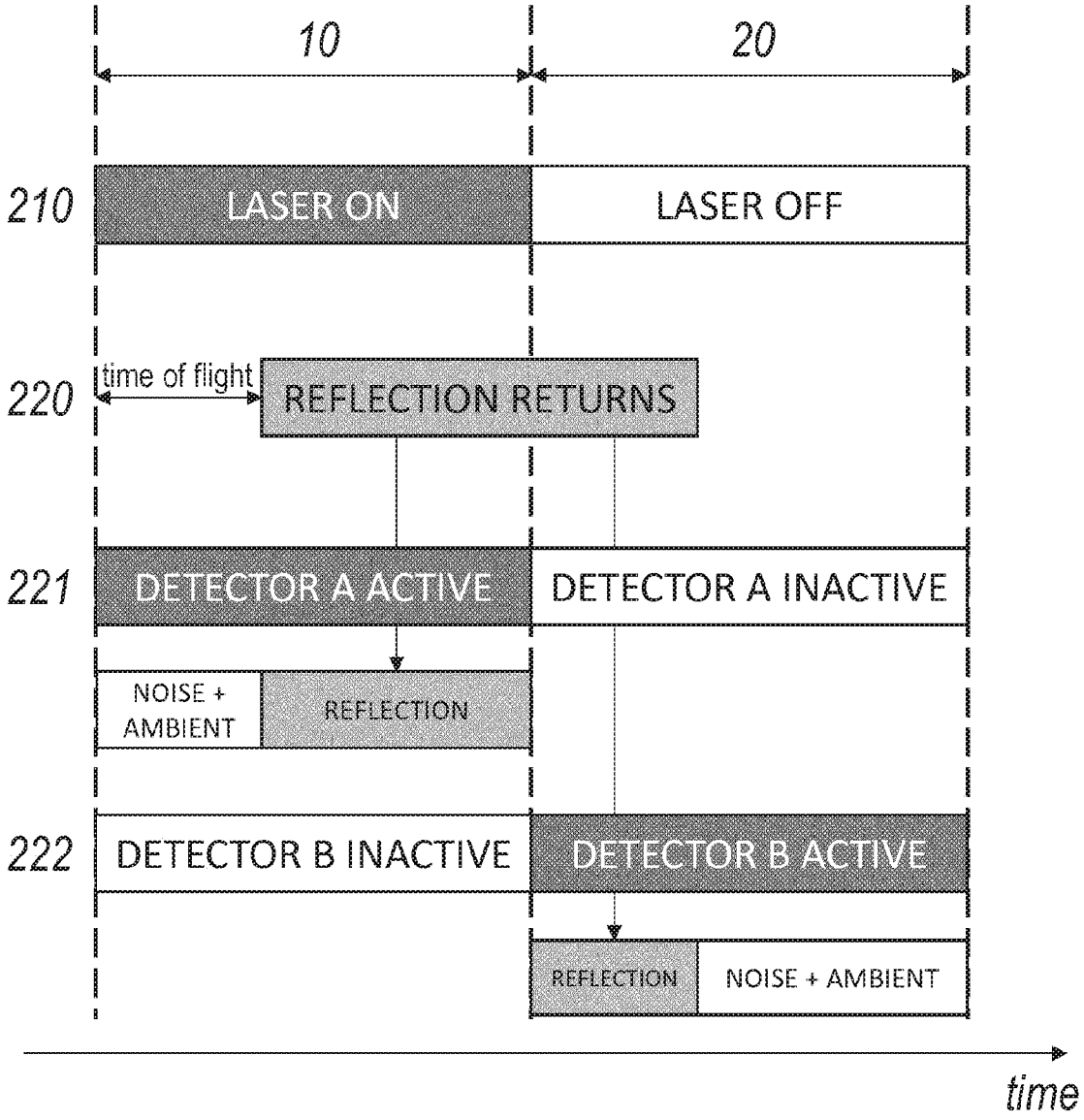

10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 3a

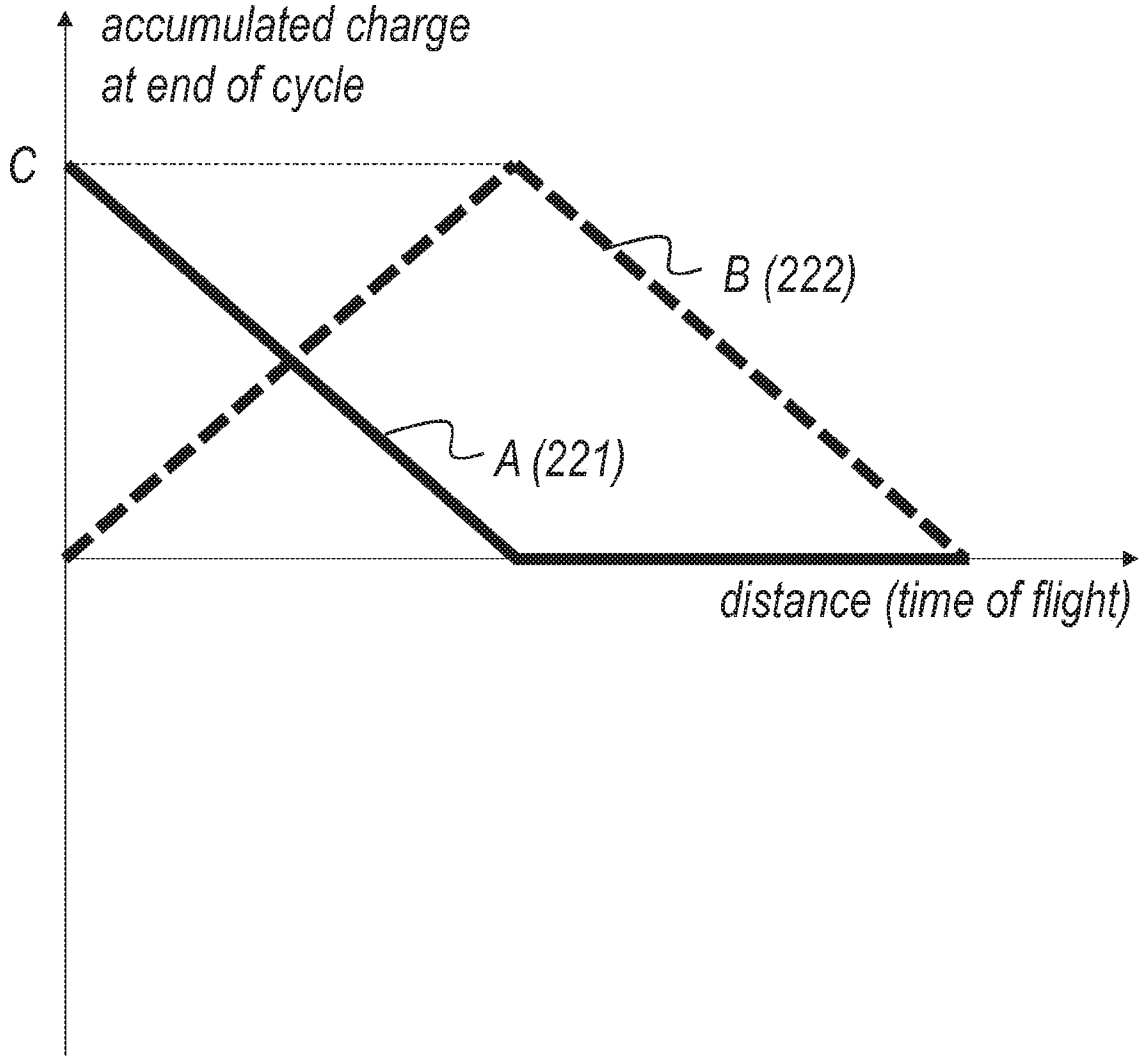

accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3b

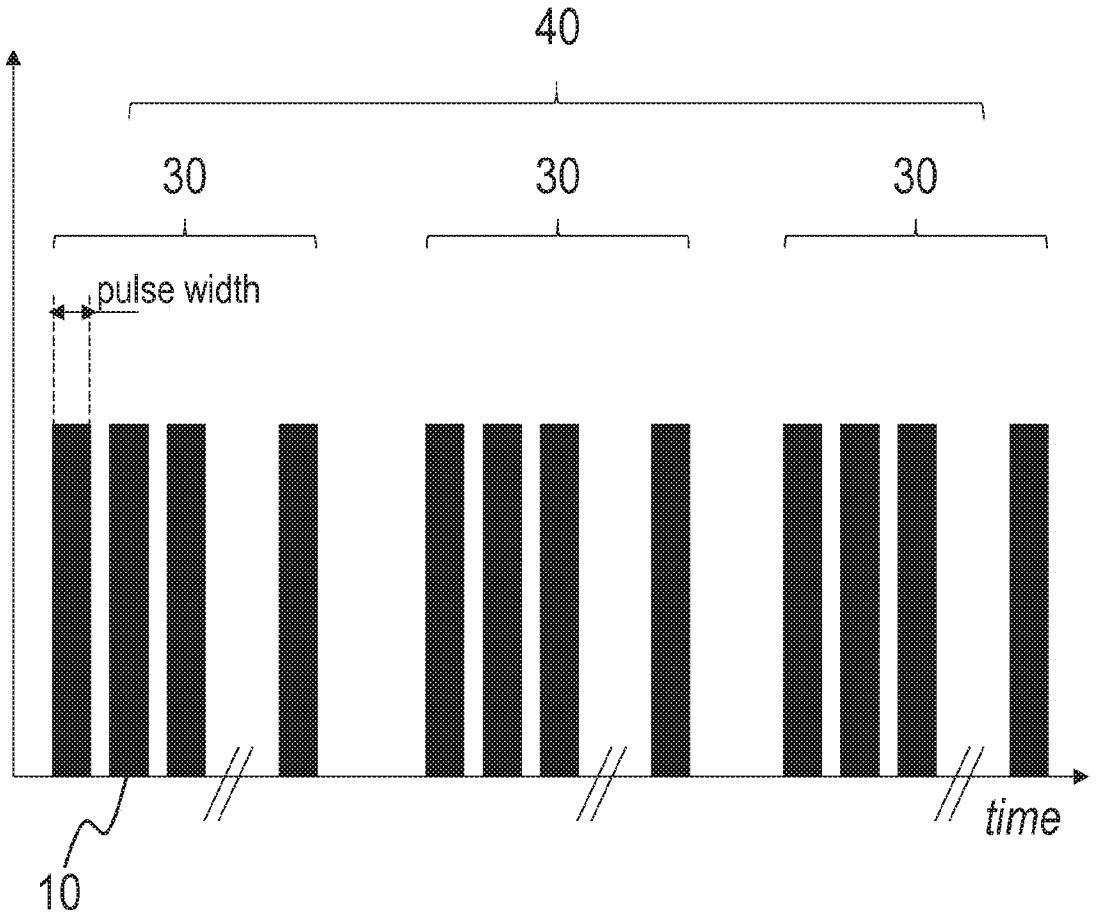


Fig. 3c

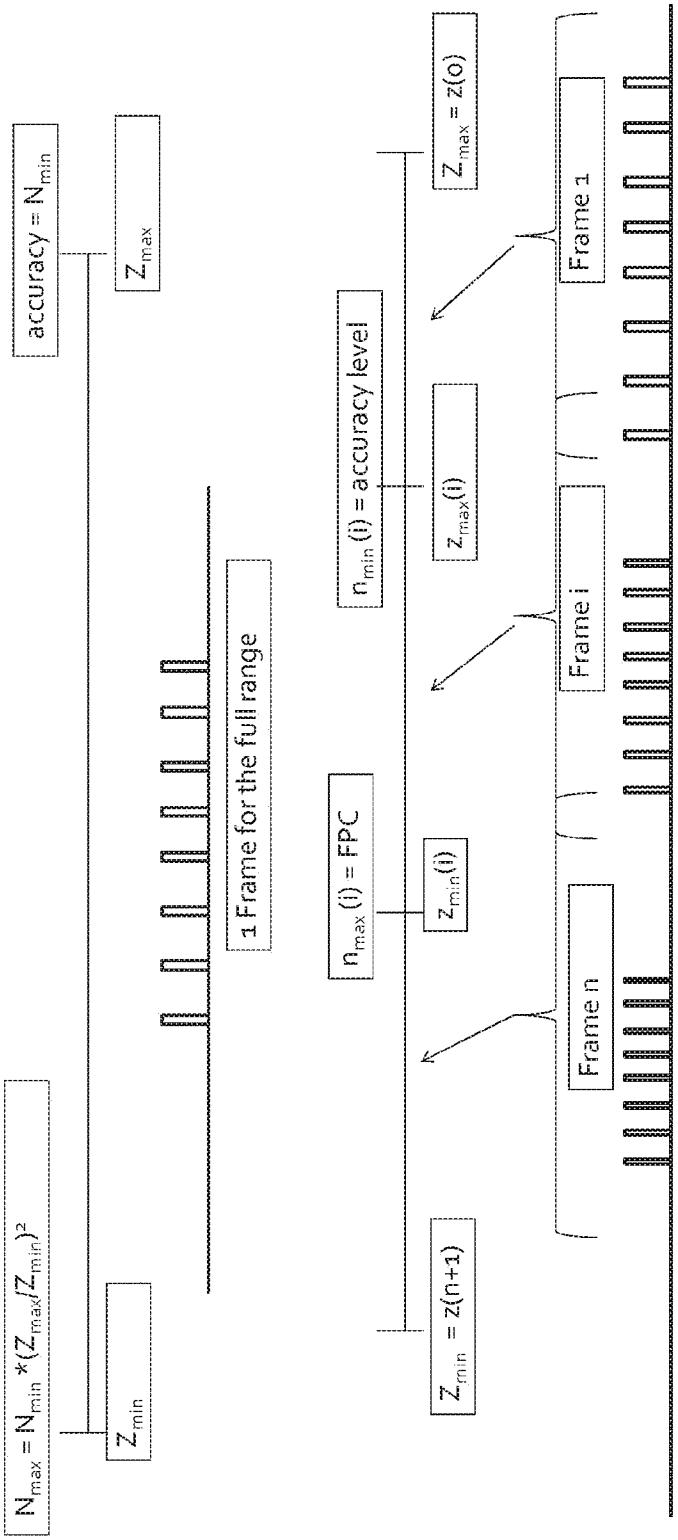

accuracy = N_{min}
Z_{max}
$N_{max} = N_{min} * (Z_{max}/Z_{min})^2$
Z_{min}
1 Frame for the full range
n_{min} (i) = accuracy level
n_{max} (i) = FPC
$Z_{max} = z(0)$
$Z_{max}(i)$
$Z_{min}(i)$
$Z_{min} = z(n+1)$
Frame 1
Frame i
Frame n

Fig. 3d

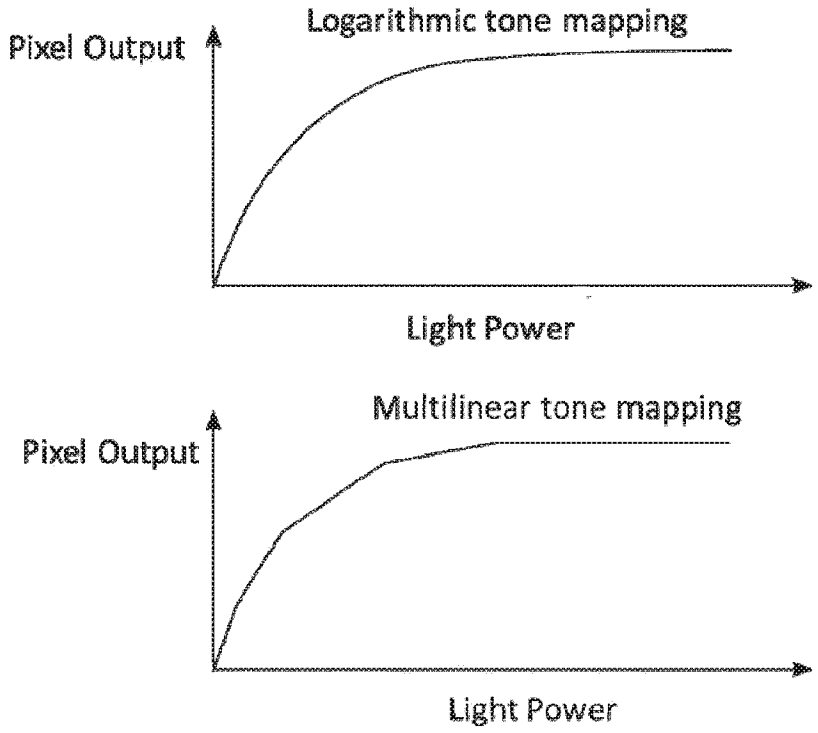

Logarithmic tone mapping
Pixel Output
Light Power
Multilinear tone mapping
Pixel Output
Light Power

Fig. 4

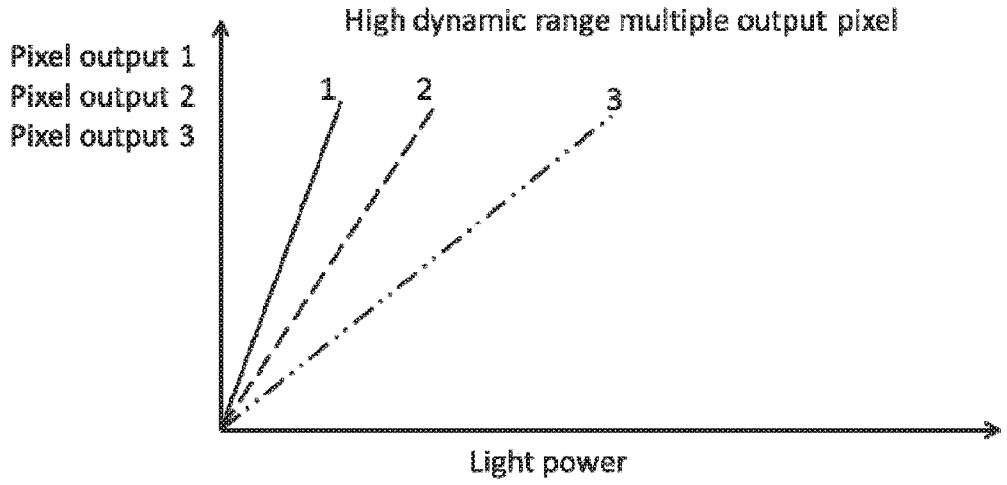

High dynamic range multiple output pixel
Pixel output 1
Pixel output 2
Pixel output 3
1
2
3
Light power

Fig. 5

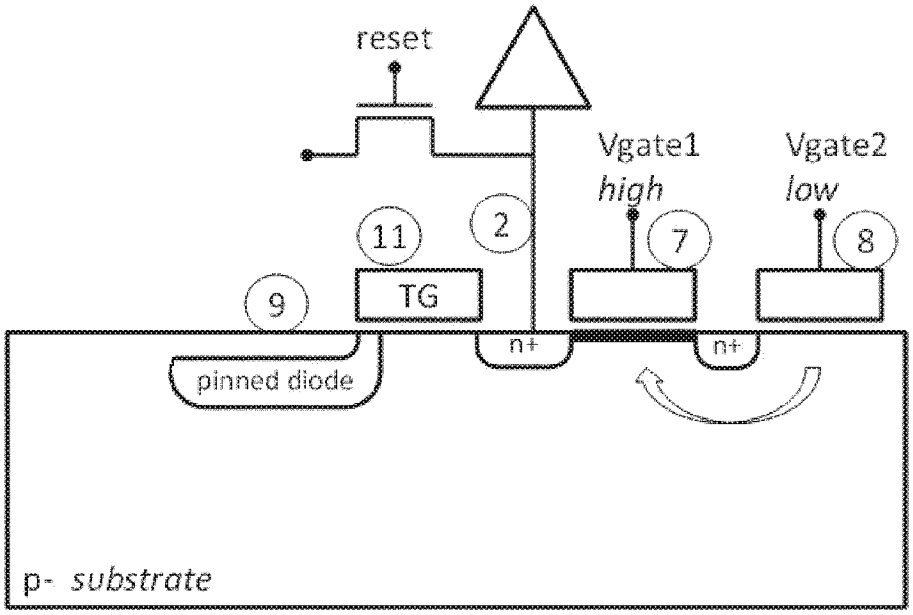

reset
Vgate1
high
Vgate2
low
11
2
7
8
9
TG
n+
n+
pinned diode
p- substrate

Fig. 6

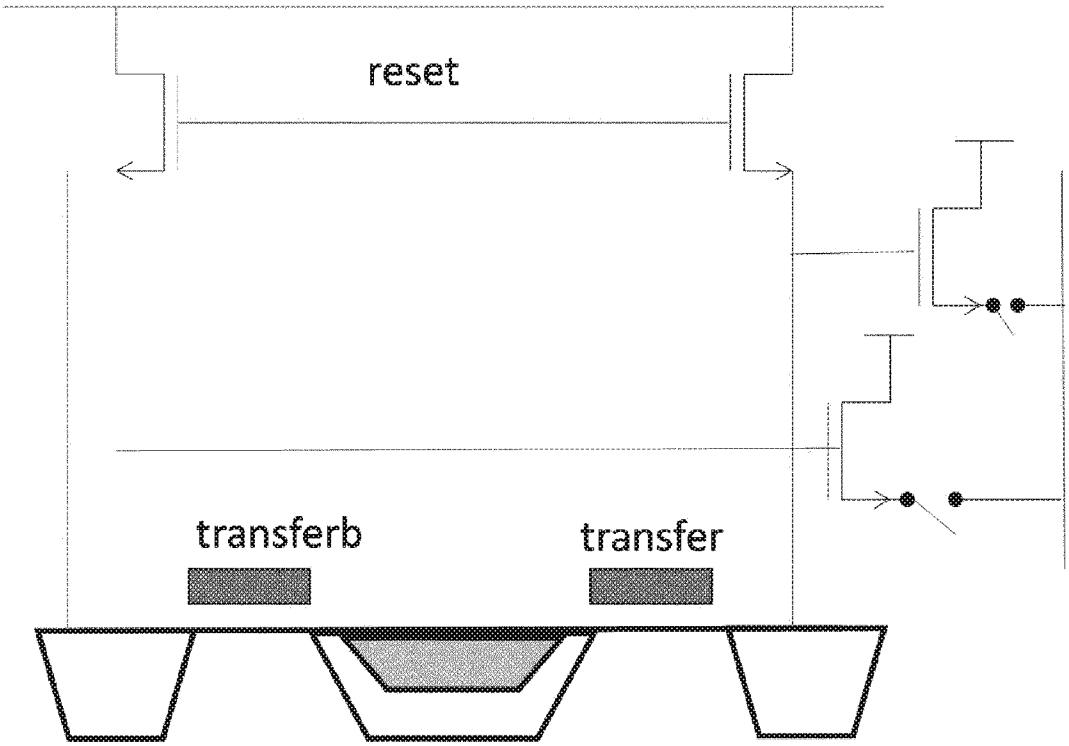


Fig. 7

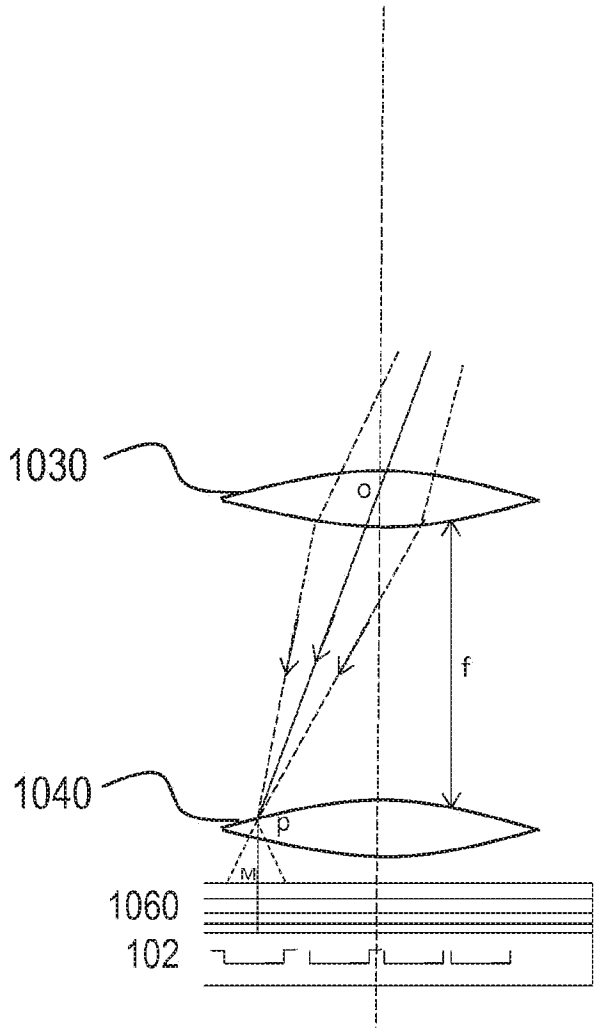


Fig. 8

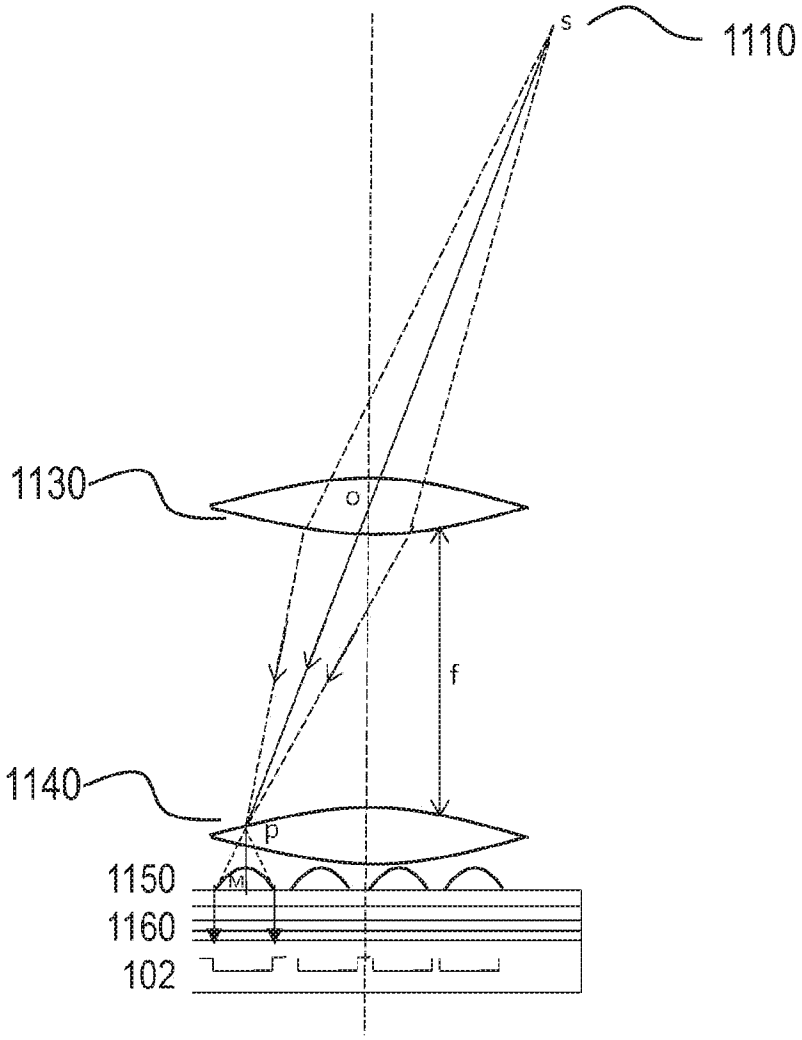


Fig. 9

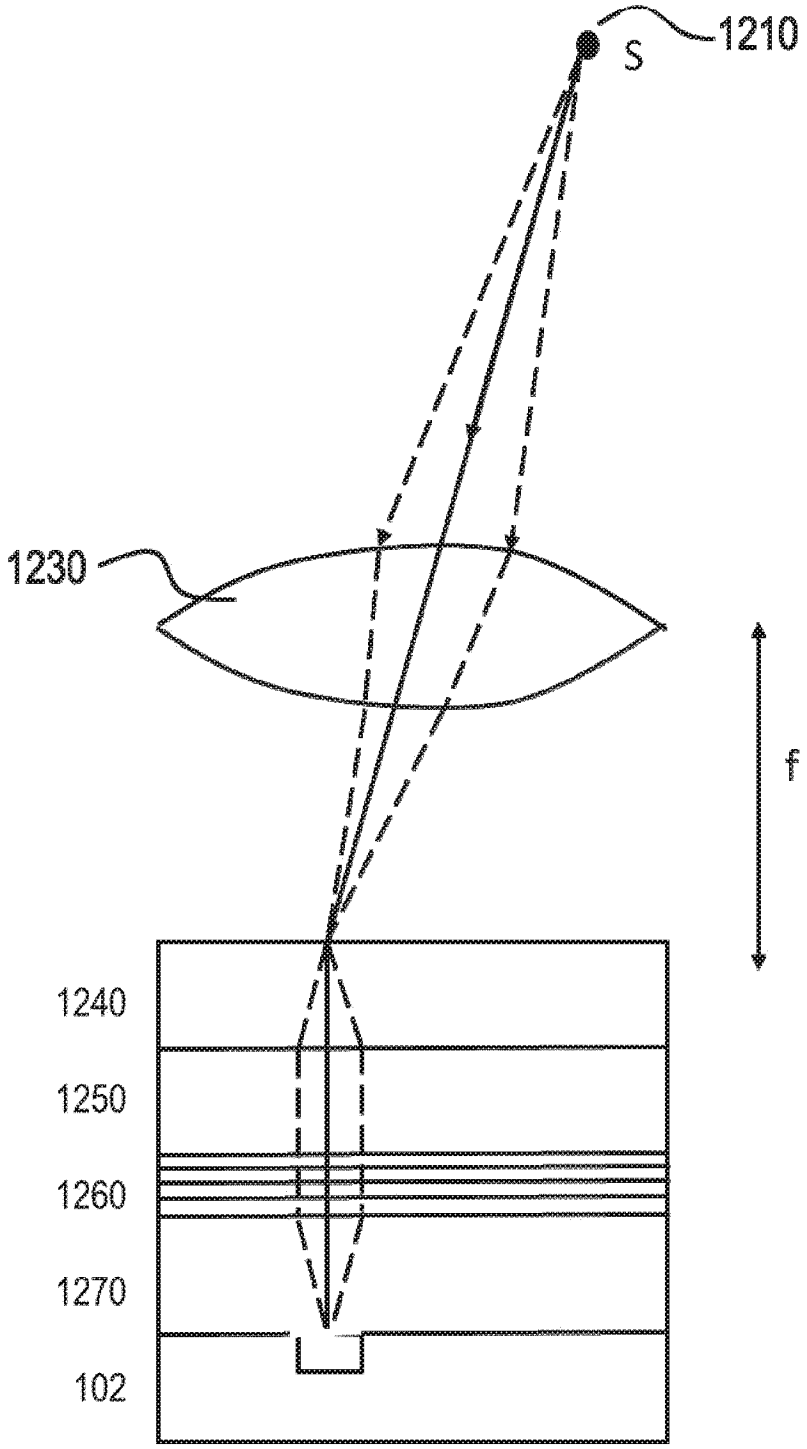


Fig. 10

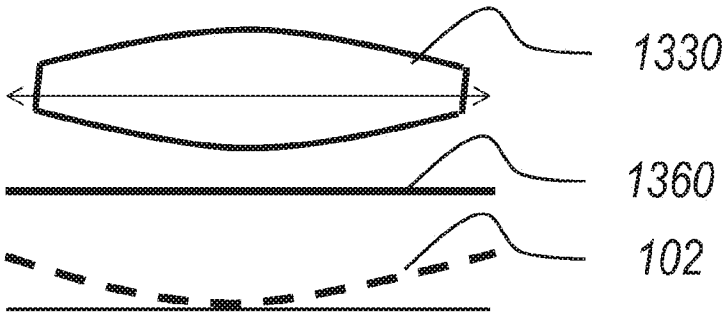


Fig. 11

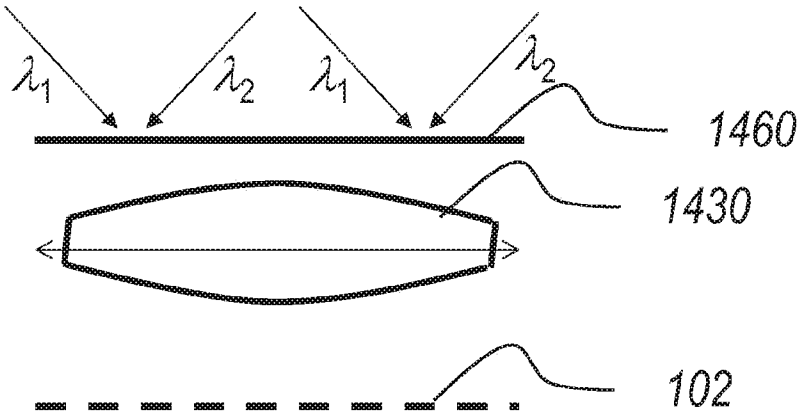


Fig. 12

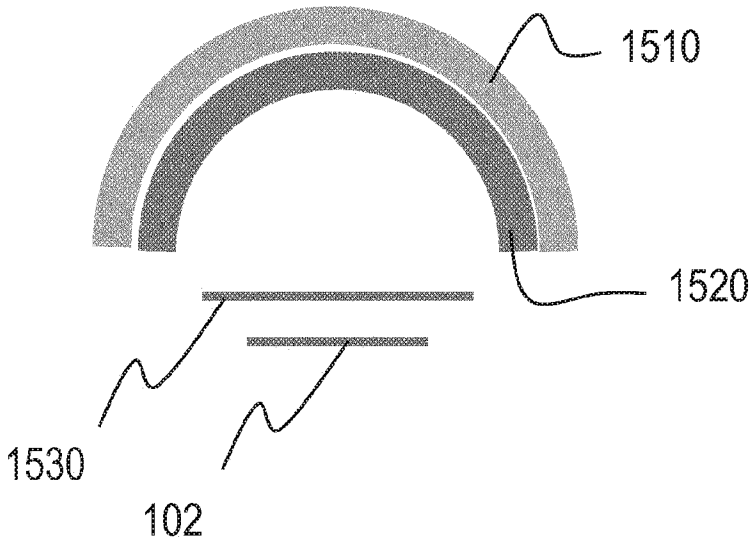


Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075096

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/89 G01S17/93 G01S17/10 G01S7/481 G01S7/486
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/148102 A1 (OGGIER THIERRY [CH]) 13 June 2013 (2013-06-13) paragraphs [0002] , [0008] , [0017] - [0028] , [0031] , [0033] , [0035] , [0039] ; figures 1,2,5b, 7	1-11
Y	BUTTGEN B ET AL: "Pseudonoise Optical Modulation for Real-Time 3-D Imaging With Minimum Interference" , IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS I: REGULAR PAPERS, IEEE, US, vol . 54, no. 10, 1 October 2007 (2007-10-01) , pages 2109-2119 , XP011194105 , ISSN: 1549-8328, DOI: 10.1109/TCSI.2007.904598 abstract paragraph [0001]	1-11

-/- .

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2018	26/01/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Metz , Carsten

Form PCT/ISA/210 (second sheet) (April 2005)

HESAI EX1002, P.777

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075096

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/231891 A1 (MASE MITSUHITO [JP] ET AL) 16 September 2010 (2010-09-16) paragraphs [0093] - [0101], [0129] - [0135], [0198] - [0211]; figures 9,6,10,24	2-4,8,10
Y	WO 2015/004213 A1 (XENOMATIX BVBA [BE]) 15 January 2015 (2015-01-15) page 4, line 26 - page 5, line 5	6

1

HESAI EX1002, P.778

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/075096

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 2013148102 A1	13-06-2013	NONE		
US 2010231891 A1	16-09-2010	CN 101784911	A	21-07-2010
		EP 2187237	A1	19-05-2010
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		US 2010231891	A1	16-09-2010
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		EP 3019824	A1	18-05-2016
		JP 2016530503	A	29-09-2016
		KR 20160029845	A	15-03-2016
		US 2016018526	A1	21-01-2016
		WO 2015004213	A1	15-01-2015

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
05 July 2018 (05.07.2018)

W!P O | PCT

(10) International Publication Number
WO 2018/122415 A1

(51) International Patent Classification:
G01S 17/10 (2006.01) *G01S 17/93* (2006.01)
G01S 17/89 (2006.01)

(21) International Application Number:
PCT/EP20 18/050080

(22) International Filing Date:
02 January 2018 (02.01.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16207630.1 30 December 2016 (30.12.2016) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available).* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.1 7(iv))*

Published:
— *with international search report (Art. 21(3))*

(54) Title: SYSTEM FOR CHARACTERIZING SURROUNDINGS OF A VEHICLE

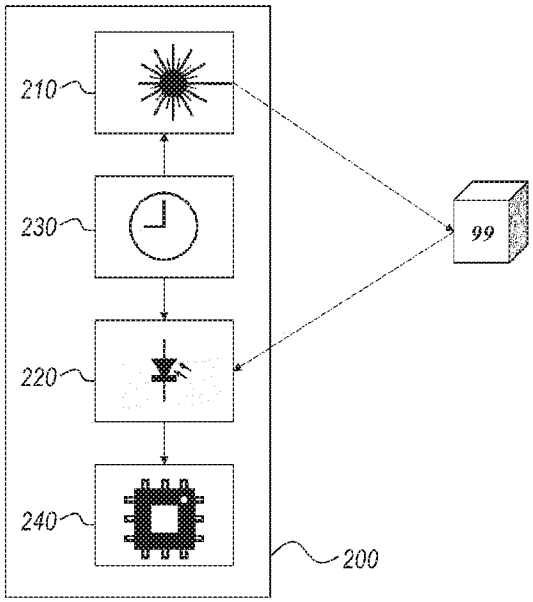


Fig. 1

(57) Abstract: The invention pertains to a system for characterizing surroundings of a vehicle, the system comprising: projection means (210) arranged for projecting a pattern of laser light towards said surroundings in a sequence of pulses; a detector (220) comprising a plurality of pixels, said detector (220) being configured for detecting light representing said pattern of laser light as reflected by said surroundings in synchronization with said sequence of pulses; and processing means (240) configured to calculate distances to objects (99) in said surroundings as a function of exposure values generated by said pixels in response to said detected light; wherein said detector (220) is further configured for detecting light forming a two-dimensional image of said surroundings at points in time that do not coincide with said sequence of pulses or at pixels that do not receive said light representing said pattern of laser light as reflected by said surroundings.

WO 2018/122415 A1

System for characterizing surroundings of a vehicle

Field of the Invention

The present invention pertains to the field of systems for determining a distance to an object, in particular to sensing systems to be used for the characterization of a scene or a part thereof, as may be used to detect obstacles in the vicinity of a vehicle .

Background

In the field of remote sensing technology, in particular with regard to the generation of high-resolution maps of a scenery which can be used in control and navigation applications including automotive and industrial applications, gaming applications, and mapping applications, it is known to use triangulation-based and time-of-flight based sensing to determine the distance of objects from a sensor.

A high-accuracy medium-range surround sensing system for vehicles that makes use of triangulation, is known from international patent application publication WO 2015/004213 A1 in the name of the present applicant. In that patent application, the localization of objects is based on the projection of pulsed radiation spots and the analysis of the displacement of detected spots with reference to predetermined reference spot positions. More in particular, the system of the cited patent application uses triangulation. However, the accuracy that can be achieved correlates with the triangulation base, which limits the miniaturization that can be achieved.

Time-of-flight based techniques include the use of RF modulated sources, range gated imagers, and direct time-of-flight (DToF) imagers. For the use of RF modulated sources and range gated imagers, it is necessary to illuminate the entire scene of interest with a modulated or pulsed source. Direct time-of-flight

systems, such as most LIDARs, mechanically scan the area of interest with a pulsed beam, the reflection of which is sensed with a pulse detector. The optical power emitted by present semiconductor lasers cannot meet the power requirements necessary for operations in the known LIDAR systems to be of practical use in automotive applications (e.g. for ranges up to 250 m). Unpublished European patent application no. EP 15 191 288.8, in the name of the present applicant, describes a system for determining a distance to an object that overcomes such limitations. It comprises: a solid-state light source arranged for projecting a pattern of discrete spots of laser light towards the object in a sequence of pulses; a detector comprising a plurality of pixels, the detector being configured for detecting light representing the pattern of discrete spots as reflected by the object in synchronization with said sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by said pixels in response to said detected light. The pixels are configured to generate said exposure values by accumulating, for each pulse of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window, said second predetermined time window occurring after said first predetermined time window.

As remote sensing technology is increasingly being relied on to provide vehicle-safety features, advanced driver assistance systems (ADAS), and even autonomous (or "self-driving") cars, there is a need for a system that more accurately characterize the surroundings of the vehicle in which the system is mounted.

Summary of the Invention

According to an aspect of the present invention, there is provided a system for characterizing surroundings of a vehicle, the system comprising:

- a projection means arranged for projecting a pattern of laser light towards said surroundings in a sequence of pulses, said pattern of laser light comprising a pattern of discrete spots ;
- a detector comprising a plurality of pixels, said detector being configured for detecting light representing said pattern of laser light as reflected by said surroundings in synchronization with said sequence of pulses; and
- processing means configured to calculate distances to objects in said surroundings as a function of exposure values generated by said pixels in response to said detected light;

wherein said detector is further configured for detecting light forming a two-dimensional image of said surroundings at points in time that do not coincide with said sequence of pulses or at pixels that do not receive said light representing said pattern of laser light as reflected by said surroundings.

It is an advantage of the invention that the characterization of the surroundings can be improved by combining 2D information and 3D information obtained from the same sensor at interleaved points in time. The 3D information is obtained from the system when used as a range sensor, by capturing the reflected light patterns in synchronization with their projection; and the 2D information is obtained from the system when used as a digital camera between the range sensing pulses.

The projection means preferably comprises a solid-state laser; it could in particular be a VCSEL array or a solid-state laser provided with an adequate grating. The pattern of laser light is preferably a pattern of spots, in particular discrete spots. The sequence of pulses may be periodically repeated, to allow for a continuous updating of the characterization of the surroundings.

In an embodiment of the system according to the present invention, the pixels are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said objects during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by said objects during a second predetermined time window, said second predetermined time window occurring after said first predetermined time window.

It is an advantage of this embodiment that it uses range-gated LIDAR techniques to obtain accurate distance information in a small form factor.

In an embodiment of the system according to the present invention, said processing means are adapted to determine said distances by determining a displacement of features of said detected light representing said pattern of laser light as reflected by said surroundings with reference to predetermined feature positions.

In this embodiment, the respective exposure values of the different pixels of the detector are analyzed to determine in which pixels reflections of the projected pattern (e.g. spots) are detectable, and in which they are not. In this manner, the displacement of parts of the reflected pattern relative to predetermined positions (e.g. spot positions) can be determined, which yields information about the distance of the objects that have reflected the respective parts of the projected pattern. It is an advantage of this embodiment that it uses familiar triangulation-based techniques to obtain accurate distance information .

In an embodiment, the system according to the present invention comprises illumination means configured to project a bundle of light onto said surroundings at said points in time that do not coincide with said sequence of pulses.

The bundle of light is intended for a homogeneous illumination of the relevant part of the surroundings, preferably coinciding with the field of view of the detector, so, unlike the projected pattern used for ranging, it must be substantially homogeneous. It is an advantage of this embodiment, that the scenery to be captured in the 2D image can be adequately lit, even when the ambient light conditions are unfavorable (e.g., at night) .

In a particular embodiment, the projection means and the illumination means share a common light source.

It is an advantage of this particular embodiment, that the system can be kept compact by avoiding the need for multiple light sources .

In a more particular embodiment, the common light source comprises a VCSEL array, and the illumination means further comprises an actively steered diffuser, configured to be activated at said points in time that do not coincide with said sequence of pulses, so as to diffuse light originating from the VCSEL array to form the bundle.

It is an advantage of this more particular embodiment, that a VCSEL array, which is well suited for projection of structured light, can also be used to provide the illumination required for 2D image capturing.

In an embodiment of the system according to the present invention, the plurality of pixels of the detector are provided with a time-dependent filter allowing light in different wavelength bands to reach the plurality of pixels at different ones of said points in time .

It is an advantage of this embodiment that an RGB image can be produced by combining three different 2D exposures that are slightly offset in time. An RGB image yields more accurate

automated feature recognition and is generally more suited for visual reproduction to a human user than a monochrome image.

In an embodiment of the system according to the present invention, the different pixels of the plurality of pixels of the detector are provided with different filters allowing light in different wavelength bands to reach the different pixels at said points in time.

It is an advantage of this embodiment that an RGB image can be produced by combining exposure values that are obtained at pixels that are slightly offset in space. An RGB image yields more accurate automated feature recognition and is generally more suited for visual reproduction to a human user than a monochrome image.

According to an aspect of the present invention, there is provided a vehicle comprising the system according to any of the preceding claims arranged so as to characterize an area surrounding said vehicle.

The present invention is well suited for use in vehicles, in particular road vehicles such as automobiles. The system may thus advantageously contribute to vehicle-safety features, advanced driver assistance systems (ADAS), and even autonomous (or "self-driving") cars. As sensors in automotive applications are competing for space, it is an additional advantage of the present invention that it combines multiple functions in the same sensor, thus providing 2D and 3D sensor fusion without requiring an additional external 2D sensor.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 schematically illustrates an embodiment of the system according to the present invention;

Figures 2-4 illustrate the operating principles of a LIDAR-based embodiment of the system according to the present invention;

Figure 5 presents several timing diagrams that can be used in embodiments of the present invention;

Figure 6 schematically illustrate a pixel arrangement for use in an embodiment of the system according to the present invention; and

Figure 7 schematically illustrate timing diagrams that can be used in embodiments of the present invention.

Detailed Description of Embodiments

Figure 1 schematically illustrates an embodiment of the system according to the present invention.

The system is intended and adapted for characterizing surroundings of a vehicle. The surroundings may include the area in front of the vehicle, including the road surface ahead of the vehicle; likewise, it may include the area behind the vehicle (in particular, when the vehicle is reversing) ; it may include any space in the vicinity of the vehicle where obstacles or other road users may be present. The surroundings of the vehicle may extend to a distance of meters, tens of meters, or even hundreds of meters. The characterization is performed by determining distances to objects in the surroundings. While distance is a fundamental measurement parameter, estimates of derived variables such as velocity (including direction of motion) and acceleration of the detected objects may be determined on the basis of multiple distance measurements at different points in time. For complex objects, which may be recognized by combining information from multiple spatially diverse measurement points, additional

parameters such as orientation and rotation may also be derived. As all measurements are relative to the sensor, measurements of "fixed" objects may also provide information about the velocity, acceleration, orientation (pitch, yaw, roll), and rotation of the sensor, and thus of the vehicle onto which it is mounted.

The system comprises projection means **210** arranged for projecting a pattern of laser light towards the surroundings in a sequence of pulses; a detector **220** comprising a plurality of pixels, the detector **220** being configured for detecting light representing the pattern of laser light as reflected by the surroundings in synchronization with the sequence of pulses; and processing means **240** configured to calculate distances to objects **99** in the surroundings as a function of exposure values generated by the pixels in response to the detected light.

If the system works according to the time-of-flight (LIDAR) principle, the pixels **220** may be configured to generate the exposure values by accumulating, for all of the pulses of the sequence, a first amount of electrical charge representative of a first amount of light reflected by the objects **99** during a first predetermined time window **10** and a second electrical charge representative of a second amount of light reflected by the objects during a second predetermined time window **20**, the second predetermined time window **20** occurring after the first predetermined time window **10**.

The operating principle of such a LIDAR-based system is illustrated by the timing diagrams in Figures 2-4. For clarity reasons, only a single pulse of the pulse sequence which is repeated periodically is illustrated, which consists of a first time window **10** and a second time window **20**. The principle is described, by way of example, with reference to a projection means comprising a solid-state light source.

As can be seen in Figure 2, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the

pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first well **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second well **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first well **221** and the larger the proportion of the pulse that will be detected in the second well **222**.

If the leading edge of the reflected pulse arrives after the closing of the first well **221** (i.e., after the end of the first time window **10**) , the proportion of the reflected pulse that can be detected in the second well **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge **A**, **B** in each of the respective wells **221**, **222** for varying distances of the object **99** is shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of **A** and **B**:

- For time of flight delays up to the duration of the first time window **10**, **B** is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value **B/(B+A)** may be used, removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.
- For time of flight delays exceeding the duration of the first time window **10**, **A** consists of daylight and noise contributions only (not illustrated), and **C–B** is substantially proportional (after correcting for the inverse square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 2 and 3 illustrate the principle of the invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 4 schematically illustrates exemplary timing characteristics of such a sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

Various optional features of a time-of-f light based sensing system are described in unpublished European patent application no. EP 15 191 288.8, in the name of the present applicant, the contents of which are incorporated by this reference for the purpose of

enabling the skilled person to include these features in embodiments of the present invention.

If the system works according to the triangulation principle, the processing means **240** may be adapted to determine the distances by determining a displacement of features of the detected light representing the pattern of laser light as reflected by the surroundings with reference to predetermined feature positions. Preferably, the projected pattern is a pattern of spots of laser light, and the distances are determined by determining a displacement of detected spots that represent the projected spots as reflected by objects in the surroundings, with reference to predetermined spot positions.

Various optional features of a triangulation based sensing system are disclosed in international patent application publication WO 2015/004213 A1 in the name of the present applicant, the contents of which are incorporated by this reference for the purpose of enabling the skilled person to include these features in embodiments of the present invention.

According to the invention, the detector **220** is further configured for detecting light forming a two-dimensional image of the surroundings at points in time that do not coincide with the sequence of pulses or at pixels that do not receive said light representing said pattern of laser light as reflected by said surroundings .

In view of the accuracy requirements of vehicular ranging systems, CMOS sensor arrays having a total array size in the order of 1 megapixel are typically selected. The inventors have found that despite the relatively coarse size of the pixels used in such sensors, in the order of 10 µm, the combined sensor is capable of yielding a surprisingly acceptable 2D image quality when used in combination with adequate optics to form a rudimentary digital camera .

The invention, and in particular the concept of detecting light forming a two-dimensional image of the surroundings at points in time that do not coincide with the sequence of pulses, is based *inter alia* on the insight of the inventors that in the time intervals between the ranging pulses, or between sequences of ranging pulses, the pixel array may be used to capture digital 2D images of the surroundings. In this way, two different functions, which provide complementary information, may be combined in a single sensor.

The invention, and in particular the concept of detecting light forming a two-dimensional image of the surroundings at pixels that do not receive said light representing said pattern of laser light as reflected by said surroundings, is further based on the insight of the inventors that as ranging systems rely on the detection of reflections of specific light patterns, such as line patterns or spot patterns, only a small subset of the total number of pixels is actually being used at any given time. This specific concept may be used when sufficient ambient light reaches the detector when the ranging function (projection and detection of a light pattern) is operational, such that the pixels which do not receive part of the projected pattern can form an image from the received light .

While the pattern-reflection based range sensing provides a depth map containing 3-dimensional information only at the points illuminated by the projected pattern of laser light, the 2D images captured in-between provide a visual snapshot of the entire scenery. The depth map can be registered to the 2D images, and depth information can be obtained for every pixel in the 2D images by interpolating the depth map values. As the 2D images and the 3D information are obtained from the same sensor, there is no parallax between the different images, which facilitates the registration .

Preferably, the interpolation of the depth map values is assisted by the pixel values in the 2D images. Thus, for example, an area

between different depth map values which corresponds to a regular luminance or color gradient in the 2D image, may be interpolated in the depth dimension by linear interpolation. An area between different depth map values which includes an abrupt step in the luminance or color value, may be interpolated by a stepwise constant depth value, with the step in the depth value is made to coincide with the step in the luminance or color value.

The combined 2D/3D image combines more information about the surroundings than either of the sources taken separately. A machine vision system may be supplied with the combined 2D/3D image to detect relevant features in the environment, such as pedestrians, vehicles, fixed objects, debris, any unevenness in the road surface, and the like.

The 2D images are preferably captured in timeslots occurring between *frames*, e.g. between sequences of pulses. Exemplary timing diagrams are shown in Figure 5. In diagram a (not according to the invention), 5 consecutive *frames* (each representing a sequence of pulses, for example a sequence 30 of Figure 2) are all used for 3D range sensing. In diagram d, one *frame* of the first four *frames* is replaced by a 2D image capturing timeslot, of the exact same duration as the remaining *frames;* hence, the overall cadence of the frames remains the same, but only 75% of the *frame* time slots are used for range sensing (the skilled person will appreciate that this figure may be varied according to the requirements of the application; the relative time reserved for range sensing may for example be 10%, 20%, 25%, 33%, 40%, 50%, 60%, 67%, 75%, 80%, etc.). In diagrams b and c, the time used for 2D image capturing is made longer and shorter than the range sensing *frames*, respectively.

Generally, the time used for 2D image capturing may be selected in function of the desired exposure time, which must be sufficiently long to accumulate a sufficient amount of light in the pixels and sufficiently short to avoid motion blur (when the sensor and/or objects in the surroundings are in motion). The time slot used for

2D image capturing may also be extended to allow consecutive capturing of light in different wavelength bands (e.g., red, green, and blue light, to generate an RGB image), as explained below with reference to Figure 7, diagram b.

As explained in great detail in the aforementioned patent applications WO 2015/004213 A1 and EP 15 191 288.8, several measures must be taken to filter out ambient light (in particular, sunlight) from the signal that reaches the sensor, such that the light that reaches the sensor is substantially limited to the desired reflection of the projected light pattern, in order to ensure accurate and long-range distance sensing. These measures include the use of a narrow bandpass filter, and optics that guide the incoming reflected light on a path that is substantially perpendicular to the narrow bandpass filter.

The measures required to optimize the range-sensing capabilities limit the usefulness of the pixel array as a 2D image camera. As the sensors is mounted on a vehicle, which, when in use, is normally moving, any increase of the exposure time to increase the total amount of light captured in a single exposure is limited by the acceptable amount of motion blur - in practice, this is a severe limitation.

In view of these negative effects, the inventors have found that the following optional features lead to better performance in the 2D image capturing.

A first solution consists of using a bandpass filter at the sensor side which can be electronically or electromechanically controlled to be active in synchronization with the pulse sequence and inactive at the points in time when the 2D images are captured.

A second solution consists of providing the system with illumination means configured to project a bundle of light onto the surroundings at the points in time that do not coincide with the sequence of pulses. Such illumination means may provide a

flash of illumination, as is often done in conventional photography in low light conditions. The projection means **210** and the illumination means may share a common light source, in particular a VCSEL array. This ensures that a "flash" can be emitted in the same wavelength band for which the narrow bandpass filter is optimized, thus maximizing the amount of light that will reach the pixel array. If the common light source is VCSEL array, the illumination means may further comprise an actively steered diffuser, configured to be activated at the points in time at which the 2D images are taken (which do not coincide with the sequence of pulses) , so as to diffuse light originating from the VCSEL array to form the desired bundle of light (instead of a series of spots) . The illumination means may also be integrated with the headlight assembly, whereby the light source must be chosen such that it provides sufficient light power in the part of the spectrum that can pass through the narrow bandpass filter at the sensor side.

In view of the above considerations, one particularly advantageous embodiment of the system according to the present invention operates according to the time-of-flight based principle described above, whereby a VCSEL array is provided to project a pulsed pattern of discrete spots onto the scenery to be characterized, the reflections of which are detected by a CMOS-based sensor array equipped with a narrow bandpass filter configured to permit substantially only the wavelength emitted by the VCSEL array to pass. A separate flash light emitting a bundle of light of the same wavelength (typically in a narrow wavelength range around 860 nm) is provided to illuminate the scenery at the moments when the 2D images are to be captured - by design, the light emitted by the flash light will also be able to pass through the narrow passband filter at the detector. Preferably, four out of every five time slots are used to project/detect ranging frames, and the remaining one out of every five time slots is used to capture 2D images.

In embodiments of the present invention, different pixels of the plurality of pixels of the detector **220** are provided with

different filters allowing light in different wavelength bands to reach the different pixels at the points in time. This is schematically illustrated in Figure 6, where a pixel array is shown with different pixels (or different wells of a pixel), provided with respective filters for near infrared (NIR) light, red light, green light, and blue light.

In other embodiments of the present invention, the plurality of pixels of the detector 220 are provided with a time-dependent filter allowing light in different wavelength bands to reach the plurality of pixels at different ones of the points in time. This is schematically shown in Figure 7, diagram a, where separate time slots are provided to capture red, green, and blue light; and in Figure 7, diagram b, where the time slot is extended to allow for consecutive capturing of red, green, and blue light in consecutive parts of the same time slot.

These sets of embodiments allow an RGB 2D image to be captured, which is suitable for rendering on a color display.

The present invention also pertains to a vehicle (in particular a road vehicle or a railway vehicle) comprising the system according to any of the preceding claims arranged so as to characterize an area surrounding the vehicle.

While the invention has been described hereinabove with reference to separate system and method embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with the system or the method alone, can also be applied to the method or the system, respectively, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A system for characterizing surroundings of a vehicle, the system comprising:

- projection means (210) arranged for projecting a pattern of laser light towards said surroundings in a sequence of pulses, said pattern of laser light comprising a pattern of discrete spots;
- a detector (220) comprising a plurality of pixels, said detector (220) being configured for detecting light representing said pattern of laser light as reflected by said surroundings in synchronization with said sequence of pulses; and
- processing means (240) configured to calculate distances to objects (99) in said surroundings as a function of exposure values generated by said pixels in response to said detected light ;

wherein said detector (220) is further configured for detecting light forming a two-dimensional image of said surroundings at points in time that do not coincide with said sequence of pulses or at pixels that do not receive said light representing said pattern of laser light as reflected by said surroundings.

2. The system according to claim 1, wherein said pixels (220) are configured to generate said exposure values by accumulating, for all of the pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said objects (99) during a first predetermined time window (10) and a second electrical charge representative of a second amount of light reflected by said objects during a second predetermined time window (20), said second predetermined time window (20) occurring after said first predetermined time window (10) .

3. The system according to claim 1, wherein said processing means (240) are adapted to determine said distances by determining a displacement of features of said detected light representing said

pattern of laser light as reflected by said surroundings with reference to predetermined feature positions.

4. The system according to any of the preceding claims, comprising illumination means configured to project a bundle of light onto said surroundings at said points in time that do not coincide with said sequence of pulses.

5. The system according to claim 4, wherein said projection means (210) and said illumination means share a common light source.

6. The system according to claim 5, wherein said common light source comprises a VCSEL array, and wherein said illumination means further comprises an actively steered diffuser, configured to be activated at said points in time that do not coincide with said sequence of pulses, so as to diffuse light originating from said VCSEL array to form said bundle.

7. The system according to any of the preceding claims, wherein said plurality of pixels of said detector (220) are provided with a time-dependent filter allowing light in different wavelength bands to reach said plurality of pixels at different ones of said points in time.

8. The system according to any of the preceding claims, wherein different pixels of said plurality of pixels of said detector (220) are provided with different filters allowing light in different wavelength bands to reach said different pixels at said points in time.

9. A vehicle comprising the system according to any of the preceding claims arranged so as to characterize an area surrounding said vehicle.

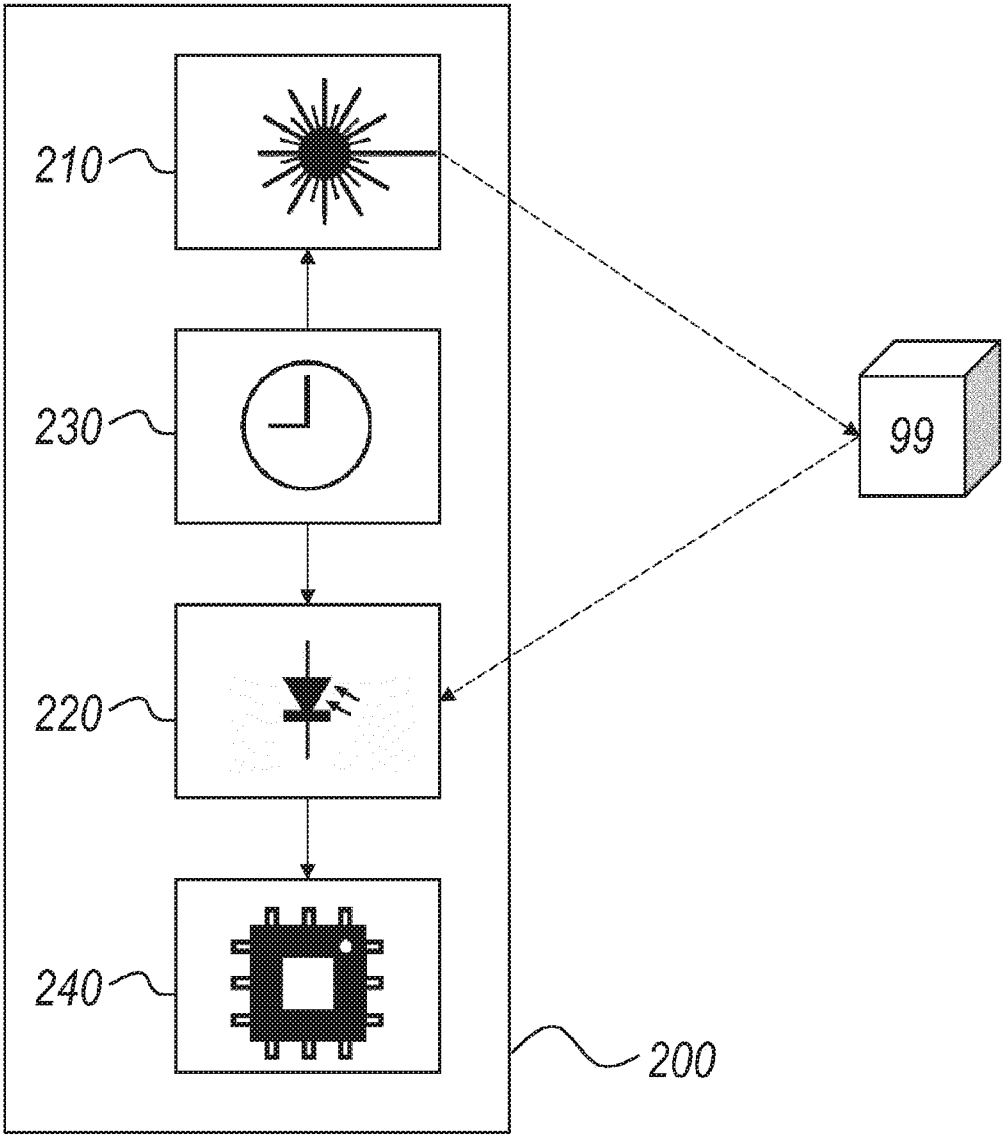


Fig. 1

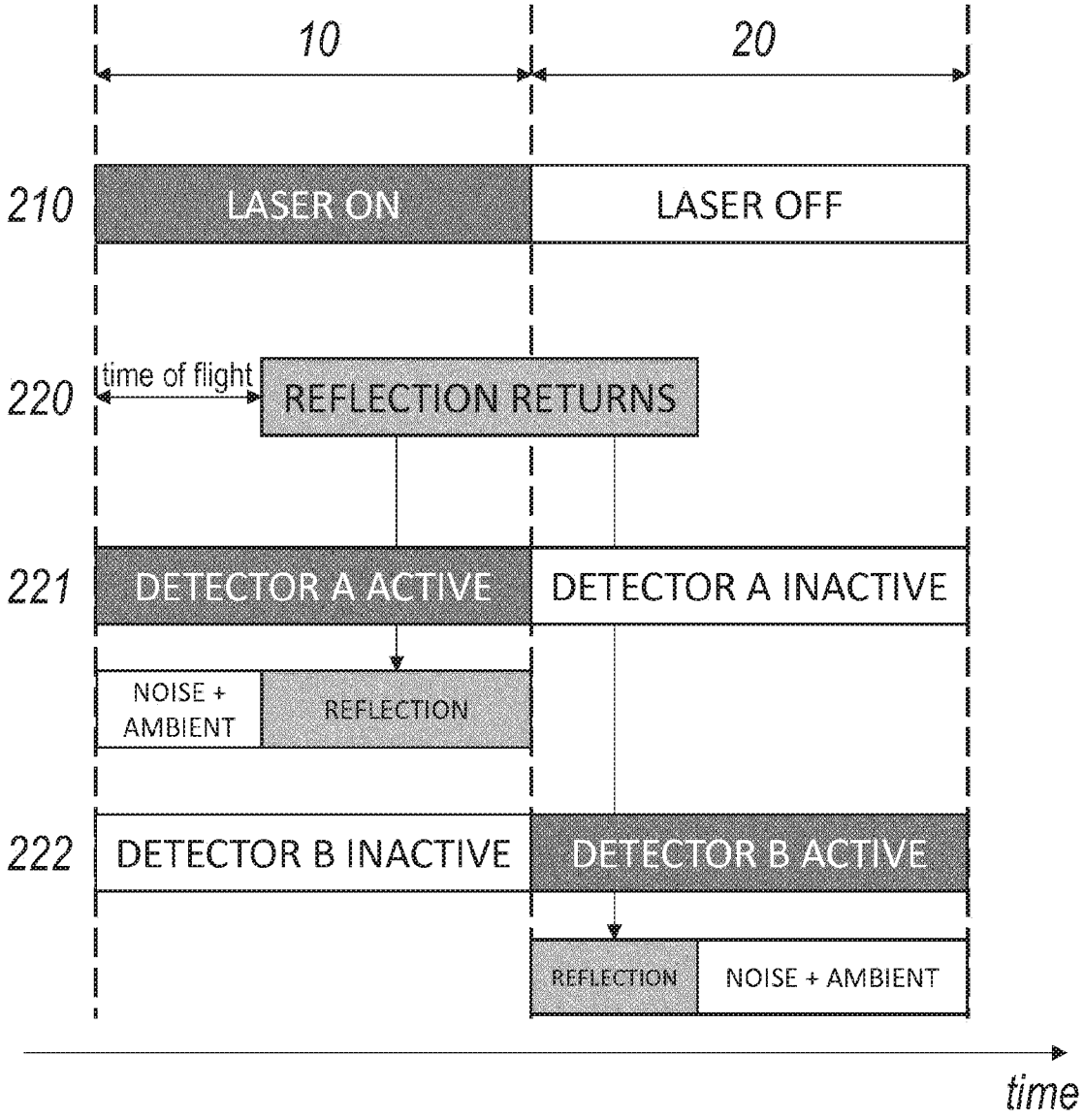

10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 2

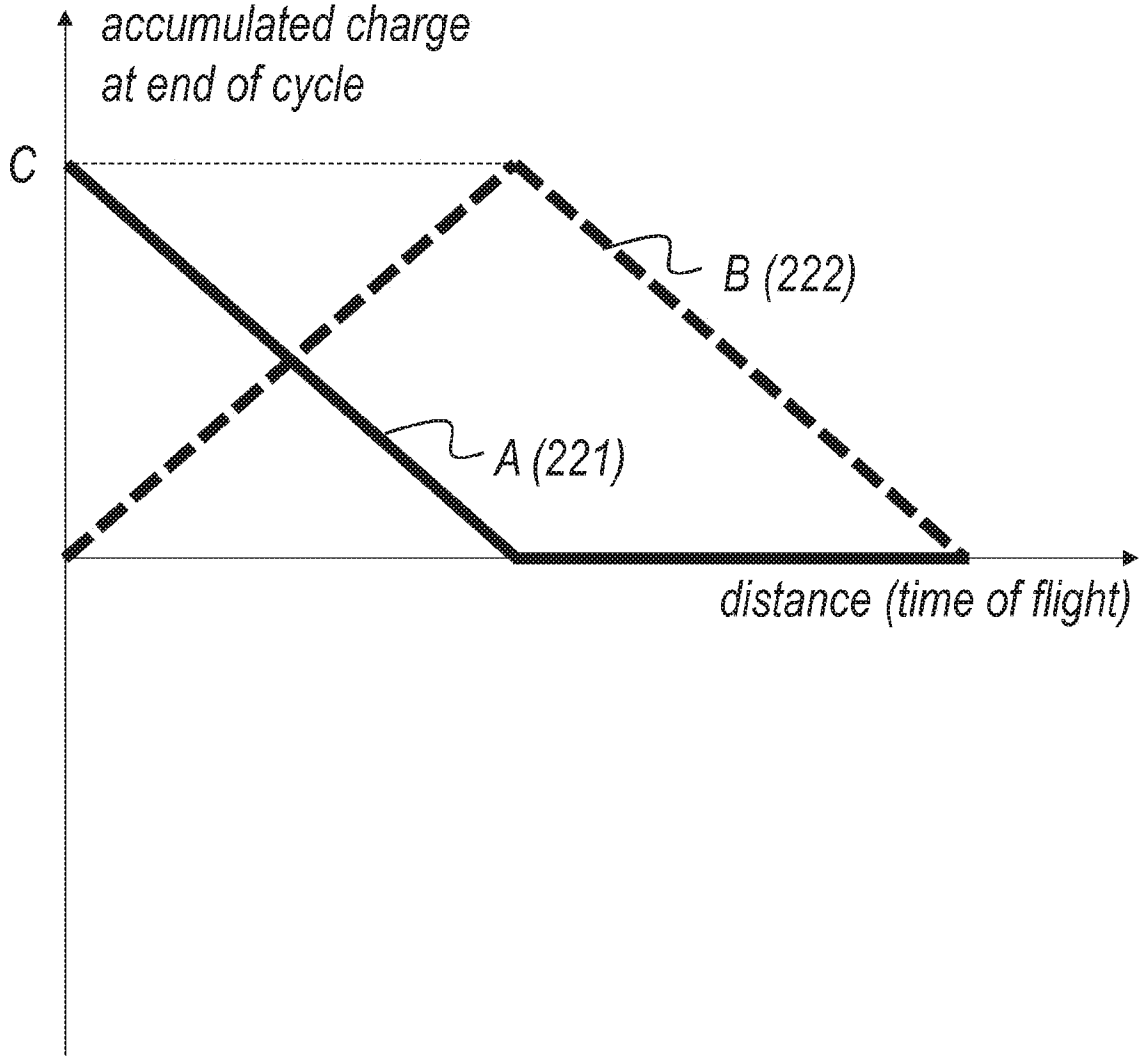

accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3

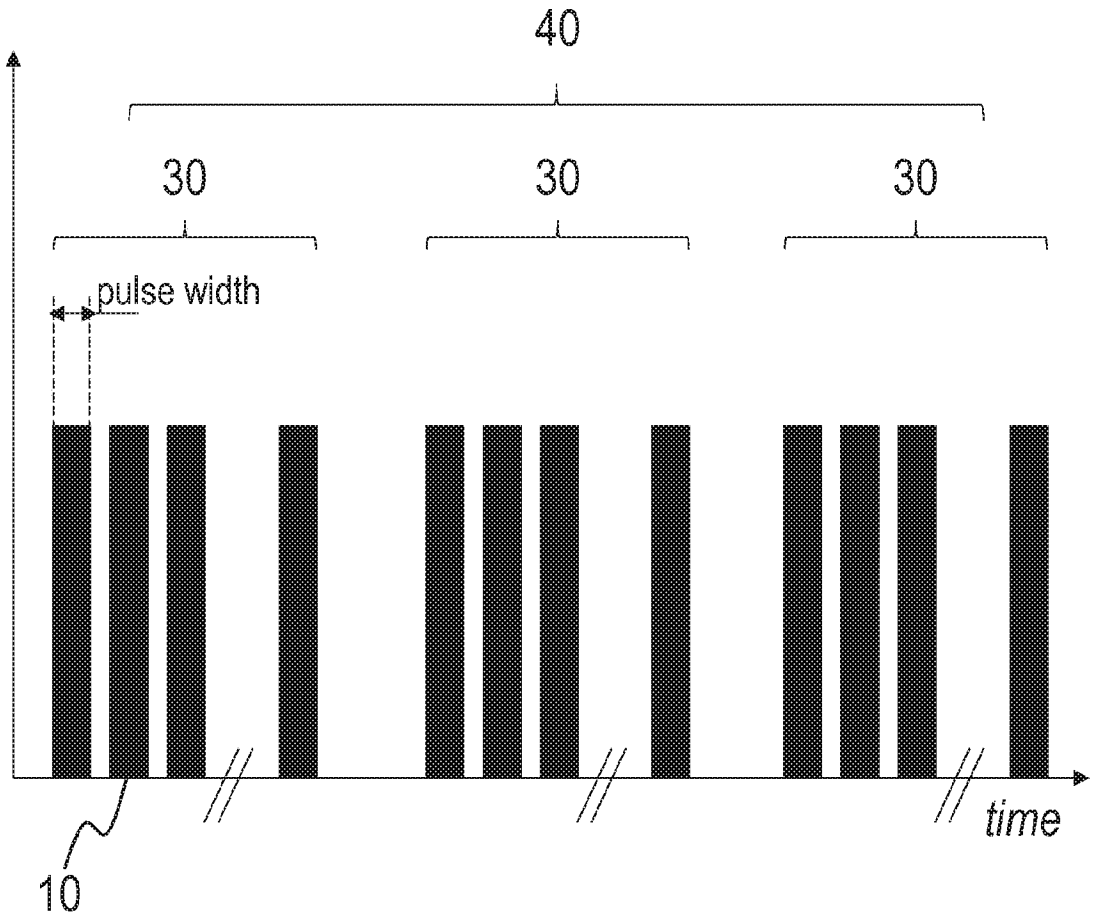


Fig. 4

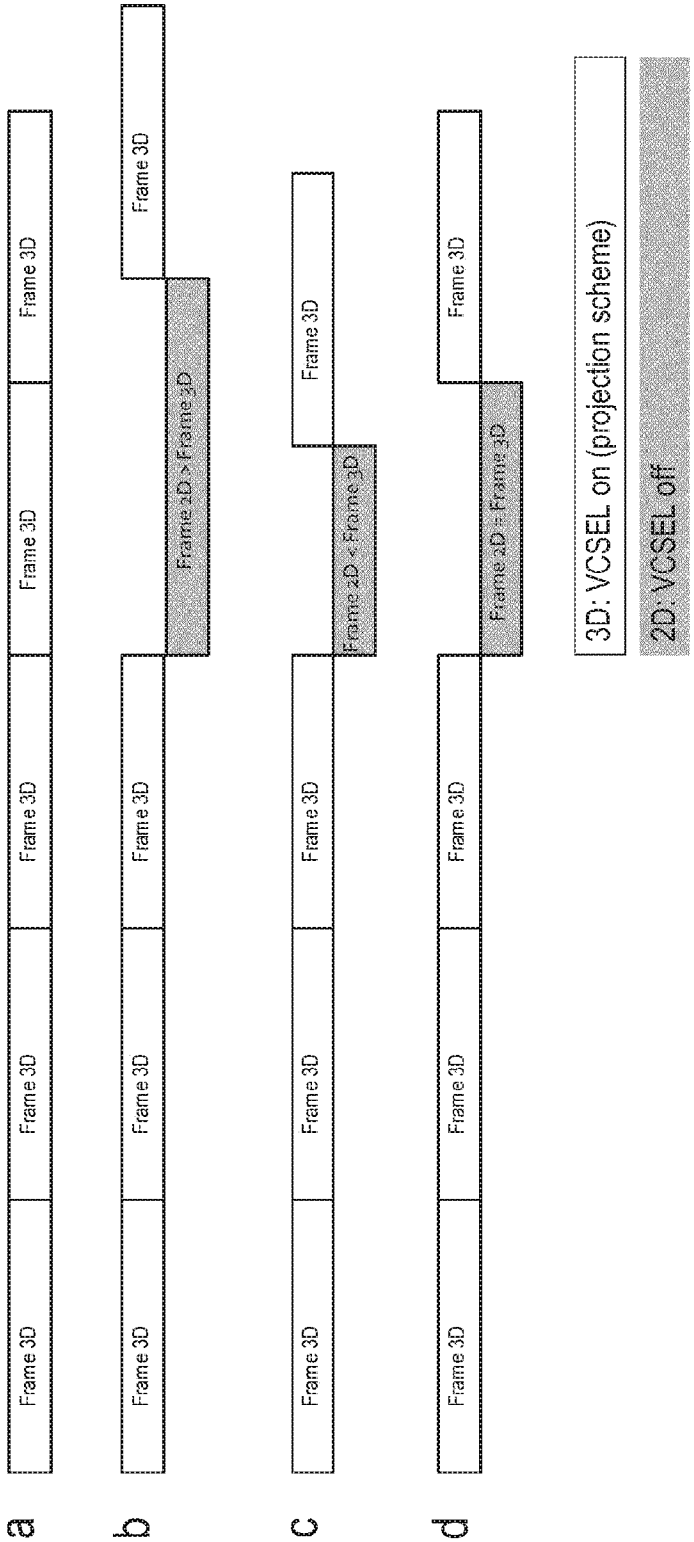

a
b
c
d
Frame 3D
Frame 2D > Frame 3D
Frame 2D < Frame 3D
Frame 2D = Frame 3D
3D: VCSEL on (projection scheme)
2D: VCSEL off

Fig. 5

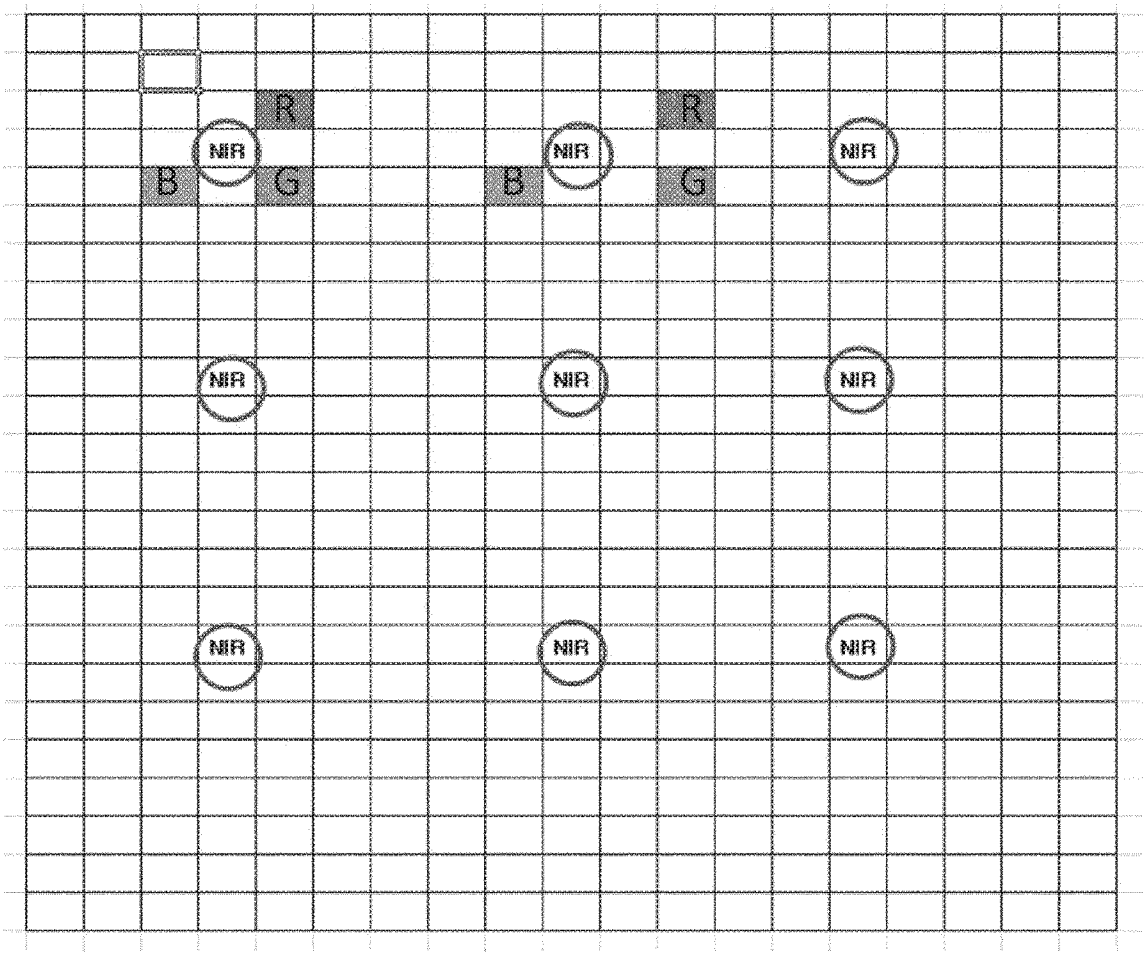
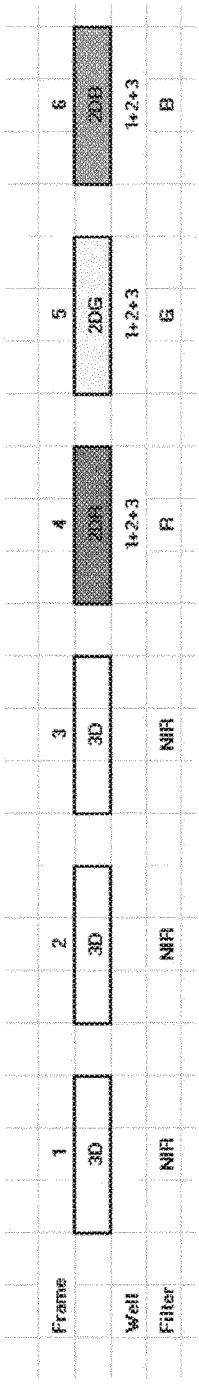


Fig. 6


Frame
1
2
3
4
5
6
3D
3D
3D
2DR
2DG
2DB
Well
1+2+3
1+2+3
1+2+3
Filter
NIR
NIR
NIR
R
G
B
a

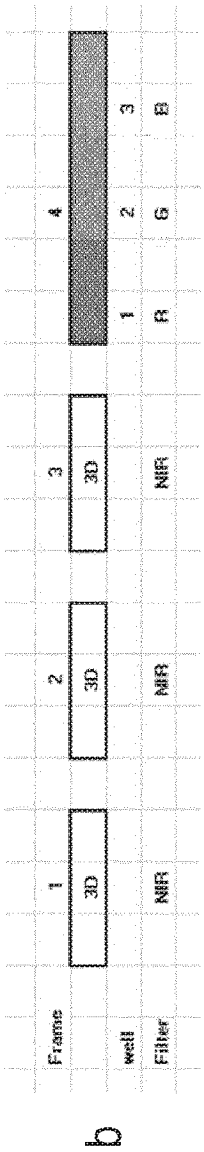

Frame
1
2
3
4
3D
3D
3D
well
1
2
3
Filter
NIR
NIR
NIR
R
G
B
b

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/050080

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S17/93
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/319347 A1 (COTTRELL WILLIAM [US]) 5 November 2015 (2015-11-05)	1-4,8,9
Y	paragraphs [0001] - [0007]	5-7
	paragraphs [0013] - [0030]	

X	US 2016/266255 A1 (NISHIKAWA YUYA [JP] ET AL) 15 September 2016 (2016-09-15)	1,3,4,8, 9
Y	paragraphs [0006] , [0012]	5-7
	paragraphs [0027] - [0052]	

X	WO 2015/162278 A1 (CATHX RES LTD [IE]) 29 October 2015 (2015-10-29)	1,3,4,9
Y	paragraph [0003]	5-7
	paragraphs [0026] - [0035]	
	paragraphs [0053] - [0065]	

	-/-	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" documentwhich may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 April 2018	19/04/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hirsch , Stefanie

1

Form PCT/ISA/210 (second sheet) (April 2005)

HESAI EX1002, P.806

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/050080

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2016/020073 A1 (CEMB S P A [IT]) 11 February 2016 (2016-02-11) pages 1-8	5,6
Y	US 2016/295133 A1 (RUDMANN HARTMUT [CH] ET AL) 6 October 2016 (2016-10-06) paragraphs [0002] - [0009]	7

1

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

HESAI EX1002, P.807

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/050080

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015319347 A1	05-11-2015	NONE	
US 2016266255 A1	15-09-2016	JP 2016166784 A	15-09-2016
		US 2016266255 A1	15-09-2016
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		EP 3074721 A1	05-10-2016
		US 2018038685 A1	08-02-2018
		WO 2016020073 A1	11-02-2016
US 2016295133 A1	06-10-2016	NONE	

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
01 November 2018 (01.11.2018)

W I P O I PCT

(10) International Publication Number
WO 2018/197441 A1

(51) International Patent Classification:
G01S 17/10 (2006.01) *G01S 7/486* (2006.01)
G01S 17/89 (2006.01)

(21) International Application Number:
PCT/EP2018/060391

(22) International Filing Date:
23 April 2018 (23.04.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
17167660.4 23 April 2017 (23.04.2017) EP

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(74) Agent: **IPLODGE BVBA**; Technologielaan 9, B-3001 Heverlee (BE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: A PIXEL STRUCTURE

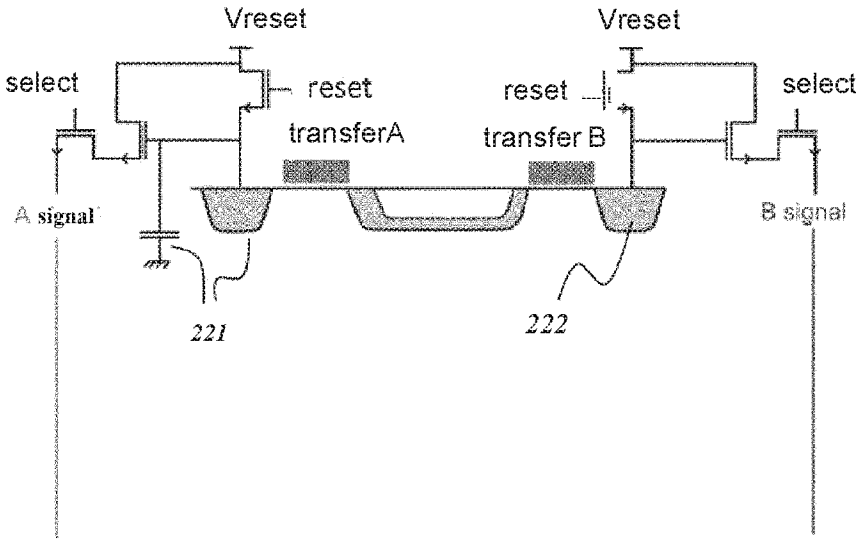


Fig. 6

(57) Abstract: The present invention pertains to a pixel for use in a system for determining a distance to an object by range gating, said pixel comprising: a first charge storage well (221) and a second charge storage well (222) for accumulating electrical charges representative of amounts of light impinging on said pixel during respective sets of exposure intervals, wherein said first charge storage well (221) has a charge capacity that is at least 50% greater than a charge capacity of said second charge storage well (222). The invention also pertains to a range gating system comprising such a pixel.

WO 2018/197441 A1

[Continued on next page]

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

A pixel structure

Field of the Invention

The present invention pertains to the field of pixels, in particular pixels for use in imaging systems for determining a distance to an object on the basis of time-of-flight information obtained by range gating.

Background

United States patent no. 8,792,087 B2 to Andreas Spickerman et al. discloses a device in which at least two different transfer gates which couple a photoactive region to at least two different evaluating capacities are driven during different drive intervals so that charge carriers generated during the drive intervals by a radiation pulse reflected from the object of measurement and/or by ambient radiation can be transported from the photoactive region to the evaluating capacities each coupled to the at least two transfer gates. Another transfer gate is driven during a time outside the drive intervals of the at least two transfer gates to connect the photoactive region to a reference potential terminal acting as a charge carrier sink during the time outside the drive intervals of the at least two transfer gates.

It is a disadvantage of the system known from US 8,702,087 B2 that the pixels get saturated by reflections from objects at short distances from the sensor.

United States patent application publication no. US 2007/158770 A1 to Shoji Kawahito, discloses a range-finding image sensor based upon measurement of reflection time of light with reduced fabrication processes compared to standard CMOS manufacturing procedures. An oxide film is formed on a silicon substrate, and two photo-gate electrodes for charge-transfer are provided on the oxide film. Floating diffusion layers are used to convert charges to electronic potential, a mechanism traditionally inherited from

the legacy technology of Charged Coupled Devices (CCD). Extra transistors are provided for resetting and a diffusion layer to provide a given reset voltage.

It is a disadvantage of the pixel disclosed in US 2007/158770 A1 that it uses non-standard technology and that the pixel design does not allow the addition of additional wells without sacrificing active surface area of the pixel. This is suboptimal for usage in sensor systems with ultra low power lasers requiring large operational range. The used process is not commonly available in standard CMOS processes, which reduces this concept's applicability and its ability to be produced at an affordable cost in large volumes.

The range of a sensor based on such a design is also limited at the near end by saturation of the pixels by the strong reflections of projected light.

The saturation of pixels when sensing short-range reflections, or highly reflective objects such as traffic signs, license plates, etc., is especially problematic when the pixels are used in sensors for automotive applications, as is the purpose of the pixel according to the present invention, because Advanced Driver Assistance Systems (ADAS) and self-driving cars require high accuracy at short range. Moreover, in this application domain, accuracy at longer ranges, the ability to operate in bright ambient light conditions, and the requirement of compactness (requiring the use of solid-state semiconductor components) must not be sacrificed for the requirement of short-range accuracy.

It is therefore an object of embodiments of the present invention to overcome the short-range saturation problem for pixels used in range-gating based imaging systems by proposing a different pixel architecture.

Unpublished European patent application no. EP15191288.8, dated 23 October 2015, in the name of the present applicant, describes a

system for determining a distance to an object comprising: a solid-state light source arranged for projecting a pattern of spots of laser light towards the object in a sequence of pulses; a detector comprising a plurality of picture elements, the detector being configured for detecting light representing the pattern of spots as reflected by the object in synchronization with said sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by said picture elements in response to said detected light; wherein the picture elements are configured to generate said exposure values by accumulating, for each pulse of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window, said second predetermined time window occurring after said first predetermined time window. Each of the plurality of picture elements may comprise at least two charge storage wells, and the detecting of the first amount of light and said detecting of said second amount of light occurs at respective ones of said at least two charge storage wells. EP15191288.8 does not describe a solution to the short-range saturation problem.

In a similar system, unpublished European patent application no. EP16192105 .1, dated 3 October 2016, in the name of the present applicant, describes that for given total pixel space, the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first well is increased, and the photon capacity represented by the second well is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost, thus maintaining the same resolution. EP16192105.1 does not describe any specific ratios between the photon capacity represented by the first well and the photon capacity represented by the second well.

Summary of the Invention

According to an aspect of the present invention, there is provided a pixel for use in a system for determining a distance to an object by range gating, said pixel comprising a first charge storage well and a second charge storage well for accumulating electrical charges representative of amounts of light reflected by said object and impinging on said pixel during respective sets of exposure intervals, and a third charge storage well, wherein said first charge storage well has a charge capacity that is at least 50% greater than a charge capacity of said second charge storage well, and wherein said third charge storage well has a smaller charge storage capacity than said first charge storage well and said second charge storage well .

The invention is based on the insight of the inventors that in certain systems, such as the range-gating based imaging system described in more detail below, it is advantageous to have a dual-well pixel (the presence of additional wells is not excluded) whereby one of the charge storage wells has a substantially larger charge capacity than the other charge storage well. The term "well" may designate a single capacitance (electron capacity) produced in a semiconductor circuit by appropriate techniques, or a multitude of interconnected capacities acting jointly as a single storage unit, arranged for example as a cascade. A pixel of this type is particularly useful where the physics of the situation in which the pixel is deployed lead to a predictable asymmetry in the amount of charge to be stored in the different wells, as is the case in a time-of-f light based measuring system requiring high accuracy and a large distance range, resulting in a large photon span.

To the extent that the pixel of the present invention resolves the short-range saturation problem, it removes the need for other work-arounds that extend the operating range at the short end. For example, in systems relying on multiple consecutive measurements for multiple sub-ranges of the desired range (multi-frame systems,

where the pulse width varies in function of the distance range to be covered by each frame) , the pixel according to the present invention allows for a reduction of the number of measurements (individual frames required to cover the full intended operating range), thus improving the temporal resolution of the sensor.

The pixel according to the present invention preferably comprises a photosensitive element compatible with standard solid-state (semiconductor) circuit production processes.

A third well is provided to perform a variety of functions, provided that it is operated according to a timing scheme that takes into account the timing of the operation of the other wells. In a distance sensing system in which the first well and the second well perform the basic range gating, as described in more detail below, the functions of the third well may include receiving the additional charges that are generated in response to photons arriving from a long-range highly reflective objects (such as a traffic sign or a license plate, outside the time slots in which the first well and the second well are active) , producing a regular 2-dimensional image of the scenery (outside the time slots in which the reflections of the projected light arrive, optionally in synchronization with a wide-angle flash light for illuminating the scenery which may consist of a VCSEL array with a diffuser) , or performing background light subtraction (by subtracting from the charge levels accumulated in the first well and the second well, an amount of charge accumulated in the third well outside the time slots in which the reflections of the projected light arrive) .

The third charge storage well may have a significantly smaller charge storage capacity than the first charge storage well and the second charge storage well, if it is only used for capturing background light, as the background light arriving at the pixel array will typically have been strongly attenuated by the ambient light reduction filters that are preferably provided in a distance sensing system. If the third charge storage well is intended to be

used for acquiring 2D images with additional lighting of the scenery (e.g., by means of a flash light) or for capturing reflections from out-of-range highly reflective objects, it may be dimensioned to a similar storage capacity as the first or second charge storage well .

In an embodiment, said pixel further comprises circuitry allowing said pixel to switch between a charging mode, in which light impinging on said pixel causes said first charge storage well or said second charge storage well to increase a stored amount of charge, and a discharging mode, in which light impinging on said pixel causes said first charge storage well or said second charge storage well to decrease a stored amount of charge.

This embodiment is based on the insight of the inventors that in a pulsed system, the "pulse on" intervals are characterized by the presence of projected light and background light, while the part of the "pulse off" intervals occurring after the arrival of the pulse reflection are characterized by the presence of background light only. The inventors developed a method in which by switching the pixel into a "discharging" mode after each exposure that corresponds with a "pulse on" interval, for a period that is equal to the exposure period, the remaining charge in each storage well will be equal to the captured reflection of the projected light without the background light component.

It is an advantage of this embodiment of the pixel according to the present invention that it can be used in a method for subtracting background light from pixels in a pixel array, e.g. as used in a range gating sensor. In particular, it enables a method of subtracting background light from an exposure value of a first pixel in an imaging array, said first pixel receiving a reflection of a spot from a scenery illuminated by a periodically pulsed pattern of spots, said periodically pulsed pattern comprising in alternation an illuminated phase and a non-illuminated phase, the method comprising: accumulating in said first pixel a charge in proportion to a first quantity of incident light, received in said

first pixel while detecting said spot during a predetermined amount of time; and decreasing said charge in proportion to a second quantity of incident light received during said predetermined amount of time in absence of said spot.

In an embodiment, said pixel further comprises circuitry allowing photocharges that are generated when an active one of said first charge storage well and said second charge storage well is filled to capacity, to be to deviated to a charge sink without entering a storage well of an adjacent pixel.

It is an advantage of this embodiment that blooming can be avoided, such that high spatial accuracy of spot detection in an array of pixels can be maintained even when individual pixels get saturated, by avoiding spill-over effects to neighboring pixels that can still be used for background measurements or for acquiring a regular 2D image.

In an embodiment, the pixel according to the present invention further comprises a fourth charge storage well.

According to an aspect of the present invention, there is provided an imaging array comprising a plurality of pixels as described above .

According to an aspect of the present invention, there is provided a system for determining a distance to an object comprising: a solid-state light source arranged for projecting a pattern of spots, preferably discrete spots, of light towards the object in a sequence of pulses, preferably a periodically repeated sequence of pulses; a detector comprising an imaging array as described above, the detector being configured for detecting light representing the pattern of spots as reflected by the object in synchronization with said sequence of pulses; and processing means configured to calculate the distance to the object as a function of exposure values generated by said pixels in response to said detected light; wherein the pixels of the imaging array are configured to

generate said exposure values by accumulating, for all pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window, said second predetermined time window occurring after said first predetermined time window, wherein the detecting of the first amount of light and the detecting of said second amount of light occurs at said first charge storage well and at said second charge storage well, respectively .

The solid-state light source is preferably a semiconductor light source. The projected discrete spots are preferably spots of laser light .

The system according to the present invention relies on the same physical principles as direct time-of-flight based ranging systems, viz. the fact that light always takes a certain amount of time to travel a given distance. However, the present invention uses range gating to determine the distance travelled by a light pulse that has been transmitted and subsequently reflected by a target object. The present invention is *inter alia* based on the insight of the inventors that by combining range gating, an at least partially simultaneous spot pattern projection (based on a novel illumination scheme) and a low-power semiconductor light source, a substantially miniaturized, full solid state and energy-efficient long-range distance detection method can be obtained. The term "pattern" as used herein refers to a spatial distribution of simultaneously projected spots, preferably discrete (non-overlapping) spots. In order to determine the position of the detected spot reflection in three-dimensional space, it is necessary to combine the distance information obtained from the ranging step with angular information to fix the remaining two spatial coordinates. A camera comprising a pixel array and suitably arranged optics can be used to provide the additional

angular information, by identifying the pixel in which the reflection is detected.

Embodiments of the present invention are based on the further insight of the inventors that in order to be able to use spot patterns generated by solid-state semiconductor light sources in a LIDAR system at the desired ranges, a way to circumvent the optical power limitations is needed. The inventors have found that by prolonging the pulse duration and by integrating the reflected energy of multiple VCSEL-generated light pulses within at least two semiconductor sensor wells or within at least two pixels, followed by a single read-out of the integrated charge, a solid-state LIDAR system can be obtained with a significantly greater operating range than is currently possible with solid-state implementations. In addition, multiple sequences of light pulses, using a different pulse duration in each sequence, may be combined to cover a larger distance range than would be possible with a single sequence. Hereinafter, the term "storage" will be used to designate the well or the pixel in which charge is accumulated in response to the detection of photons.

It is an advantage of the system according to the present invention that the solid-state light source and the solid-state sensor (such as a CMOS sensor, a CCD sensor or the like) may be integrated on the same semiconductor substrate. The solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern.

Moreover, by assessing the reflected light energy detected in two consecutive time windows, and normalizing for the total accumulated charge in the two consecutive windows, the impact of varying reflectivity of the object under study and the contribution of ambient light can adequately be accounted for in the distance calculation algorithm.

Finally, by using the pixel as described above, the system according the present invention is less susceptible to saturation

of the charge storage wells due to intense reflections received from objects at short range.

In an embodiment, the system is configured to perform the projecting and the detecting for at least two consecutive sequences of pulses, each of the sequences being operated with a different duration of the first predetermined time window and the second predetermined time window.

This embodiment is further based on the insight of the inventors that the range of the system can be improved by splitting up the sensing of the full range over multiple frames (i.e., multiple sequences of pulses), each of which allows computation of the distance for a different range by virtue of operating with different timing parameters (the first predetermined time window and the second predetermined time window) .

A judicious choice of these operating parameters can ensure that in each frame, the number of reflected photons expected to be detected for the maximal distance of the desired range corresponds to an amount of charge that can be reliably read out from the charge storage well. On the other hand, the nearest point at which accurate measurements can be carried out is determined by the number of photons that will saturate the capacity of the pixels. The ratio between the minimal detectable number of photons and the maximal number of photons that can be received without saturation determines the distance range that can be spanned in a single frame .

In an embodiment of the system according to the present invention, the imaging array is further adapted to perform 2D video image acquisition .

The 2D video image acquisition may be performed in the same frames in which the range gating takes place, by employing the third charge storage well and/or a fourth charge storage well or by employing pixels of the pixel array that are not being illuminated

by reflections of the projected light spots. Additionally or alternatively, the 2D video image acquisition may be performed in the other frames that the frames in which the range gating takes place, optionally in synchronization with a global illumination of the scenery.

Brief Description of the Figures

These and other aspects and advantages of the present invention will now be described in more detail with reference to the accompanying drawings , in which:

Figure 1 represents a flow chart of the range gating process applied by an embodiment of the system according to the present invention, in which the pixel according to the present invention may be used;

Figure 2 schematically represents an embodiment of the system according to the present invention, in which the pixel according to the present invention may be used;

Figures 3a-c present timing schemes of the range gating process applied by an embodiment of the system according to the present invention, to illustrate the operation of the two wells involved in range gating;

Figure 4 schematically represents an embodiment of the pixel according to the present invention;

Figure 5 schematically represents an embodiment of the pixel according to the present invention, showing a first way of obtaining the asymmetry of the wells;

Figure 6 schematically represents an embodiment of the pixel according to the present invention, showing a second way of obtaining the asymmetry of the wells; and

Figures 7a-7g represent timing diagrams for light projection and detection in embodiments of the present invention, to illustrate the operation of additional wells.

Throughout the figures, like numerals are used to refer to like elements .

Detailed Description of Embodiments

The inventors have found that the pixel array according to the present invention can advantageously be applied in a novel type of ranging system which aims to achieve the same power/performance characteristics with a compact, semiconductor based time-of-flight based system. Accordingly, an aspect of the present invention concerns a ranging system comprising a plurality of pixels as will be described below, arranged in a pixel array.

In this aspect of the invention, the limitations of the existing LIDAR-based systems are overcome by changing the way the time-of-flight based system operates. The total amount of light energy emitted for each time-of-flight measurement (and thus, the number of photons available for detection at the detector for each time-of-flight measurement) may be increased by increasing the duration of individual pulses and by producing a virtual "composite pulse", consisting of a sequence of a large number of individual pulses. This bundling of extended pulses allowed the inventors to obtain the required amount of light energy (photons) for the desired operational range with low-power solid-state lasers, such as VCSELs .

Where an individual pulse of pre-existing LIDAR systems may have a duration of 1 ns, the presently described systems benefit from a substantially longer pulse duration to partially compensate for the relatively low power level of semiconductor lasers such as VCSELs; in embodiments of the present invention, individual pulses within a sequence may have an exemplary duration of 1 µs (this is one possible value, chosen here to keep the description clear and

simple; more generally, in embodiments of the present invention, the pulse duration may for example be 500 ns or more, preferably 750 ns or more, most preferably 900 ns or more) . In an exemplary system according to the present invention, a sequence may consist of 1000 pulse cycles, thus adding up to a duration of 1 ms. Given the fact that light would need approximately 0.66 µs to travel to a target at a distance of 100 m and back to the detector, it is possible to use composite pulses of this duration for ranging at distance of this order of magnitude; the skilled person will be able to adjust the required number of pulse cycles in function of the selected pulse width and the desired range. The detection of the sequence preferably comprises detecting the individual pulses in synchronization with the VCSEL-based light source, and accumulating the charges generated in response to the incoming photons at the pixel well level for the entire sequence prior to read-out. The term "exposure value" is used hereinafter to designate the value representative of the charge (and thus of the amount of light received at the pixel) integrated over the sequence. The sequence emission and detection may be repeated periodically .

The ranging system of the present invention operates by using range gating. Range gated imagers integrate the detected power of the reflection of the emitted pulse for the duration of the pulse. The amount of temporal overlap between the pulse emission window and the arrival of the reflected pulse depends on the return time of the light pulse, and thus on the distance travelled by the pulse. Thus, the integrated power is correlated to the distance travelled by the pulse. The present invention uses the principle of range gating, as applied to the sequences of pulses described hereinabove. In the following description, the integration of individual pulses of a sequence at the level of a picture element to obtain a measurement of the entire sequence is implicitly understood.

Figure 1 represents a flow chart of an applicable ranging method. Without loss of generality, the ranging method is described with

reference to a range gating algorithm. In a first time window **10**, the method comprises projecting **110** a pattern of spots of laser light (e.g. a regular or an irregular spatial pattern of spots) from a light source comprising a solid-state light source **210** onto any objects in the targeted area of the scenery. The spatial pattern is repeatedly projected in a sequence of pulses.

As indicated above, the solid-state light source may comprise a VCSEL array or a laser with a grating adapted to produce the desired pattern. In order for the system to operate optimally, even at long ranges and with high levels of ambient light (e.g., in daylight) , a VCSEL for use in embodiments of the present invention is preferably arranged to emit a maximum optical power per spot per unit of area. Thus, lasers with a good beam quality (low M2-factor) are preferred. More preferably, the lasers should have a minimal wavelength spread; a particularly low wavelength spread can be achieved with monomode lasers. Thus, substantially identical pulses can reproducibly be generated, with the necessary spatial and temporal accuracy.

During the same time window in which a pulse is emitted, or in a substantially overlapping time window, a first amount of light representing the pattern of spots as reflected by the object of interest is detected **120** at a detector, which is preferably arranged as near as possible to the light source. The synchronicity or near synchronicity between the projection **110** of the spot pattern and the first detection **120** of its reflection, is illustrated in the flow chart by the side-by-side arrangement of these steps. In a subsequent second predetermined time window **20**, a second amount of light representing the reflected light spot is detected **130** at the detector. During this second window **20**, the solid-state light source is inactive. The distance to the object can then be calculated **140** as a function of the first amount of reflected light and the second amount of reflected light.

The first predetermined time window **10** and the second predetermined time window **20** are preferably back-to-back windows

of substantially equal duration, to facilitate noise and ambient light cancellation by subtracting one of the detected amounts from the other one. An exemplary timing scheme will be described in more detail below in conjunction with Figure 3.

The detector comprises a pixel array as described above with adequate optics arranged to project an image of the scenery (including the illuminated spots) onto the picture element.

The term "picture element" as used herein may refer to an individual light-sensitive area or well of a pixel, or to an entire pixel (which may comprise multiple wells, see below). For every given projected spot, the detecting **120** of the first amount of light and the detecting **130** of the second amount of light occurs at the same one or the same group of the plurality of picture elements.

Without loss of generality, each of the picture elements may be a pixel comprising at least two charge storage wells **221, 222,** such that the detecting **120** of the first amount of light and the detecting **130** of the second amount of light can occur at the respective charge storage wells **221, 222** of the same pixel or pixel group. The third well may perform a variety of functions, provided that it is operated according to a timing scheme that takes into account the timing of the projector and/or the other wells.

Figure 2 schematically represents an embodiment of the system according to the present invention, in relation to an object **99** in the scenery of interest. The system **200** comprises a solid-state light source **210** for projecting a pattern of a sequence of spots, which may be repeated periodically, onto the object **99**. A detector **220** is arranged near the light source and configured to detect light reflected by the object.

The light beam bouncing off the object **99** is illustrated as an arrow in dashed lines, travelling from the light source **210** to the

object **99** and back to the detector **220**. It should be noted that this representation is strictly schematic, and not intended to be indicative of any actual relative distances or angles.

A synchronization means **230**, which may include a conventional clock circuit or oscillator, is configured to operate the solid-state light source **210** so as to project the pattern of spots onto the object during first predetermined time windows **10** and to operate the detector **220** so as to detect a first amount of light representing the light spot(s) reflected by the object **99** at substantially the same time. It further operates the detector **220** to detect a second amount of light representing the light spots reflected by the object **99**, during respective subsequent second predetermined time windows **20**. Appropriate processing means **240** are configured to calculate the distance to the object as a function of the first amount of reflected light and the second amount of reflected light.

Figure 3 (consisting of Figures 3a, 3b, and 3c) represents a timing diagram for light projection and detection in embodiments of the present invention. For clarity reasons, only a single pulse of the pulse sequence which is repeated periodically of Figure 3 is illustrated, which consists of a first time window **10** and a second time window **20**.

As can be seen in Figure 3a, during the first time window **10**, the solid-state light source **210** is in its "ON" state, emitting the pattern of light spots onto the scenery. During the second time window **20**, the solid-state light source **210** is in its "OFF" state.

The arrival of the reflected light at the detector **220** is delayed relative to the start of the projection by an amount of time that is proportional to the distance travelled (approximately 3.3 ns/m in free space) . Due to this delay, only a part of the reflected light will be detected at the first well **221** of the detector **220**, which is only activated during the first time window **10**. Thus, the charge accumulated in this first well during its period of

activation (the first time window **10**) consists of a part representing only the noise and the ambient light impinging on the pixel prior to the arrival of the reflected pulse, and a part representing the noise, the ambient light, and the leading edge of the reflected pulse.

The latter part of the reflected pulse will be detected at the second well **222** of the detector **220**, which is only activated during the second time window **20**, which preferably immediately follows the first time window **10**. Thus, the charge accumulated in this second well during its period of activation (the second time window **20**) consists of a part representing the noise, the ambient light, and the trailing edge of the reflected pulse, and a part representing only the noise and the ambient light impinging on the pixel after the arrival of the reflected pulse.

The greater the distance between the reflecting object **99** and the system **200**, the smaller the proportion of the pulse that will be detected in the first well **221** and the larger the proportion of the pulse that will be detected in the second well **222**.

If the leading edge of the reflected pulse arrives after the closing of the first well **221** (i.e., after the end of the first time window **10**), the proportion of the reflected pulse that can be detected in the second well **222** will decrease again with increasing time of flight delay.

The resulting amounts of charge **A**, **B** in each of the respective wells **221**, **222** for varying distances of the object **99** are shown in Figure 3b. To simplify the representation, the effect of the attenuation of light with distance, according to the inverse square law, has not been taken into account in the diagram. It is clear that for time of flight delays up to the combined duration of the first time window **10** and the second time window **20**, the time of flight delay can in principle unambiguously be derived from the values of **A** and **B**:

- For time of flight delays up to the duration of the first time window **10**, **B** is proportional to the distance of the object **99**. To easily arrive at a determination of the absolute distance, the normalized value **B/ (B+A)** may be used, removing any impact of non-perfect reflectivity of the detected object and of the inverse square law.
- For time of flight delays exceeding the duration of the first time window **10**, **A** consists of daylight and noise contributions only (not illustrated) , and **C—B** is substantially proportional (after correcting for the inverse square law) to the distance of the object **99**, where **C** is an offset value.

While Figures 3a and 3b illustrate the principle of the system according to the present invention in relation to a single pulse emitted in the time window **10**, it shall be understood that the illustrated pulse is part of a sequence of pulses as defined above. Figure 3c schematically illustrates exemplary timing characteristics of such a sequence. As illustrated, the illumination scheme **40** consists of a repeated emission of a sequence **30** of individual pulses **10**. The width of the individual pulses **10** is determined by the maximal operating range. The entire sequence may be repeated at a frequency of, for example, 60 Hz.

The inventors have found that in systems such as described herein, reflections of light by objects at a short distances are more likely to cause pixel saturation, because the attenuation of such a reflection will be much less than that of a reflection originating from a more distant object (due to the inverse-square law of light attenuation over distance) . As certain applications, such as automotive applications, require accurate system operation up to relatively long distances, a large photon span must be covered between the nearest distances of operation and the farthest distances of operation. With these constraints, pixel saturation at short range is a very real risk, in particular at the first well (which receives the bulk of the reflection at short range) . The inventors have found that for given total pixel space,

the saturation problem can be mitigated by using an asymmetric well arrangement, in which the photon capacity represented by the first well is increased, and the photon capacity represented by the second well is decreased. If the increase and decrease are balanced, an increase of the dynamic range can be obtained at no additional pixel surface cost.

The inventors have further found that to obtain a useful operating range (between the lowest detectable light level and the light level at which saturation occurs), the first charge storage should have a charge capacity that is at least 50% greater than the charge capacity of the second charge storage well. Preferably, the first charge storage should have a charge capacity that is at least 75% greater than the charge capacity of the second charge storage well, and most preferably the first charge storage should have a charge capacity that is at least 100% greater than the charge capacity of the second charge storage well.

An exemplary asymmetric dual-well pixel according to the present invention, including anti-blooming circuitry, is schematically presented in Figure 4. The charge storage wells 221, 222 (SN A, SN B) are connected to a photactive region (PH) by means of transfer gates (TG A, TG B), which are controlled to synchronize the active states of the two charge storage wells with the transmission of the projection pulses as described above.

Figure 5 schematically represents an embodiment of the pixel according to the present invention, showing a first way of obtaining the asymmetry of the wells. As shown in Figure 5, the first well 221 (the depletion zone on the A-signal side) has been made at least 50% larger than the second well 222 (the depletion zone on the B-signal side) during the semiconductor fabrication process .

Figure 6 schematically represents an embodiment of the pixel according to the present invention, showing a second way of obtaining the asymmetry of the wells. In this case, both

semiconductor wells **221, 222** are of identical side, but an additional capacitor is provided on the A-signal side to increase the effective capacity of the first well **221.**

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel. Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels, or in other wells of the same pixel. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, to bleed off the excess charge before it saturates the relevant well and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels.

The pixel may further comprise circuitry allowing the pixel to switch between a charging mode and a discharging mode. In the charging mode, light impinging on said pixel causes the first charge storage well or the second charge storage well (according to the present stage of the illumination scheme) to increase a stored amount of charge. In the discharging mode, preferably activated after the charging mode for an equal amount of time, light impinging on said pixel causes said first charge storage well or said second charge storage well to decrease the stored amount of charge. This switching scheme allows an amount of charge corresponding to the background light to be removed from the charge storage wells.

Embodiments of the present invention may employ correlated double sampling to correct the samples for the thermal noise related to the capacity of the wells (also designated as "kTC noise") . To this end, the electronics of the pixel may be designed to carry out a differential measurement between the reset voltage (V_{reSet}) and the signal voltage (V_{Signa}), for example by measuring V_{reSet} at

the beginning of the frame and measuring V_{signal} at the end of the frame. As an alternative to an electronic (in-pixel) implementation, correlated double sampling may also be implemented by digitally subtracting the read-out signals $(V_{signal} - V_{reset})$ in a processor.

To increase the amount of light that reaches the photosensitive elements (in particular diodes) in the pixel structure, embodiments of the present invention may use backside illumination; in that case, the pixel circuitry is behind the photosensitive layer, thus reducing the number of layers that must be traversed by the impinging photons to read the photosensitive elements .

In addition to being applicable in the system described above, the pixel and the pixel array according to the present invention may also be integrated with a triangulation-based system in accordance with WO 2015/004213 A1. If miniaturization is aimed for, the triangulation-based system will end up having a relatively small distance between its projector and its detector, thus leaving it with a reduced operating range. However, it is precisely at short range that the combination presents its benefit, because the triangulation-based system can cover the distances at which the time-of-flight based system cannot operate sufficiently accurately.

The entire ranging process may be repeated iteratively, preferably periodically, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that require information about the distance to detected objects on a continuous basis, such as advanced driver assistance systems, vehicles with an active suspension, or autonomous vehicles.

The entire ranging process may be repeated iteratively, so as to monitor the distance to the detected object or objects over time. Thus, the result of this method can be used in processes that

require information about the distance to detected objects on a continuous basis, such as detection and tracking of objects in the surroundings of a vehicle, advanced driver assistance systems, vehicles with an active suspension, autonomous driving or autonomous vehicles. An iteratively repeated range gating sequence is schematically represented in the timing diagram of Figure 7a, in which each frame corresponds of a sequence of pulses of the projector (P) (the timing of the pulses is indicated by the lowercase 'ρ'), which is synchronized to activations of the imager (I) (the accumulation of charges in the first well is indicated by the lowercase 'a', while the accumulation of charges in the second well is indicated by the lowercase 'b'). Without loss of generality, only two consecutive frames are illustrated.

Figure 7b represents a modified timing scheme, containing two additional time slots for every projection pulse. These additional time slots are used to discharge the respective wells at a rate proportional to the intensity of the light impinging on the pixel when no reflection of the projected light is received. As the light received in the absence of a pulse represents the background light, with only a tiny time offset relative to the point in time at which the pulse reflection is received, this scheme effectively removes the background light component from the charge accumulated in the first well and the second well, for each projector pulse.

In order to implement the above mentioned discharging phase, the pixel may comprise a capacitor for storing the charge, coupled to the photodiode by appropriate transfer gates. The accumulating phase then comprises transferring charges to a first side of the capacitor, and the decreasing comprises transferring charges to the second side of the capacitor.

The following timing diagrams illustrate how additional wells (e.g. the aforementioned third charge storage well and fourth charge storage well) may be used.

Figure 7c represents a modified timing scheme, containing one additional time slot for every projection pulse. This additional time slot is used to accumulate photocharges in a third well (the accumulation of charges in the third well is indicated by the lowercase 'c'). As the light received in the third well arrives in the absence of a pulse, it represents the background light, with only a tiny time offset relative to the point in time at which the pulse reflection is received. The charge accumulated in the third well may therefore be subtracted from the charges in the first well and the second well to effectively remove the background light component from the latter charges. The light received in the third well may also include reflections of projected spots arriving from highly reflective objects outside the range covered by the operation of the first well and the second well, and the accumulated charges may accordingly be used to detect such objects. The light received in the third well may also be used to generate a 2D image of the scenery, which may optionally be combined with the ranging information obtianed from the operation of the first well and the second well to create a 3D image.

Figure 7d represents a variant of the timing scheme of Figure 7c, in which the third well is activated during a number of time slots after the completion of the same number of projector pulses. As the light thus received in the third well arrives in the absence of a pulse, it represents the background light, with only a slightly larger time offset relative to the points in time at which the pulse reflection is received. The charge accumulated in the third well may therefore be subtracted from the charges in the first well and the second well to effectively remove the background light component from the latter charges. The charge accumulated in the third well in the separate time slots may also be used to generate a 2D image of the scenery, in which case the scenery may optionally be illuminated by a flash light.

Figure 7e represents yet another variant of the timing scheme of Figure 7c, in which the first well is activated in a separate frame, after the completion of a range-gating frame in which the

projector and the first and second well are active. As the light thus received in the first well arrives in the absence of a pulse, it represents the background light, with again a slightly larger time offset relative to the points in time at which the pulse reflection is received. The charge accumulated in the first well in the separate frame may therefore be subtracted from the charges previously accumulated in the first well and the second well to effectively remove the background light component from the latter charges. The charge accumulated in the first well in the separate frame may also be used to generate a 2D image of the scenery, in which case the scenery may optionally be illuminated by a flash light .

The combination of the large desired operational range (in the order of 200 m) and the high desired accuracy (correctly detect as few as 1000 photons at the furthest point) results in a huge span between the largest number of photons that may be received in one well in one frame (in the case of reflections at short range) , and the lowest number that may be received in one well in one frame.

Figure *1f* represents a modified timing scheme, which differs from the scheme of Figure 7a in that the duration of a single time slot varies from one slot to the next. In this way, the detection threshold and the saturation point for different frames will occur at different distances, and the information obtained from a number of consecutive frames may be combined to obtain accurate distance measurements for both nearby objects and far-away objects.

Figure 7g schematically illustrates how the individual frames in the sequence of Figure 3c, which may fail to cover the entire targeted range of distances $[z_{min}, z_{max}]$ as a result of the constraints imposed by N_{max} (maximal number of electrons that can be stored without saturating the pixel) and N_{min} (minimum number of pixels required for accurate read-out) , can be broken down into sequences with different timing parameters, each covering a portion of the targeted range $[z_{min}(i), z_{max}(i)]$ that can more

easily be covered within the same constraints on the number of photons .

With reference to the symbols introduced above and used in Figure 7g, the corresponding electron amounts $n_{min(i)}$ and $n_{max(i)}$ of the subranges are defined by:

- The maximum allowable number of electrons (using "FPC" for the full pixel capacity, which corresponds to full well capacity in case there are no additional capacities) :

  $n_{max} = N_{min} \times \left(\frac{z(i)}{z(i+1)}\right) \leq FPC$, with $z_{(0)} = Z_{max}$

- The minimum required accuracy level : $n_{min} = N_{min}$
- $Z_{max(i)} = Z_{min(i-1)}$

Additionally, the pulse characteristics can be determined as follows :

- the pulsewidth $\tau(i) = \frac{z_{max(i)}}{c}$
- the total "on" time is reduced proportionally to $\frac{N_{max}}{N_{min}}$ to respect the limits imposed by the full pixel capacity and the accuracy level.

The above principles may be further clarified by the following non-limiting numerical example.

A Lambertian reflecting surface with 10% reflectivity at a distance of 150m must provide 1000 electrons to obtain an accuracy of 1,6%. At the same distance, a 100% reflecting surface will generate 10000 electrons. With a full well capacity of 200000 electrons, the following multi-frame solution is proposed:

	Sub-range	Pulse Width	Total "on" time
Frame 1	150m - 33m	1 µs	1 ms
Frame 2	7.4m - 33m	22 ns	50 µs
Frame 3	1.65m - 7.4m	4.9 ns	2.5 µs
Frame 4	0.37m - 1.65m	1.1 ns	0.125 µs

It should be noted that for robustness reasons, it may be advantageous to provide an overlap in the subranges .

For assuring the same 3D resolution, it may be advantageous to use a faster camera: e.g., a camera operating at 180Hz with 3-frame interleaving gives the same data speed as a 60Hz with single frame operation .

Depending on the mode in which a system according to the present invention is used (as exemplified in Figures 7a-7g) , the duty cycle will vary. It can easily be seen that when some frames are used for capturing out-of-range reflections or acquiring a 2D image, a smaller fraction of time is available for the actual ranging. It is an advantage of the use of three-well or four-well pixel according to the present invention that several functions can be performed simultaneously.

Blooming is a phenomenon that happens when the charge in a pixel exceeds the saturation level of that specific pixel (as in the case of short-range reflections or reflections from highly reflective surfaces such as traffic signs or license plates) . Consequently, the charge starts to overflow and causes nuisance in adjacent pixels. This creates inaccurate data in the neighboring pixels. Preferably, the pixels of the system according to the present invention are provided with anti-blooming electronics, which may in particular include a fourth well, to bleed off the excess charge before it saturates the relevant well and spills over to the wells of adjacent pixels. In particular when the information from neighboring spots is used for the elimination of background light, it is of great importance to have an accurate estimation of the background light which is obtained independently (and without contamination from) neighboring pixels. Likewise, when the pixels that do not receive spot reflections are used to simultaneously generate a regular 2D image, it is highly desirable that pixels adjacent to pixels receiving a spot reflection are not affected by charge spills from the latter pixels.

In order for all elements of the system as described to operate optimally, the system has to be thermally stable. Thermal stability avoids, among other things, undesired wavelength shifts of the optical elements (thermal drift), which would otherwise impair the proper functioning of the optical filters and other elements of the optical chain. Embodiments of the system according to the present invention achieves thermal stability by their design, or by active regulation by means of a temperature control loop with a PID-type controller.

WO 2015/004213 A1 discloses various techniques to minimize the amount of ambient light that reaches the pixels during the detection intervals, thus improving the accuracy of the detection of the patterned laser spots. While these techniques have not been disclosed in the context of a LIDAR system, the inventors of the present invention have found that several such techniques yield excellent results when combined with embodiments of the present invention. This is particularly true for the use of narrow bandpass filters at the detector, and the use of adequate optical arrangements to ensure nearly perpendicular incidence of the reflected light onto the filters. The details of these arrangements as they appear in WO 2015/004213 A1 are hereby incorporated by reference. Further features and details are provided hereinafter.

European patent application publication nos. EP 3045935 B1 and EP 3045936 B1, both in the name of the present applicant, disclose optical arrangements that may be used in conjunction with the system disclosed in the present application to further minimize the amount of ambient light that reaches the pixels during the detection intervals. The details of these arrangements as they appear in EP 3045935 B1 and EP 3045936 B1 are hereby incorporated by reference. Accordingly, a pixel according to the present invention may be provided with a microlens in order to guide the impinging light, after optional filtration, to the photosensitive region.

While these various techniques may be applied to embodiments of the present invention to minimize the amount of ambient light that reaches the pixels during the detection intervals, a certain amount of ambient light cannot be avoided. In a multi-pixel system, only some of the pixels will be illuminated by reflected spots, while others will be illuminated by residual ambient light only. The signal levels of the latter group of pixels can be used to estimate the contribution of the ambient light to the signals in the pixels of interest, and to subtract that contribution accordingly .

In some embodiments, the detector may be a high dynamic range detector, i.e. a detector having a dynamic range of at least 90 dB, preferably at least 120 dB. The presence of a high dynamic range sensor, i.e. a sensor capable of acquiring a large amount of photons without saturation while maintaining sufficient discrimination of intensity levels in the darkest part of the scene, is an advantage of the use of such a sensor; it allows for a sensor that has a very long range and yet remains capable of detection objects at short distance (where the reflected light is relatively intense) without undergoing saturation. The inventors have found that the use of a high dynamic range sensor not based on tone mapping is more advantageous than the use of a sensor that applies tone mapping. In tone mapping, the sensor linear range is compressed towards the higher resolution. In literature, several compression methods are documented, such as logarithmic compression or multilinear compression. However, this non-linear compression necessitates relinearization of the signals before performing logical or arithmetic operations on the captured scene to extract the relief information. The solution according to the invention therefore increases detection accuracy without increasing the computational requirements. It is a further advantage of some embodiments to use a fully linear high dynamic range sensor. A pixel architecture and an optical detector that are capable of providing the desired dynamic range characteristics are disclosed in US patent application publication no. US

2014/353472 A1, in particular paragraphs 65-73 and 88, the content of which is incorporated by reference for the purpose of allowing the skilled person to practice this aspect of the present invention .

Embodiments of the present invention use a high dynamic range pixel. This can be obtained by a sizeable full-well capacity of the charge reservoirs or by designs limiting the electronic noise per pixel or by usage of CCD gates that do not add noise at charge transfer, or through a design with a large detection quantum efficiency (DQE) (e.g., in the range of 50% for front illumination or 90% in case of back illumination, also known as back thinning) , or by a special design, or by any combination of the listed improvements. Furthermore, the dynamic range can be further enlarged by adding an overflow capacity to the pixel in overlay at its front side (this implementation requires back thinning) . Preferably, the pixel design implements an anti-blooming mechanism.

A system according to the invention may include an implementation of steps of the methods described above in dedicated hardware (e.g., ASIC), configurable hardware (e.g., FPGA) , programmable components (e.g., a DSP or general purpose processor with appropriate software), or any combination thereof. The same component (s) may also include other functions. The present invention also pertains to a computer program product comprising code means implementing the steps of the methods described above, which product may be provided on a computer-readable medium such as an optical, magnetic, or solid-state carrier.

The present invention also pertains to a vehicle comprising the system described above.

Embodiments of the present invention may be used advantageously in a wide variety of applications, including without limitation automotive applications, industrial applications, gaming applications, and the like, and this both indoor and outdoor, at

short or long range. In some applications, different sensors according to embodiments of the present invention may be combined (e.g., daisy-chained) to produce panoramic coverage, preferably over a full circle (360° field of view) .

It should be noted that the method, the pixel, and the pixel array according to the present invention may also be used in triangulation-based systems such as the system of WO 2015/004213 A1, and in existing LIDAR systems, to improve the quality of the measurements in the presence of ambient light.

While the invention has been described hereinabove with reference to separate embodiments, this was done for clarifying purposes only. The skilled person will appreciate that features described in connection with one embodiment, can also be applied to other embodiments, with the same technical effects and advantages. Furthermore, the scope of the invention is not limited to these embodiments, but is defined by the accompanying claims.

Claims

1. A pixel for use in a system for determining a distance to an object by range gating,
said pixel comprising:
a first charge storage well (221) and a second charge storage well (222) for accumulating electrical charges representative of amounts of light reflected by said object and impinging on said pixel during respective sets of exposure intervals, and a third charge storage well (223);
wherein said first charge storage well (221) has a charge capacity that is at least 50% greater than a charge capacity of said second charge storage well (222); and
wherein said third charge storage well (223) has a smaller charge storage capacity than said first charge storage well (221) and said second charge storage well (222).

2. The pixel according to claim 1, further comprising circuitry allowing said pixel to switch between:

- a charging mode, in which light impinging on said pixel causes said first charge storage well (221) or said second charge storage well (222) to increase a stored amount of charge, and
- a discharging mode, in which light impinging on said pixel causes said first charge storage well (221) or said second charge storage well (222) to decrease a stored amount of charge.

3. The pixel according to any of the preceding claims, further comprising circuitry allowing photocharges that are generated when an active one of said first charge storage well (221) and said second charge storage well (222) is filled to capacity, to be to deviated to a charge sink without entering a storage well of an adjacent pixel.

4. The pixel according to any of the preceding claims, further comprising a fourth charge storage well (224).

5. An imaging array comprising a plurality of pixels according to any of the preceding claims.

6. A system for determining a distance to an object comprising:

- a solid-state light source arranged for projecting a pattern of spots, preferably discrete spots, of light towards the object in a sequence of pulses, preferably a periodically repeated sequence of pulses;
- a detector comprising an imaging array according to claim 5, the detector being configured for detecting light representing the pattern of spots as reflected by the object in synchronization with said sequence of pulses; and
- processing means configured to calculate the distance to the object as a function of exposure values generated by said pixels in response to said detected light;

wherein the pixels of the imaging array are configured to generate said exposure values by accumulating, for all pulses of said sequence, a first amount of electrical charge representative of a first amount of light reflected by said object during a first predetermined time window and a second electrical charge representative of a second amount of light reflected by said object during a second predetermined time window, said second predetermined time window occurring after said first predetermined time window, and

wherein the detecting of the first amount of light and the detecting of said second amount of light occurs at said first charge storage well (221) and at said second charge storage well (222), respectively.

7. The system according to claim 6, further configured to perform the projecting and the detecting for at least two consecutive sequences of pulses, each of the sequences being operated with a different duration of the first predetermined time window and the second predetermined time window.

8. The system according to claim 6 or claim 7, wherein the imaging array is further adapted to perform 2D video image acquisition.

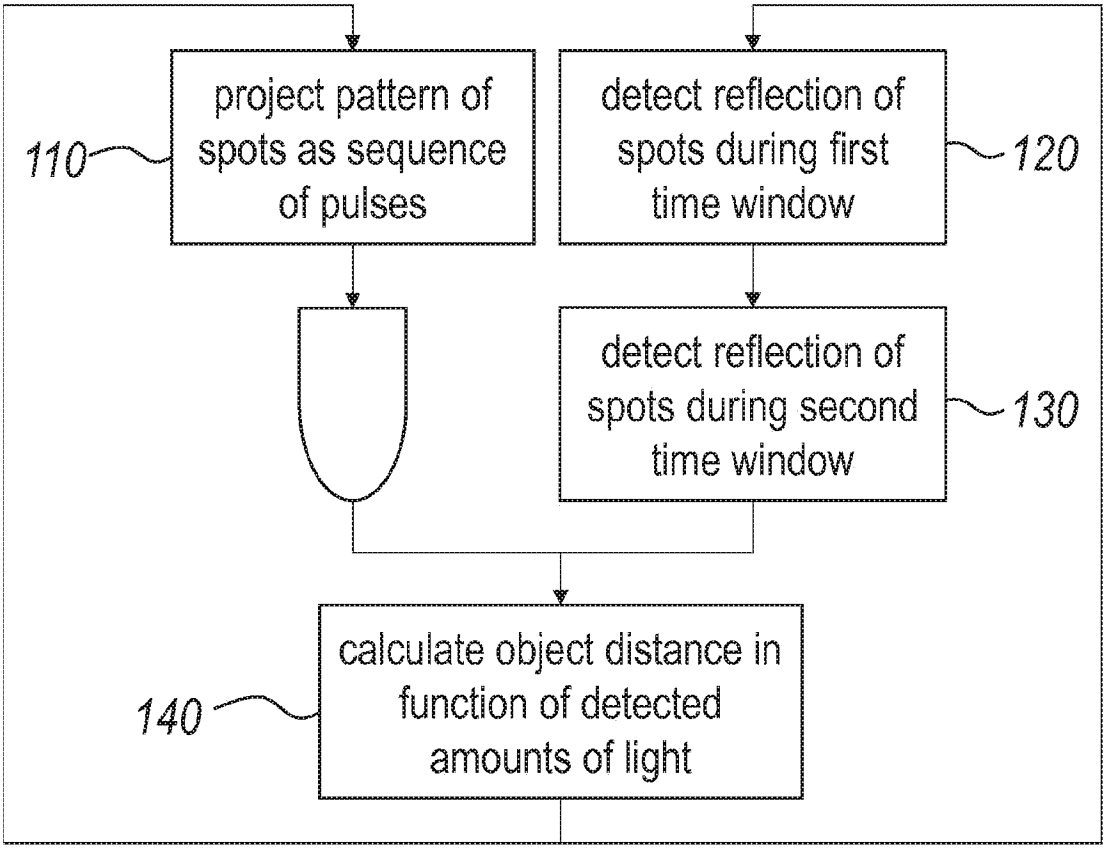

project pattern of spots as sequence of pulses
110
detect reflection of spots during first time window
120
detect reflection of spots during second time window
130
calculate object distance in function of detected amounts of light
140

Fig. 1

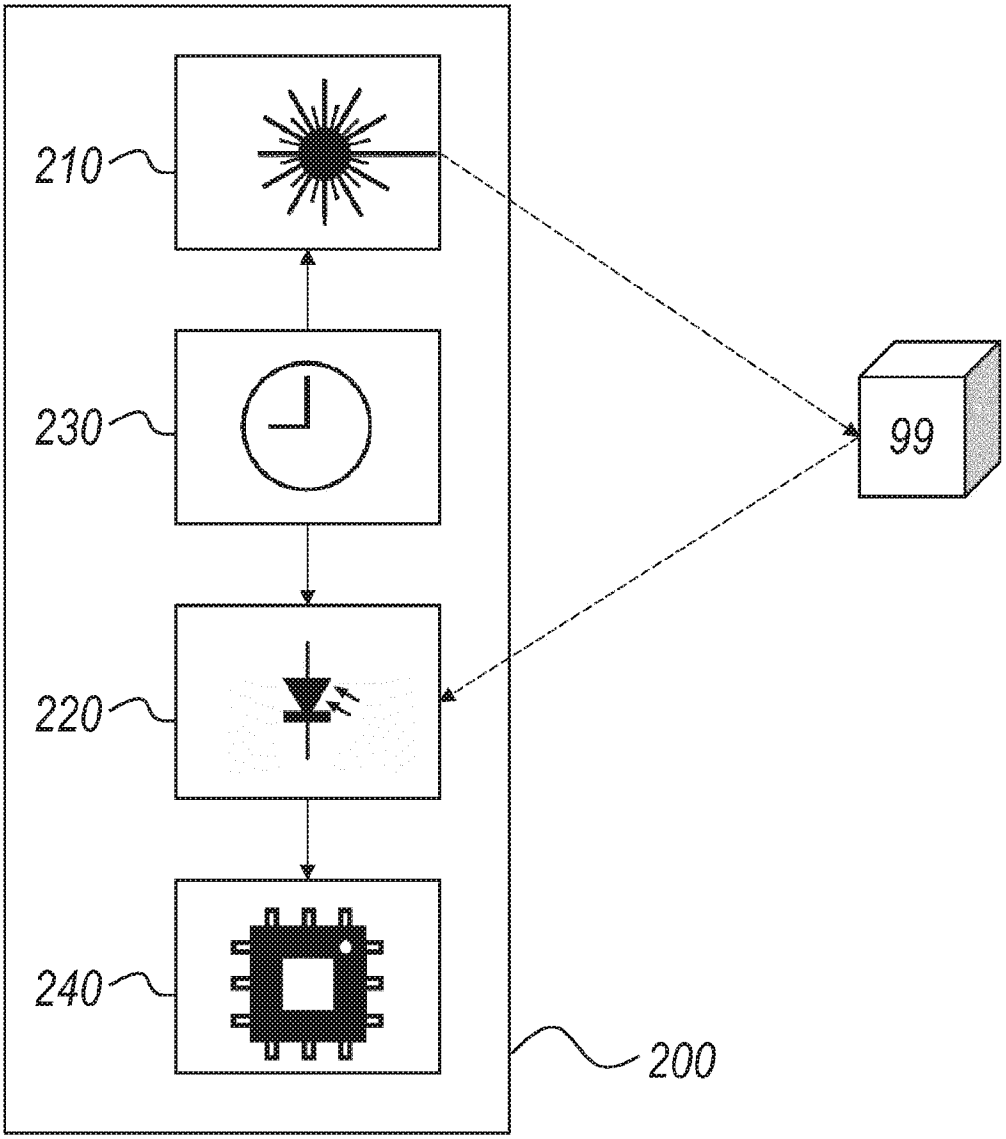


Fig. 2

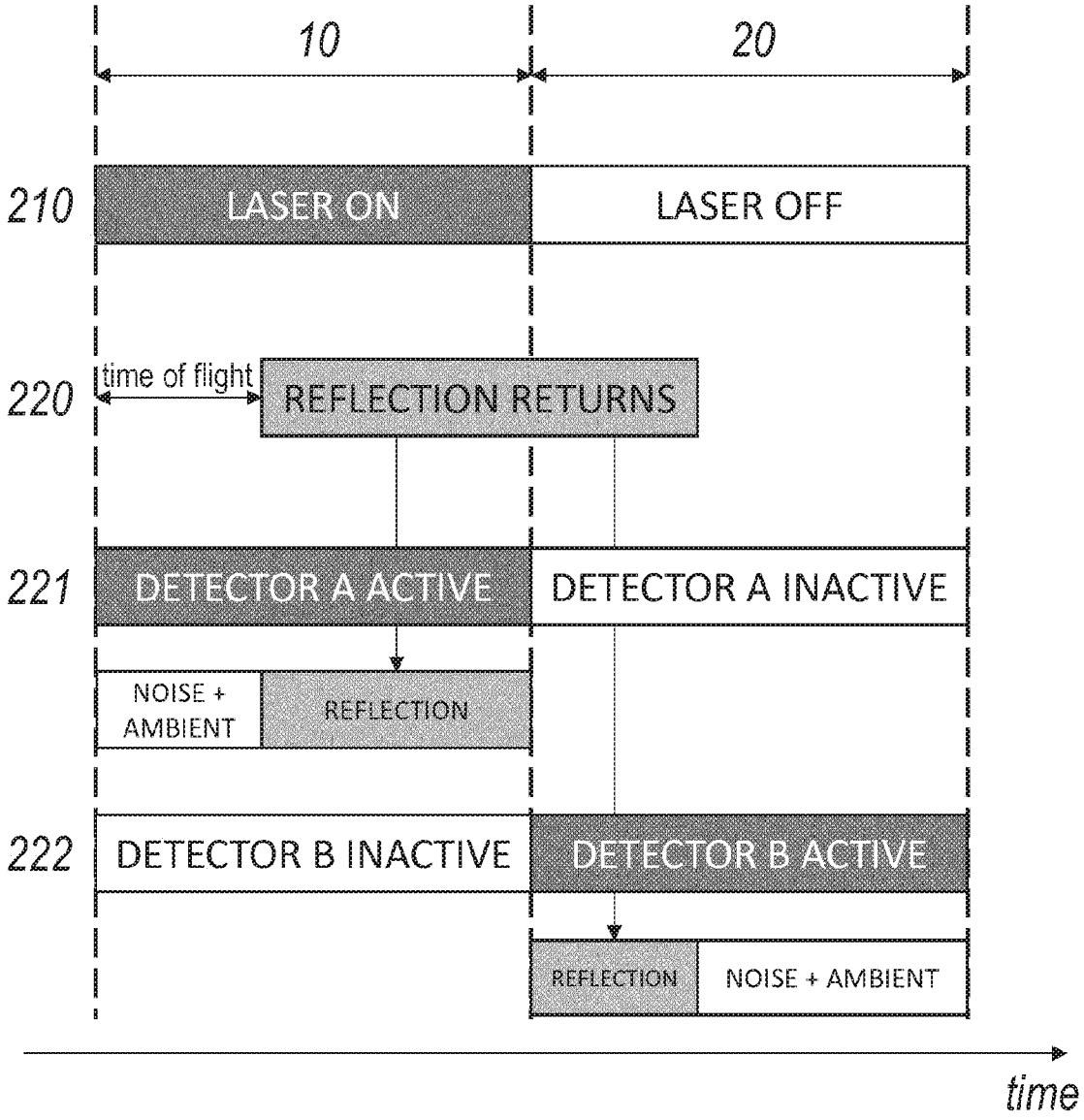

10
20
210
LASER ON
LASER OFF
220
time of flight
REFLECTION RETURNS
221
DETECTOR A ACTIVE
DETECTOR A INACTIVE
NOISE + AMBIENT
REFLECTION
222
DETECTOR B INACTIVE
DETECTOR B ACTIVE
REFLECTION
NOISE + AMBIENT
time

Fig. 3a

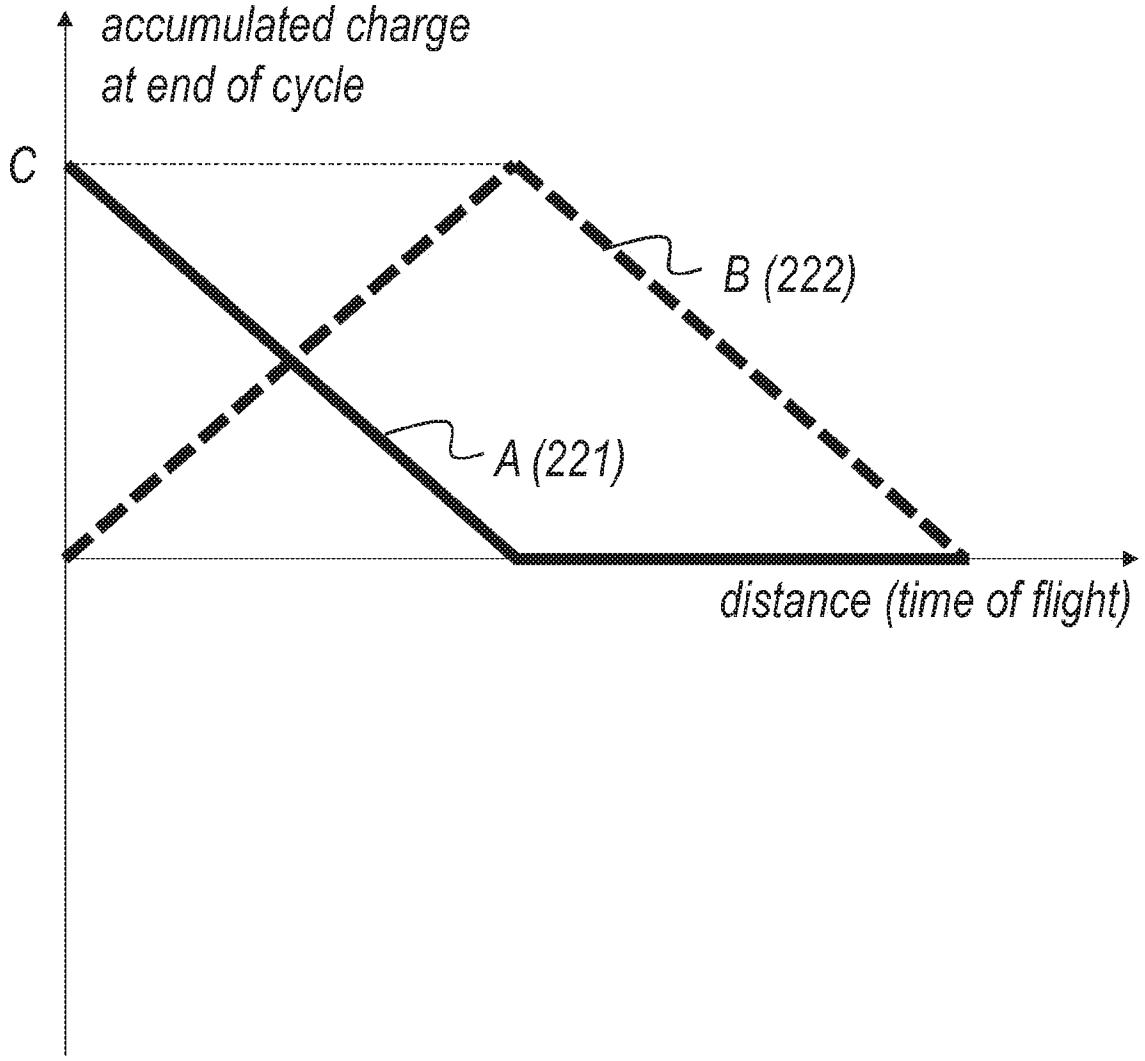

accumulated charge
at end of cycle
C
B (222)
A (221)
distance (time of flight)

Fig. 3b

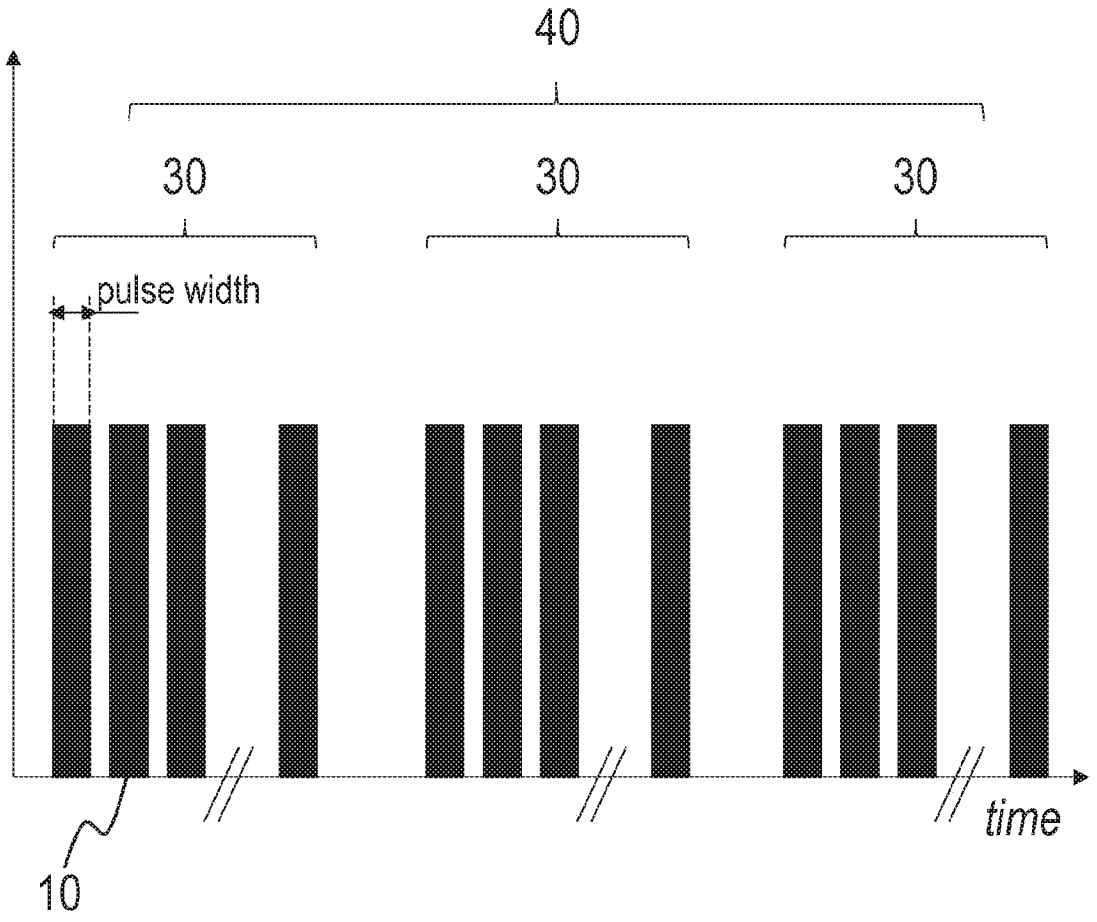


Fig. 3c

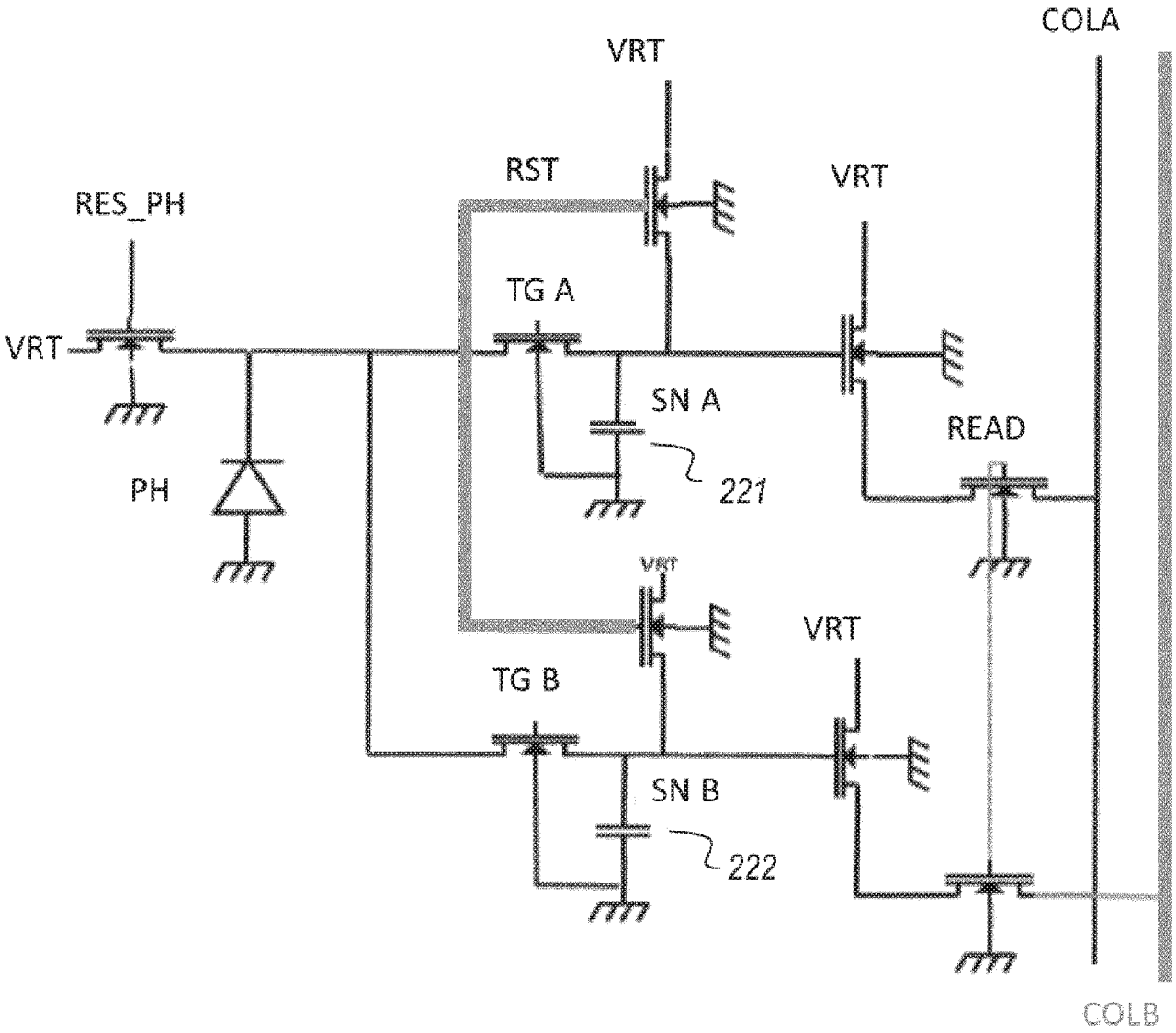

COLA
VRT
RST
VRT
RES_PH
TG A
VRT
SN A
READ
221
PH
VRT
VRT
TG B
SN B
222
COLB

Fig. 4

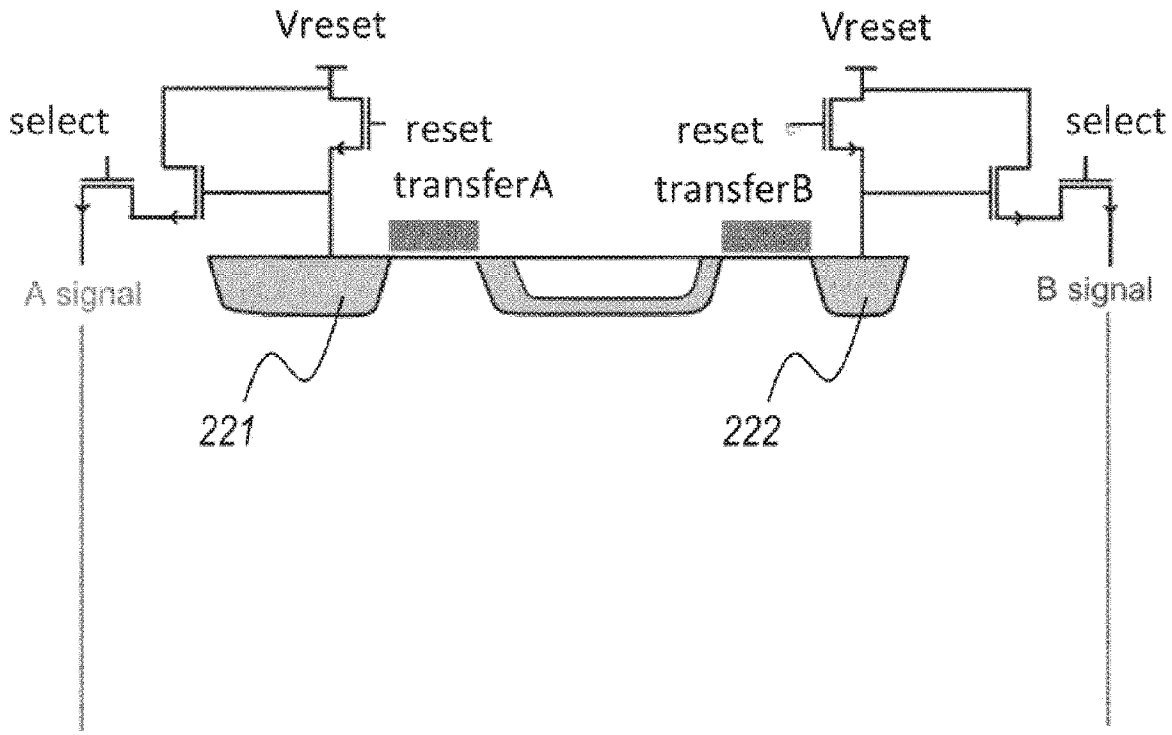

Vreset
Vreset
select
reset
transferA
reset
transferB
select
A signal
B signal
221
222

Fig. 5

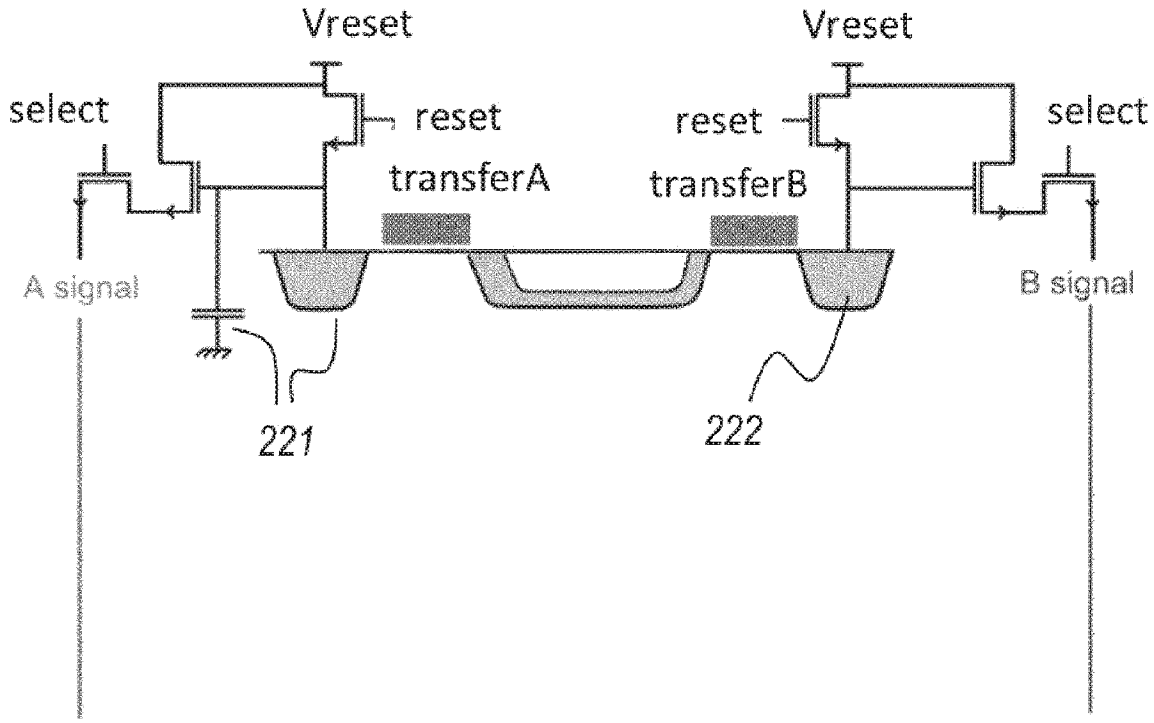

Vreset
Vreset
select
reset
transferA
reset
transferB
select
A signal
B signal
221
222

Fig. 6

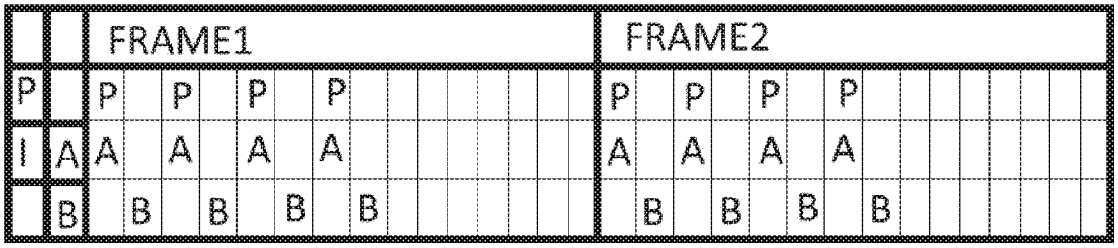


Fig. 7a

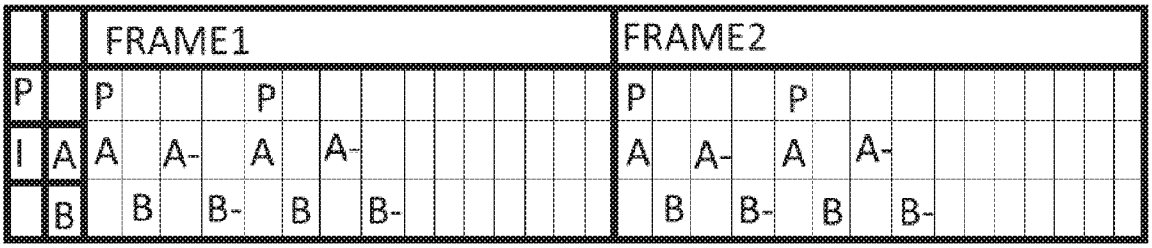


Fig. 7b

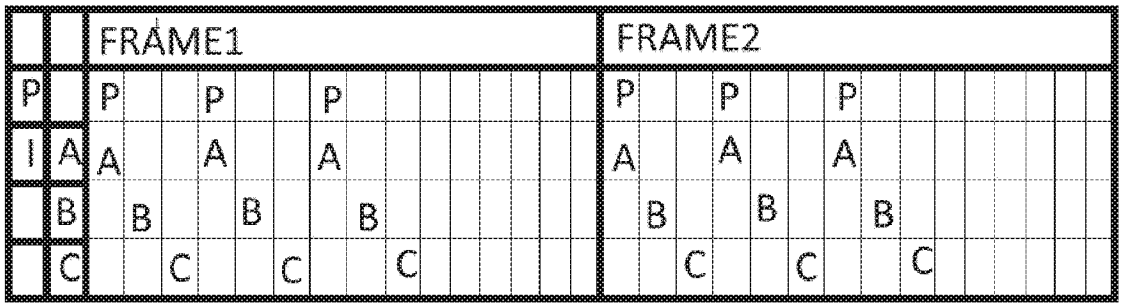


Fig. 7c

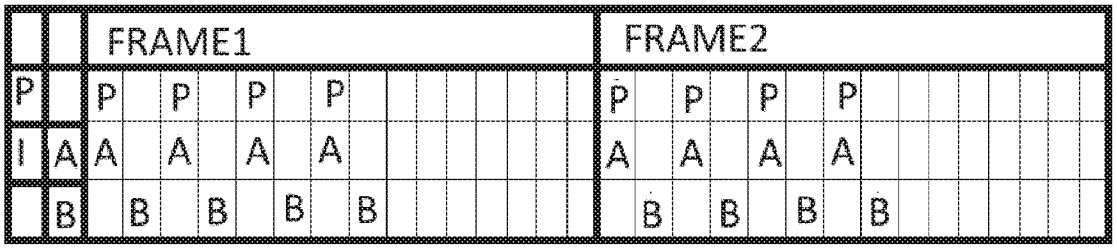


Fig. 7d

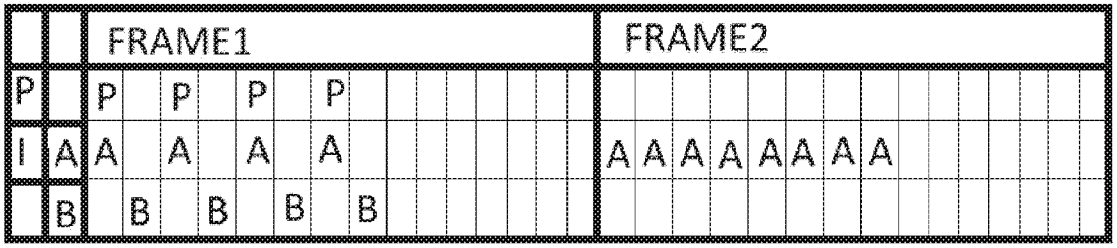


Fig. 7e

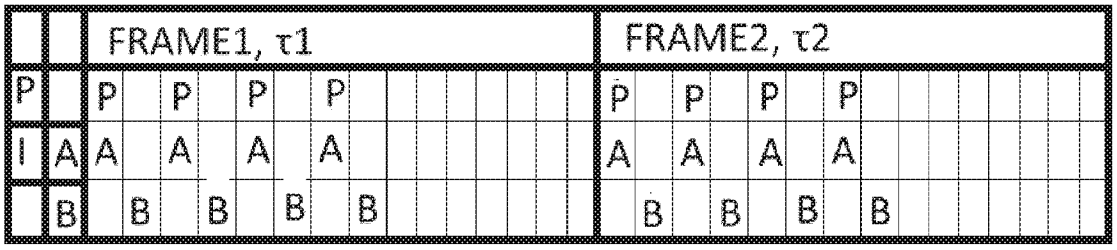


Fig. 7f

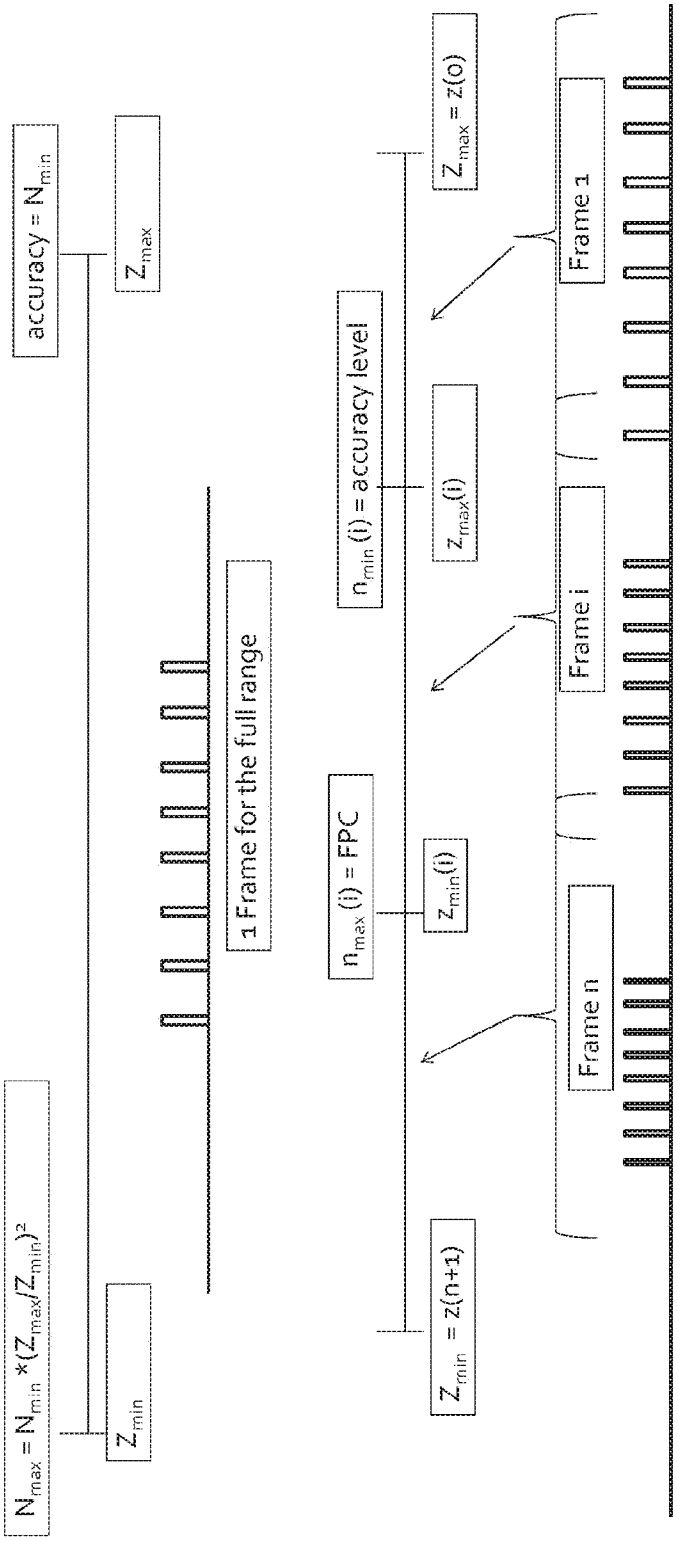

accuracy = N_{min}
Z_{max}
$N_{max} = N_{min} * (Z_{max}/Z_{min})^2$
Z_{min}
1 Frame for the full range
$n_{max}(i)$ = FPC
$n_{min}(i)$ = accuracy level
$Z_{min}(i)$
$Z_{max}(i)$
$Z_{min} = z(n+1)$
$Z_{max} = z(0)$
Frame n
Frame i
Frame 1

Fig. 7g

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/060391

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/10 G01S17/89 G01S7/486
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S G01B H04N H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/041077 A1 (FOSSUM ERIC R [US]) 4 March 2004 (2004-03-04)	1-5
A	abstract; figures 18-21 paragraphs [0015] , [0059] - [0061] , [0077] - [0080] , [0091] , [0092]	6-8
A	US 2015/253429 A1 (DORRINGTON ADRIAN ANDREW [NZ] ET AL) 10 September 2015 (2015-09-10) paragraphs [0013] , [0030] , [0089] , [0118] ; figure 5c	6-8
A	US 2015/144790 A1 (VELICHKO SERGEY [US] ET AL) 28 May 2015 (2015-05-28) paragraphs [0014] - [0016] , [0019] , [0031] - [0040] ; figures 5,6	1-8

-/- .

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" documentwhich may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 July 2018	06/08/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax (+31-70) 340-3016	Grubl , Alexander

1

Form PCT/ISA/210 (second sheet) (April 2005)

HESAI EX1002, P.854

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/060391

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 045 935 A1 (XENOMATIX BVBA [BE]) 20 July 2016 (2016-07-20) cited in the application abstract	6

1

HESAI EX1002, P.855

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/060391

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004041077 A1	04-03-2004	US 2004041077 A1	04-03-2004
		US 2005168608 A1	04-08-2005
		US 2009021627 A1	22-01-2009
US 2015253429 A1	10-09-2015	CN 106662650 A	10-05-2017
		EP 3114503 A2	11-01-2017
		US 2015253429 A1	10-09-2015
		WO 2015133910 A2	11-09-2015
US 2015144790 A1	28-05-2015	NONE	
EP 3045935 A1	20-07-2016	NONE	

Electronic Acknowledgement Receipt

EFS ID:	35509329
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/LaRenda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	22-MAR-2019
Filing Date:	14-MAY-2018
Time Stamp:	19:23:24
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		P006US3_IDS.pdf	182301 27c2541b760b92c69c09b70b63e4b97311709712	yes	5

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Information Disclosure Statement (IDS) Form (SB08)	3	5
	Transmittal Letter	1	2

Warnings:					
Information:					
2	Foreign Reference	EP3045935A1.pdf	903626 6604f41934e60a5c14556fc9fab1f29af43b51ad	no	33
Warnings:					
Information:					
3	Foreign Reference	EP3316000A1.pdf	384972 8ba1196090a6b856858d44c58eecb940208970f4	no	11
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Information:					
4	Foreign Reference	WO2018065426A1.pdf	7734001 4f64e7b833f422a6be52c2c498b3b907251ef854	no	36
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5	Foreign Reference	WO2018065427A1.pdf	10574327 2959a079045077779457 1a536ff1a1a70c390506	no	50
Warnings:					
Information:					
6	Foreign Reference	WO2018065428A3.pdf	1945480 7d46bc3ec72c96580ce81fad869cd77734876d46	no	7
Warnings:					
Information:					
7	Foreign Reference	WO2018065429A1.pdf	11914118 6cc95ae8fa39bafa44221613de04ce4ca03d7b3b	no	56
Warnings:					

Information:					
8	Foreign Reference	WO2018122415A1.pdf	7512437 707b7a47354d2fb534286d505607a4d76bc9e482	no	29
Warnings:					
Information:					
9	Foreign Reference	WO2018197441A1.pdf	11040325 45229720b9d42e35b24e89e99e2a98f45a3f9be8	no	48
Warnings:					
Information:					
			Total Files Size (in bytes):	52191587	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/979,266	05/14/2018	Angus PACALA	103033-P006US3-1086284

CONFIRMATION NO. 9761

20350
KILPATRICK TOWNSEND & STOCKTON LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, GA 30309

PUBLICATION NOTICE

OC000000103834452

Title:SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW

Publication No.US-2018-0329061-A1
Publication Date:11/15/2018

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Public Records Division. The Public Records Division can be reached by telephone at (571) 272-3150 or (800) 972-6382, by facsimile at (571) 273-3250, by mail addressed to the United States Patent and Trademark Office, Public Records Division, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently https://portal.uspto.gov/pair/PublicPair. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	15/979,266
Filing Date	May 14, 2018
First Named Inventor	Angus Pacala
Art Unit	2875
Examiner Name	Not yet assigned
Attorney Docket Number	103033-P006US3-1086284

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	5745153	A	Apr 28, 1998	Kessler et al.	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	2.	20050035474	A1	Feb 17, 2005	Itoh	
	3.	20150055117	A1	Feb 26, 2015	Pennecot et al.	
	4.	20150260830	A1	Sep 17, 2015	Ghosh et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	5	PCT/US2018/032601 , "International Search Report and Written Opinion", September 21, 2018, 16 pages	
	6	PCT/US2018/032601 , "Invitation to Pay Additional Fees and, Where Applicable, Protest Fee", July 26, 2018, 2 pages	

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-P006US3-1086284

EXAMINER SIGNATURE			
Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.
[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: Stephen A. Mao
Kilpatrick Townsend & Stockton LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, Georgia 30309
United States of America

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 21 SEP 2018
Applicant's or agent's file reference 1087057	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US18/32601	International filing date *(day/month/year)* 14 May 2018 (14.05.2018)
Applicant OUSTER, INC.	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   How? Directly to the International Bureau of WIPO preferably through ePCT or on paper to, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 82 70

   For more detailed instructions, see *PCT Applicant's Guide*, International Phase, paragraphs 9.004 – 9.011.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to any protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:
   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with any request to forward the texts of both the protest and the decision thereon to the designated Offices.
   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   The applicant may **submit comments on an informal basis on the written opinion of the International Searching Authority** to the International Bureau. These comments will be made available to the public after international publication. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established.

   Shortly after the expiration of **18 months from the priority date, the international application will be published** by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau before the completion of the technical preparations for international publication (Rules 90*bis*.1 and 90*bis*.3).

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for **entry into the national phase** before those designated Offices. In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months. For details about the applicable time limits, Office by Office, see www.wipo.int/pct/en/texts/time_limits.html and the *PCT Applicant's Guide*, National Chapters.

   Within **22 months from the priority date, the applicant may request that a supplementary international search be carried out** by a different International Searching Authority that offers this service (Rule 45*bis*.1). The procedure for requesting supplementary international search is described in the *PCT Applicant's Guide*, International Phase, paragraphs 8.006-8.032.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 Telephone No. PCT OSP: 571-272-7774

Form PCT/ISA/220 (July 2017)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 1087057	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US18/32601	International filing date *(day/month/year)* 14 May 2018 (14.05.2018)	(Earliest) Priority Date *(day/month/year)* 15 May 2017 (15.05.2017)
Applicant OUSTER, INC.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☒ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 4

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US18/32601

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-20

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US18/32601

A. CLASSIFICATION OF SUBJECT MATTER

IPC - G01J 1/02, 1/08, 1/44 (2018.01)

CPC - G01J 1/0295, 1/0252, 1/08, 1/44, G01B 11/026, 11/24, 27/2214, 27/46, G01S 7/481, 7/4815, 7/497, 17/42, 17/89

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2015/0260830 A1 (PRINCETON OPTRONICS INC.) September 17, 2015; abstract; figures 7, 10, 12-13; paragraphs [0021, 0036, 0074, 0075, 0086, 0096, 0101, 0104-0112].	1-3, 6, 10 and 12 --- 4, 5, 7-9, 11, 13-20
X	US 5,745,153 A (KESSLER, D. et al.) April 28, 1998; figures 1-3; column 4, lines 29-50; column 5, lines 56-column 6, line 33.	1, 2, 6
Y	US 7,433,042 B1 (CAVANAUGH, D. et al.) October 7, 2008; figures 2 and 3; column 4, lines 5-67.	4, 5, 15, 16 and 17
Y	US 2005/0035474 (ITOH, N) February 17, 2005; figure 9A and 9B; paragraphs [0099].	7-9, 11, 13, and 14
Y	US 2015/0055117 A1 (GOOGLE, INC.) February 26, 2015; figures 1 and 2 and 9; paragraphs [0043, 0066-0068, 0078, 0102].	18-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 July 2018 (13.07.2018)	21 SEP 2018
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US18/32601

-***-Continued from Box No. III Observations where unity of invention is lacking-***-

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-20 are directed towards an optical system comprising a reduced-sized spot image.
Group II: Claims 21-40 are directed towards an optical system comprising a non-uniform optical filter layer.
Group III: Claims 41-100 are directed towards an optical system comprising a motor and a second plurality of lenses.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic, which are not present in Groups II-III.

The special technical features of Group II include at least wherein the non-uniform optical filter layer is configured to allow different micro-optic channels to measure different ranges of wavelengths, which are not present in Groups I and III.

The special technical features of Group III include at least a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing; and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device; and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors, which are not present in Groups I-II.

The common technical features shared by Groups I-III are an optical system for performing distance measurements, the optical system comprising: a bulk transmitter optic; an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system; a bulk receiver optic configured to receive the discrete beams of light from the field; and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field, the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors.

However, these common features are previously disclosed by US 2015/0260830 A1 to PRINCETON OPTRONICS INC. (hereinafter "Princeton") in view of US 7,433,042 B1 to CAVANAUGH et al. (hereinafter "Cavanaugh"). Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vscel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a bulk transmitter optic (imaging lens 1264; figures 12; paragraphs [0104-0106]); an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139 which avoids cross talk; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]). However, Princeton fails to disclose a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; the optical assembly comprising: and a plurality of lenses positioned between the aperture layer and the array of photosensors. Cavanaugh discloses a bulk receiver optic configured to receive the discrete beams of light from the field (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic (aperture masks 135 and 137 is an array of openings part of aperture 150 which may be placed at the focus of the MLA; figure 2; column 4, lines 5-58); an array of photosensors disposed behind the aperture layer (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); and a plurality of lenses positioned between the aperture layer and the array of photosensors (micro lens array 130 are between aperture masks 135 and 137 and detector array 110; figure 2; column 4, lines 5-58). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors, as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk between lenses on the detector array, in order to get a stronger sensitivity.

Since the common technical features are previously disclosed by Princeton in view of Cavanaugh, these common features are not special and so Groups I-III lack unity.

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: Stephen A. Mao
Kilpatrick Townsend & Stockton LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, Georgia 30309
United States of America

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	21 SEP 2018
Applicant's or agent's file reference 1087057	**FOR FURTHER ACTION** See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US18/32601	14 May 2018 (14.05.2018)	15 May 2017 (15.05.2017)

International Patent Classification (IPC) or both national classification and IPC
IPC - G01J 1/02, 1/08, 1/44 (2018.01)
CPC - G01J 1/0295, 1/0252, 1/08, 1/44, G01B 11/026, 11/24, 27/2214, 27/46, G01S 7/481, 7/4815, 7/497, 17/42, 17/89

Applicant OUSTER, INC.

1. This opinion contains indications relating to the following items:

- [x] Box No. I Basis of the opinion
- [ ] Box No. II Priority
- [ ] Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- [x] Box No. IV Lack of unity of invention
- [x] Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- [ ] Box No. VI Certain documents cited
- [x] Box No. VII Certain defects in the international application
- [ ] Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	13 July 2018 (13.07.2018)	Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (January 2015)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US18/32601

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a)).

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed:

      ☐ in the form of an Annex C/ST.25 text file.

      ☐ on paper or in the form of an image file.

   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).

      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US18/32601

Box No. IV Lack of unity of invention

1. ☒ In response to the invitation (Form PCT/ISA/206) to pay additional fees the applicant has, within the applicable time limit:

   ☐ paid additional fees.

   ☐ paid additional fees under protest and, where applicable, the protest fee.

   ☐ paid additional fees under protest but the applicable protest fee was not paid.

   ☒ not paid additional fees.

2. ☐ This Authority found that the requirement of unity of invention is not complied with and chose not to invite the applicant to pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rule 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:

-***-See next supplemental page-***-

4. Consequently, this opinion has been established in respect of the following parts of the international application:

   ☐ all parts.

   ☒ the parts relating to claims Nos. Group I: Claims 1-20

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US18/32601

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	4, 5, 7-9, 11, 13-20	YES
	Claims	1-3, 6, 10 and 12	NO
Inventive step (IS)	Claims	NONE	YES
	Claims	1-20	NO
Industrial applicability (IA)	Claims	1-20	YES
	Claims	NONE	NO

2. Citations and explanations:

Claims 1, 2 and 6 lack novelty under PCT Article 33(2) as being anticipated by US 5,745,153 A to Kessler, D. et al. (hereinafter 'Kessler').

As for claim 1, Kessler discloses an optical system for performing distance measurements (the preamble is not brought into the body of the claim an is not given patentable weight), the optical system comprising: a bulk transmitter optic (printing lens 22 is telecentric lens; figures 1-3; column 4, lines 29-44; column 6, lines 8-33); an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system (laser diode array 12 comprises a plurality of diode lasers 12 projects beams through the printing lens 22 on to provide a far field conjugate of the lasers 13 on the light sensitive media 27; figures 1-3; column 4, lines 29-50; column 6, lines 8-33); and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic (micro lenslet array 20 between laser diode array 12 and the printing lens 22; figures 1-3; column 4, lines 29-44), the micro-optic channel array defining a plurality of micro-optic channels (micro lenslet array 20 between laser diode array 12 and the printing lens 22; figures 1-3; column 4, lines 29-44), each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters (micro lenslet array 20 has micro lenslets 21 spaced apart from laser diode array 12 and the printing lens 22; figures 1-3; column 4, lines 29-44; column 5, lines 56-column 6, line 33) with the micro-optic lens being configured to receive a light cone from the light emitter (micro lenslet array 20 has micro lenslets 21 receive a diverging beam from the lasers 13; figures 1-3; column 4, lines 29-44; column 5, lines 56-column 6, line 33) and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic (micro lenslets 21 focuses the light beams of corresponding lasers 13 on to the pupil 24 of the lens 22, with the stop of lens 22 at pupil 22, allowing the lens 22 to image the laser diode array 12; figures 1-3; column 4, lines 29-44; column 5, lines 56-column 6, line 33).

As for claim 2, Kessler discloses the optical system for performing distance measurements set forth in claim 1 wherein the bulk transmitter optic comprises one or more lenses configured as an image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other (the telecentric lens 22 allows imaging the laser diode array 12 via the microlenslets 21 to create a series of discrete beams forming laser spots 26 shown as parallel beams; figures 1-3; column 4, lines 29-44; column 5, lines 56-column 6, line 33).

As for claim 6, Kessler discloses the optical system for performing distance measurements set forth in claim 1 wherein the micro-optic lens for each channel is configured to receive a light cone from a light emitter and generate a reduced-size real spot image of the emitter at a focal point between the micro-optic lens and the bulk transmitter optic (each micro lenslets 21 focuses the light beams of corresponding lasers 13 on to the pupil 24 of the lens 22, with the stop of lens 22 at pupil 22, allowing the lens 22 to image the laser diode array 12; figures 1-3; column 4, lines 29-44; column 5, lines 56-column 6, line 33).

Claims 1-3, 6, 10 and 12 lack novelty under PCT Article 33(2) as being anticipated by US 2015/0260830 A1 to Princeton Optronics Inc. (hereinafter ' Princeton').

As for claim 1, Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vscel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a bulk transmitter optic (imagining lens 1264; figures 12; paragraphs [0104-0106]); an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens elements 1262; figures 12; paragraphs [0104-0106]), the micro-optic channel array defining a plurality of micro-optic channels (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]), each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]) with the micro-optic lens being configured to receive a light cone from the light emitter (the microlens array 1273 including microlens elements 1262 receives a group of beams 1261, 1265 from the light source 1200; figures 12; paragraphs [0104-0106]) and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]).

-***-Continued Within the Next Supplemental Box-***-

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US18/32601

Box No. VII Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

Claim 17 objected to under PCT Rule 66.2(a)(iii) as containing the following defect(s) in the form or contents thereof: Claim 17 lacks an end period. For the purposes of this examination, Claim 17 is interpreted as having an ending period.

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US18/32601

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

-***-Continued from Box No. IV Lack of unity of invention-***-

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-20 are directed towards an optical system comprising a reduced-sized spot image.
Group II: Claims 21-40 are directed towards an optical system comprising a non-uniform optical filter layer.
Group III: Claims 41-100 are directed towards an optical system comprising a motor and a second plurality of lenses.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic, which are not present in Groups II-III.

The special technical features of Group II include at least wherein the non-uniform optical filter layer is configured to allow different micro-optic channels to measure different ranges of wavelengths, which are not present in Groups I and III.

The special technical features of Group III include at least a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing; and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device; and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors, which are not present in Groups I-II.

The common technical features shared by Groups I-III are an optical system for performing distance measurements, the optical system comprising: a bulk transmitter optic; an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system; a bulk receiver optic configured to receive the discrete beams of light from the field; and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field, the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors.

However, these common features are previously disclosed by US 2015/0260830 A1 to PRINCETON OPTRONICS INC. (hereinafter "Princeton") in view of US 7,433,042 B1 to CAVANAUGH et al. (hereinafter "Cavanaugh"). Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vcsel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a bulk transmitter optic (imaging lens 1264; figures 12; paragraphs [0104-0106]); an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139 which avoids cross talk; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]). However, Princeton fails to disclose a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; the optical assembly comprising: and a plurality of lenses positioned between the aperture layer and the array of photosensors. Cavanaugh discloses a bulk receiver optic configured to receive the discrete beams of light from the field (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic (aperture masks 135 and 137 is an array of openings part of aperture 150 which may be placed at the focus of the MLA; figure 2; column 4, lines 5-58); an array of photosensors disposed behind the aperture layer (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); and a plurality of lenses positioned between the aperture layer and the array of photosensors (micro lens array 130 are between aperture masks 135 and 137 and detector array 110; figure 2; column 4, lines 5-58). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors, as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk between lenses on the detector array, in order to get a stronger sensitivity.

Since the common technical features are previously disclosed by Princeton in view of Cavanaugh, these common features are not special and so Groups I-III lack unity.

Supplemental Box

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-***-Continued from Box V: Citations and Explanations-***-

As for claim 2, Princeton discloses the optical system for performing distance measurements set forth in claim 1 wherein the bulk transmitter optic comprises one or more lenses configured as an image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other (imagining lens 1264 may be configured such that beams 1270 and 1271 shown in dotted lines are at a zero angle with respect to the plane of the lens 1264, making the output beams discrete and parallel to each other; figures 12; paragraphs [0104-0106]).

As for claim 3, Princeton discloses the optical system for performing distance measurements set forth in claim 2 further comprising a light sensing module configured to detect photons emitted from the illumination source and reflected from surfaces within the field (the lightfield source may be applied in a scanning apparatus with a receiver 1334 which detects reflected signals 1341; figures 13; paragraphs [0108-0110]).

As for claim 6, Princeton discloses the optical system for performing distance measurements set forth in claim 1 wherein the micro-optic lens for each channel is configured to receive a light cone from a light emitter and generate a reduced-size real spot image of the emitter at a focal point between the micro-optic lens and the bulk transmitter optic (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]).

As for claim 10, Princeton discloses the optical system for performing distance measurements set forth in claim 6 wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264, and the microlenses 1262 are shown as double sided lenses; figures 12; paragraphs [0104-0106]) and wherein the reduced-size real spot image of the emitter is formed at a focal point after the optical surface (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]).

As for claim 12, Princeton discloses the optical system for performing distance measurements set forth in claim 1 wherein the micro-optic lens for each channel is configured to receive a light cone from a light emitter and generate a reduced-size virtual spot image of the emitter (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]).

Claims 4, 5, 15, 16 and 17 lack an inventive step under PCT Article 33(3) as being obvious over Princeton in view of US 7,433,042 B1 to Cavanaugh, D. et al. (hereinafter 'Cavanaugh').

As for claim 4, Princeton discloses the optical system for performing distance measurements set forth in claim 3 wherein the light sensing module comprises: a lens layer including a plurality of lenses (the receiver 1334 may be a receiver 1034, 1134 with a microlens array 1039, 1139; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]); and a photosensor layer including a plurality of photosensors (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]), wherein the, lens layer, and photosensor layer are arranged to form a plurality of receiver channels with each receiver channel in the plurality of receiver channels (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]), a lens from the plurality of lenses and a photosensor from the plurality of photosensors and being configured to communicate light incident to the photosensor of the receiver channel (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]). However Princeton fails to disclose a bulk receiver optic; an aperture layer including a plurality of apertures; wherein the aperture layer, lens layer, and photosensor layer are arranged to form a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures; and a lens from the plurality of lenses and a photosensor from the plurality of photosensors and being configured to communicate light incident from the bulk receiving optic to the photosensor of the receiver channel. But Cavanaugh discloses a bulk receiver optic (telecentric objective lens 140; figure 2; column 4, lines 5-58); an aperture layer including a plurality of apertures (aperture masks 135 and 137 is an array of openings; figure 2; column 4, lines 5-58); wherein the aperture layer, lens layer, and photosensor layer are arranged to form a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67), a lens from the plurality of lenses and a photosensor from the plurality of photosensors and being configured to communicate light incident from the bulk receiving optic to the photosensor of the receiver channel (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110 with light being introduced from the lens 140 into the detector 110; figures 2 and 3; column 4, lines 5-67). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a bulk receiver optic; an aperture layer including a plurality of apertures; wherein the aperture layer, lens layer, and photosensor layer are arranged to form a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures; and a lens from the plurality of lenses and a photosensor from the plurality of photosensors and being configured to communicate light incident from the bulk receiving optic to the photosensor of the receiver channel, as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk between lenses on the detector array, in order to get a stronger sensitivity.

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Supplemental Box

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As for claim 5, Princeton, in view of Cavanaugh, discloses the optical system for performing distance measurements set forth in claim 4, and Princeton further discloses wherein the illumination source is configured to selectively project the discrete beams of light through the bulk transmitter optic according to an illumination pattern that matches, in size and geometry across a range of distances from the system, the fields of view of the receiver channels (the lightfield source may be applied in a scanning apparatus with a receiver 1334 which detects reflected signals 1341 transmitted from imaging lens 1364, each of the beams focused at a different length such that receiver can view a sharp image for the furthers plane covered; figures 13; paragraphs [0108-0110]).

As for claim 15, Princeton discloses the optical system for performing distance measurements set forth in claim 1 but Princeton fails to disclose wherein the bulk transmitter optic comprises multiple aperture stops configured to reduce stray light emitted by the optical system. However, Cavanaugh discloses wherein the bulk transmitter optic comprises multiple aperture stops configured to reduce stray light emitted by the optical system (telecentric objective lens 140 has aperture 150 including entrance and exit pupils 150 and 152 to reduce stray light; figures 1 and 3; column 4, lines 5-67). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the bulk transmitter optic comprises multiple aperture stops configured to reduce stray light emitted by the optical system., as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk in order to get a stronger sensitivity.

As for claim 16, Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vscel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a light emission system (light field optical source 1200; figures 12; paragraphs [0104-0106]) comprising: a bulk transmitter (imagining lens 1264; figures 12; paragraphs [0104-0106]) optic; an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens elements 1262; figures 12; paragraphs [0104-0106]), the micro-optic channel array defining a plurality of micro-optic channels (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]), each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]) with the micro-optic lens being configured to receive a light cone from the light emitter (the microlens array 1273 including microlens elements 1262 receives a group of beams 1261, 1265 from the light source 1200; figures 12; paragraphs [0104-0106]) and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]); and a light detection system (the lightfield source may be applied in a scanning apparatus with a receiver 1334 which detects reflected signals 1341; figures 13; paragraphs [0108-0110) comprising: a receiver optic configured to receive the discrete beams of light from the field (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]); and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139 which avoids cross talk; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]), the optical assembly comprising: an array of photosensors (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 010); and a plurality of lenses positioned behind the array of photosensors (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]). However Princeton fails to disclose a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors. But Cavanaugh discloses a bulk receiver optic configured to receive the discrete beams of light from the field (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic (aperture masks 135 and 137 is an array of openings part of aperture 150 which may be placed at the focus of the MLA; figure 2; column 4, lines 5-58); an array of photosensors disposed behind the aperture layer (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67), a plurality of lenses positioned between the aperture layer and the array of photosensors (micro lens array 130 are between aperture masks 135 and 137 and detector array 110; figure 2; column 4, lines 5-58). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors, as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk between lenses on the detector array, in order to get a stronger sensitivity.

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Supplemental Box

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As for claim 17 Princeton, in view of Cavanaugh, discloses the optical system for performing distance measurements set forth in claim 16 and Princeton further discloses wherein the bulk transmitter optic comprises one or more lenses configured as image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other (imagining lens 1264 may be configured such that beams 1270 and 1271 shown in dotted lines are at a zero angle with respect to the plane of the lens 1264, making the output beams discrete and parallel to each other; figures 12; paragraphs [0104-0106]).

Claims 7-9, 11, 13, and 14 lack an inventive step under PCT Article 33(3) as being obvious over Princeton in view of US 2005/0035474 A1 to Itoh, N (hereinafter 'Itoh').

As for claim 7, Princeton discloses the optical system for performing distance measurements set forth in claim 6 wherein the micro-optic lens for each channel includes a first optical surface facing the light emitter (the micro lens array 1273 of microlenses 1262 a double sided lens between the light source 1200 and the imaging lens 1264 taking light from the emitters 1210, 1220 and focusing it at the focal plane 1275 between the array 1273 and the lens 1264; figures 12; paragraphs [0104-0106]) and a second optical surface on an opposing side facing away from the light emitter (the micro lens array 1273 of microlenses 1262 a double sided lens between the light source 1200 and the imaging lens 1264 taking light from the emitters 1210, 1220 and focusing it at the focal plane 1275 between the array 1273 and the lens 1264; figures 12; paragraphs [0104-0106]) and wherein the reduced-size real spot image of the emitter is formed at a focal point after the first and second optical surfaces (the micro lens array 1273 of microlenses 1262 a double sided lens between the light source 1200 and the imaging lens 1264 taking light from the emitters 1210, 1220 and focusing it at the focal plane 1275 between the array 1273 and the lens 1264; figures 12; paragraphs [0104-0106]). However Princeton fails to disclose wherein the micro-optic lens for each channel includes a first optical surface with an optical power on a side facing the light emitter and a second optical surface with an optical power on an opposing side facing away from the light emitter. However, Itoh discloses wherein the micro-optic lens for each channel includes a first optical surface with an optical power on a side facing the light emitter (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens; figure 9A and 9B; paragraphs [0099]) and a second optical surface with an optical power on an opposing side facing away from the light emitter (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens; figure 9A and 9B; paragraphs [0099]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the micro-optic lens for each channel includes a first optical surface with an optical power on a side facing the light emitter and a second optical surface with an optical power on an opposing side facing away from the light emitter as taught by Itoh, in order to provide an advantage of double convex lenses to expand or contrast a beam of light.

As for claim 8, Princeton in view of Itoh, discloses the optical system for performing distance measurements set forth in claim 7, and Princeton further discloses wherein a divergence of the light cone from the light emitter is less than a divergence of a light cone from the second optical surfaces of the micro-optic lens for generating the reduced- size real spot image (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262, the beams 1261, 1265 in parallel before the microlens array 1273 focuses them; figures 12; paragraphs [0104-0106]).

As for claim 9, Princeton in view of Itoh, discloses the optical system for performing distance measurements set forth in claim 7, and Princeton further discloses wherein the micro-optic lens is separated from the illumination source to define an open space between the micro-optic lens and the illumination source (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262, the beams 1261, 1265 in an open space between the microlens arrays and the light source 1200; figures 12; paragraphs [0104-0106]).

As for claim 11, Princeton discloses the optical system for performing distance measurements set forth in claim 6, and Princeton further discloses wherein the optical surface includes a plurality of convex lenses having a first surface upon which the optical surface is disposed and a second surface opposite of the first surface that is directly attached to a surface of the illumination source (the micro lens array 1273 of microlenses 1262 a double sided lens (double convex lens) between the light source 1200 and the imaging lens 1264 taking light from the emitters 1210, 1220 and focusing it at the focal plane 1275 between the array 1273 and the lens 1264, and the vscels may be integrated with the optical components; figures 12; paragraphs [0021, 0086, 0104-0106]). But Princeton fails to disclose wherein the optical surface includes a plurality of convex lenses positioned on a substrate, the substrate having a first surface upon which the optical surface is dispose and a second surface opposite of the first surface that is directly attached to a surface of the illumination source. However, Ito discloses wherein the optical surface includes a plurality of convex lenses positioned on a substrate (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]), the substrate having a first surface upon which the optical surface is disposed (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]) and a second surface opposite of the first surface that is directly attached to a surface of the illumination source (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the optical surface includes a plurality of convex lenses positioned on a substrate, the substrate having a first surface upon which the optical surface is dispose and a second surface opposite of the first surface that is directly attached to a surface of the illumination source as taught by Itoh, in order to provide an advantage of double convex lenses to expand or contrast a beam of light.

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Continuation of:

-***-Continued from Previous Supplemental Box-***-

As for claim 13, Princeton in view of Itoh, discloses the optical system for performing distance measurements set forth in claim 12 and Princeton further discloses wherein the reduced-size virtual spot image of the emitter is formed at a focal point within the respective channel (the microlens array 1273 focuses beams 1261, 1265 on to the focal plane 1275 between the microlense and imagiing lens; figures 12; paragraphs [0104-0106]). However, Princeton fails to disclose wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter. However Itoh discloses wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter as taught by Itoh, in order to provide an advantage of double convex lenses to expand or contrast a beam of light.

As for claim 14, Princeton in view of Itoh, discloses the optical system for performing distance measurements set forth in claim 13 and Princeton further discloses a second surface opposite of the first surface that is directly attached to a surface of the illumination source (the micro lens array 1273 of microlenses 1262 a double sided lens (double convex lens) between the light source 1200 and the imaging lens 1264 taking light from the emitters 1210, 1220 and focusing it at the focal plane 1275 between the array 1273 and the lens 1264, and the vscels may be integrated with the optical components; figures 12; paragraphs [0021, 0086, 0104-0106]). However Princeton fails to disclose wherein the optical surface includes a plurality of concave surfaces formed on substrate, the substrate having a first surface upon which the optical surface is disposed. However Itoh discloses wherein the optical surface includes a plurality of concave surfaces formed on substrate (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]), the substrate having a first surface upon which the optical surface is disposed (two microlens arrays may be laminated together with convex lenses 82, 84 aligned to create a double convex lens array; figure 9A and 9B; paragraphs [0099]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the optical surface includes a plurality of concave surfaces formed on substrate, the substrate having a first surface upon which the optical surface is disposed as taught by Itoh, in order to provide an advantage of double convex lenses to expand or contrast a beam of light.

Claims 18-20 an inventive step under PCT Article 33(3) as being obvious over Princeton in view of US 2015/0055117 A1 to Google, Inc. (hereinafter 'Google').

As for claim 18, Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vscel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a light ranging device comprising an optical transmitter comprising: a bulk transmitter optic (imagining lens 1264; figures 12; paragraphs [0104-0106]); an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens elements 1262; figures 12; paragraphs [0104-0106]), the micro-optic channel array defining a plurality of micro-optic channels (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]), each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters (a group of beams 1261, 1265, are grouped between the light source 1200 and the imaging lens 1264 into the microlens array 1273 including microlens elements 1262; figures 12; paragraphs [0104-0106]) with the micro-optic lens being configured to receive a light cone from the light emitter (the microlens array 1273 including microlens elements 1262 receives a group of beams 1261, 1265 from the light source 1200; figures 12; paragraphs [0104-0106]) and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic (the focal plane 1275 of the micro lens array 1273 is between the light source 1200 and the imaging lens 1264; figures 12; paragraphs [0104-0106]). However Princeton fails to disclose a stationary housing having an optically transparent window; and a light ranging device disposed within the housing, the light ranging device comprising an optical transmitter coupled to a platform. However, Google discloses a stationary housing having an optically transparent window (a Lidar housing 210 with a lens 250; figure 2; paragraphs [0066]); and a light ranging device disposed within the housing (a lidar device 200; figure 2; paragraphs [0066]), the light ranging device comprising an optical transmitter coupled to a platform (a lidar device 200 has transmit block 220 with light sources 222; figure 2; paragraphs [0066, 0068]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a stationary housing having an optically transparent window; and a light ranging device disposed within the housing, the light ranging device comprising an optical transmitter coupled to a platform as taught by Google, in order to provide an being able to scan objects freely for use in lidar.

-***-Continued Within the Next Supplemental Box-***-

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

-***-Continued from Previous Supplemental Box-***-

As for claim 19, Princeton in view of Google discloses the optical system for performing distance measurements set forth in claim 18 and Princeton further discloses a system controller disposed within the housing (a programmable current driver 1332 activates each VSCEL and may be within the box; figures 7, 13; paragraphs [0074, 0075, 0110, 0111]), the system controller configured to start and stop light detection operations of the light ranging device (programmable current driver 1332 activates each VSCEL and controls the scanning beam; figures 13; paragraphs [0110, 0111, 0112]). However Princeton discloses wherein the light ranging device is a spinning light ranging device further comprising: a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform and optical transmitter within the housing; and a system controller configured to control the motor. However, Google discloses wherein the light ranging device is a spinning light ranging device further comprising: a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform and optical transmitter within the housing (the lidar device 200 may have motor to rotate the lidar device in the direction 290 including the transmitter block 220; figures 1 and 2; paragraphs [0043, 0067-0068, 0078]); and a system controller configured to control the motor (the lidar device 200 may have motor to rotate the lidar device in the direction 290 including the transmitter block 220 and be controlled by step 902 to rotate; figures 1 and 2 and 9; paragraphs [0043, 0067-0068, 0078, 0102]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide wherein the light ranging device is a spinning light ranging device further comprising: a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform and optical transmitter within the housing; and a system controller configured to control the motor as taught by Google, in order to provide an being able to scan objects freely for use in lidar.

As for claim 20, Princeton in view of Google discloses the optical system for performing distance measurements set forth in claim 18, and Princeton futher discloses wherein the bulk transmitter optic comprises one or more lenses configured as image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other (imagining lens 1264 may be configured such that beams 1270 and 1271 shown in dotted lines are at a zero angle with respect to the plane of the lens 1264, making the output beams discrete and parallel to each other; figures 12; paragraphs [0104-0106]).

Claims 1-20 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: Stephen A. Mao
Kilpatrick Townsend & Stockton LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, Georgia 30309
United States of America

PCT

INVITATION TO PAY ADDITIONAL FEES
AND, WHERE APPLICABLE, PROTEST FEE

(PCT Article 17(3)(a) and Rules 40.1 and 40.2(e))

Applicant's or agent's file reference 1087057	Date of mailing *(day/month/year)* 26 JUL 2018 **PAYMENT DUE** within **ONE MONTH** from the above date of mailing
International application No. PCT/US18/32601	International filing date *(day/month/year)* 14 May 2018 (14.05.2018)
Applicant OUSTER, INC.	

1. This International Searching Authority

(i) considers that there are 3 *(number of)* inventions claimed in the international application covered by the claims indicated below/on an extra sheet:

Group I: Claims 1-20; Group II: Claims 21-40; Group III: Claims 41-100

(ii) therefore considers that **the international application does not comply with the requirement of unity of invention** (Rules 13.1, 13.2 and 13.3) for the reasons indicated below/on an extra sheet:

-***-Continued within extra sheet-***-

(iii) ☐ has carried out a partial international search (see Annex) ☒ will establish the international search report on those parts of the international application which relate to the invention first mentioned in claims Nos.:

Group I: Claims 1-20

(iv) will establish the international search report on the other parts of the international application only if, and to the extent to which, additional fees are paid.

2. Consequently, the applicant is hereby **invited to pay**, within the time limit indicated above, additional fees in the amount indicated below:

$2080.00 (Fee per additional invention) x 2 (number of additional inventions) = $4,160.00 (See Item 2 of annex) (total amount of additional fees/currency)

3. The applicant is informed that, according to Rule 40.2(c), **the payment of any additional fees may be made under protest**, that is, a reasoned statement to the effect that the international application complies with the requirement of unity of invention or that the amount of the required additional fees is excessive, where applicable, subject to the payment of a protest fee.

Where the applicant pays additional fees under protest, the applicant is hereby invited, within the time limit indicated above, to pay a protest fee (Rule 40.2(e)) in the amount of _____ *(amount/currency)*

Where the applicant has not, within the time limit indicated above, paid the required protest fee, the protest will be considered not to have been made and the International Searching Authority will so declare.

4. ☐ Claim(s) Nos. _____ have been found to be unsearchable under Article 17(2)(b) because of defects under Article 17(2)(a) and therefore have not been included with any invention.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Shane Thomas PCT Helpdesk: 571-272-4300

Form PCT/ISA/206 (April 2005)

INVITATION TO PAY ADDITIONAL FEES
AND, WHERE APPLICABLE, PROTEST FEE

International application No.
PCT/US18/32601

Item 2 (continued). For International Applications filed on or after 01 January 2014, Applicant is reminded that the search fee per additional invention indicated in item 2 is the undiscounted fee per additional invention. An Applicant may pay the search fee per additional invention fee reduced by 50% (small entity assertion) or 75% (micro entity certification), as appropriate. See 37 CFR 1.27 and 1.29.

-***-Continued from 1.(ii)-***-

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-20 are directed towards an optical system comprising a reduced-sized spot image.
Group II: Claims 21-40 are directed towards an optical system comprising a non-uniform optical filter layer.
Group III: Claims 41-100 are directed towards an optical system comprising a motor and a second plurality of lenses.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic, which are not present in Groups II-III.

The special technical features of Group II include at least wherein the non-uniform optical filter layer is configured to allow different micro-optic channels to measure different ranges of wavelengths, which are not present in Groups I and III.

The special technical features of Group III include at least a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing; and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device; and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors, which are not present in Groups I-II.

The common technical features shared by Groups I-III are an optical system for performing distance measurements, the optical system comprising: a bulk transmitter optic; an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system; a bulk receiver optic configured to receive the discrete beams of light from the field; and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field, the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors.

However, these common features are previously disclosed by US 2015/0260830 A1 to PRINCETON OPTRONICS INC. (hereinafter "Princeton") in view of US 7,433,042 B1 to CAVANAUGH et al. (hereinafter "Cavanaugh"). Princeton discloses an optical system for performing distance measurements (an apparatus for 3d imaging and scanning using a vscel array to provide a comprehensive set of measured distances; abstract; figure 13; paragraph [0108]), the optical system comprising: a bulk transmitter optic (imaging lens 1264; figures 12; paragraphs [0104-0106]); an illumination source comprising a plurality of light emitters aligned to project light through the bulk transmitter optic into a field ahead of the optical system (light field optical source 1200 includes a VSCEL array chip comprising one or more VCSEL arrays 1210, 1220; figures 12; paragraphs [0104-0106]); and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field (the receiver 1334 may be a receiver 1034, 1134 with a photodetector array 1038, 1138 receiving reflected light via the microlens array 1039, 1139 which avoids cross talk; figures 10, 11 and 13; paragraphs [0036, 0096, 0101, 0109]). However, Princeton fails to disclose a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; the optical assembly comprising: and a plurality of lenses positioned between the aperture layer and the array of photosensors. Cavanaugh discloses a bulk receiver optic configured to receive the discrete beams of light from the field (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); the optical assembly comprising: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic (aperture masks 135 and 137 is an array of openings part of aperture 150 which may be placed at the focus of the MLA; figure 2; column 4, lines 5-58); an array of photosensors disposed behind the aperture layer (telecentric objective lens 140, aperture masks 135 and 137, and micro lens array 130 form channels for detector array 110; figures 2 and 3; column 4, lines 5-67); and a plurality of lenses positioned between the aperture layer and the array of photosensors (micro lens array 130 are between aperture masks 135 and 137 and detector array 110; figure 2; column 4, lines 5-58). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the system of Princeton invention to provide a bulk receiver optic configured to receive the discrete beams of light from the field; an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors, as taught by Cavanaugh, in order to provide an advantage of avoiding cross talk between lenses on the detector array, in order to get a stronger sensitivity.

Since the common technical features are previously disclosed by Princeton in view of Cavanaugh, these common features are not special and so Groups I-III lack unity.

Electronic Acknowledgement Receipt

EFS ID:	34028526
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/La Renda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	16-OCT-2018
Filing Date:	14-MAY-2018
Time Stamp:	17:49:30
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		IDS_with_PTOSB08A_P006US3-1086284.pdf	177855 9fb41522768e1575f3c53deeffcf7775879eb66e	yes	4

	Multipart Description/PDF files in .zip description			
	Document Description	**Start**	**End**	
	Transmittal Letter	1	2	
	Information Disclosure Statement (IDS) Form (SB08)	3	4	
Warnings:				
Information:				
2	Non Patent Literature	ISR_WO.pdf	2720770 6827f7ab173b57daaa67122247595bba8de7c13c	no	16
Warnings:				
Information:				
3	Non Patent Literature	invitation_pay_addtl_fees.pdf	165145 0b4ed9f1e8adea13f307b73c06eed7da06c5f824	no	2
Warnings:				
Information:				
		Total Files Size (in bytes):	3063770	

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on October 16, 2018.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer/

PATENT
Attorney Docket No.: 103033-P006US3-1086284
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus PACALA	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: 2875
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patent and U.S. Patent Application Publications are not provided. Copies of the references are not enclosed.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed before the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/Stephen A. Mao/

Stephen A. Mao
Registration No. 73418

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	15/979,266
Filing Date	May 14, 2018
First Named Inventor	Angus Pacala
Art Unit	2875
Examiner Name	Not yet assigned
Attorney Docket Number	103033-P006US3-1086284

U.S. PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	1.	10063849	B2	08-28-2018	Pacala, Angus	
	2.	9989406	B2	06-05-2018	Pacala, Angus	
	3.	9992477	B2	06-05-2018	Pacala, Angus	
	4.	10063849	B2	08-28-2018	Pacala, Angus	

U.S. PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
	5.	20180209841	A1	07-26-2018	Pacala, Angus	
	6.	20180152691	A1	05-31-2018	Pacala, Angus	
	7.	20180059222	A1	03-01-2018	Pacala, Angus	
	8.	20180217236	A1	08-02-2018	Pacala, Angus	

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines where Relevant Passages or Relevant Figures Appear	T[5]

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[5]

EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	2875
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-P006US3-1086284

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document.
[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e) (1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e) (2).

☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Stephen A. Mao/	Date (YYYY-MM-DD)	2018-09-18
Name/Print	Stephen A. Mao	Registration Number	73418

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Electronic Acknowledgement Receipt

EFS ID:	33759070
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/LaRenda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	18-SEP-2018
Filing Date:	14-MAY-2018
Time Stamp:	18:19:49
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		SIDS-P006US3-1086284.pdf	166145 b4641ba388a1049f48d49f422e00e99a52ea9e1a	yes	4

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Transmittal Letter	1	2
	Information Disclosure Statement (IDS) Form (SB08)	3	4
Warnings:			
Information:			
	Total Files Size (in bytes):	166145	

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on September 18, 2018.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer/

PATENT
Attorney Docket No.: 103033-1086284-P006US3
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus Pacala	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: 2875
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patent and U.S. Patent Application Publications are not provided. Copies of the references are not enclosed.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no

representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed before the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/Stephen A. Mao/

Stephen A. Mao
Registration No. 73418

KILPATRICK TOWNSEND & STOCKTON LLP

Attachment

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/979,266	05/14/2018	Angus PACALA	103033-P006US3-1086284

CONFIRMATION NO. 9761

POA ACCEPTANCE LETTER

20350
KILPATRICK TOWNSEND & STOCKTON LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, GA 30309

OC000000100933968

Date Mailed: 07/13/2018

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 07/10/2018.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/mbeyene/

Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82B (07-13)
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POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

Application Number	Filing Date
15/979,266	May 14, 2018

(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☑ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above: 20350

OR

☐ I hereby appoint Practitioner(s) named in the attached list (form PTO/AIA/82C) as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above. (Note: Complete form PTO/AIA/82C.)

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☑ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number:

OR

Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

Ouster, Inc.

☐ Inventor or Joint Inventor (title not required below)
☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)
☑ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature	Mark Frichtl	Date (Optional)	2017-10-04
Name	Mark Frichtl		
Title	CTO		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☑ Total of forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Electronic Acknowledgement Receipt

EFS ID:	33138381
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	William Leland Shaffer/La Renda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	10-JUL-2018
Filing Date:	14-MAY-2018
Time Stamp:	16:13:47
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Power of Attorney	POA_1086284.pdf	91410 cca62fb624e1e391b08ea05aa0aaa4aa50d1e106	no	1

Warnings:

Information:	
Total Files Size (in bytes):	91410

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/AIA/01 (06-12)
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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 15/979,266

filed on May 14, 2018.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: Mark FRICHTL Date (Optional): 2018-05-16

Signature: Mark Frichtl

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

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As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 15/979,266

filed on May 14, 2018.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

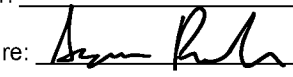
I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

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LEGAL NAME OF INVENTOR

Inventor: Angus PACALA Date (Optional): 5/17/2018

Signature: 

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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LEGAL NAME OF INVENTOR

Inventor: Marvin SHU Date (Optional) :

Signature:

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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EFS ID:	33138274
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	William Leland Shaffer/La Renda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	10-JUL-2018
Filing Date:	14-MAY-2018
Time Stamp:	16:10:08
Application Type:	Utility under 35 USC 111(a)

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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Oath or Declaration filed	DeclarationFRICHTL_103033-P006US3-1086284.PDF	201507 ef5cbd969cbad882ebc1feacebd473482c811d3d	no	2

Warnings:

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2	Oath or Declaration filed	DeclarationP006US3-1086284.PDF	147440 6ea5abc6e7764e322f6053d281baed0e286acae9	no	2
Warnings:					
Information:					
3	Oath or Declaration filed	DeclarationSHU_P006US3-1086284.PDF	335644 17deb279760d0b5100027e407b593acf0b0385e9	no	2
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<u>New Applications Under 35 U.S.C. 111</u>
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
<u>National Stage of an International Application under 35 U.S.C. 371</u>
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
<u>New International Application Filed with the USPTO as a Receiving Office</u>
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15/979,266
	Filing Date	May 14, 2018
	First Named Inventor	Angus Pacala
	Art Unit	Not yet assigned
	Examiner Name	Not yet assigned
	Attorney Docket Number	103033-P006US3-1086284

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EXAMINER SIGNATURE

Examiner Signature		Date Considered	

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[4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e) (1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application and to the knowledge of the person signing the certification after making reasonable inquiry no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e) (2).

☐ See attached certification statement.

☐ The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

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☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Stephen A. Mao/	Date (YYYY-MM-DD)	2018-06-15
Name	Stephen A. Mao	Registration Number	73418

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