

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

SHENZHEN JIMUYIDA TECHNOLOGY CO., LTD.,

Petitioner,

v.

ARTEC EUROPE S.A.R.L.,

Patent Owner.

Case IPR2023-01148

U.S. Patent No. 7,768,656

DECLARATION OF MOHIT GUPTA IN SUPPORT OF PETITION FOR

***INTER PARTES* REVIEW OF U.S. PATENT NO. 7,768,656**

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I. INTRODUCTION

1. I have been retained by Shenzhen Creality 3D Technology Co., Ltd. (“Creality”) and Shenzhen Jimuyida Technology Co., Ltd. (“Jimuyida”) to provide my opinions on certain issues related to U.S. Patent No. 7,768,656 (the “’656 patent,” which I have been informed has been designated as EX1001) in connection with the above-captioned *inter partes* review (IPR) proceeding. Specifically, I have been asked to provide my analyses and opinions regarding whether claims 1-4, 6-15, and 17-22 (“Challenged Claims”) are obvious over the prior art references identified in this analysis and whether a person of ordinary skill in the art could reasonably have found these references.

2. I understand the ‘656 patent is titled “System and Method for Three-Dimensional Measurement of the Shape of Material Objects.” The ‘656 patent identifies two named inventors—Nikolay L. Lapa and Yury A. Brilov—and appears to be currently assigned to Artec Europe S.A.R.L.

3. I understand the file history for the ‘656 patent has been designated as EX1002. I have reviewed and considered this file history, which I will refer to as the “’656 File History” or by its exhibit number.

4. I understand that the ‘656 patent was filed as U.S. Patent Application 11/846,494 on August 28, 2007.

5. I have fully reviewed and considered the prior art cited in this declaration, including:

- a. U.S. Pat. Appl. 2004/0005092 to Tomasi (“Tomasi”), titled “Coded-Array Technique for Obtaining Depths and Other Position Information of an Observed Object,” filed on June 19, 2003, claiming priority to Provisional Application No. 60/390,232 (filed on June 19, 2002), and published on January 8, 2004. I understand that a copy of this publication has been designated as EX1004.
- b. WIPO WO 2007/059780 to Vinther, titled “Coded Structured Light,” filed on November 28, 2006, and published on May 31, 2007. I understand that a copy of this publication has been designated as EX1005.
- c. Vuylsteke and Oosterlinck, “Range Image Acquisition with a Single Binary-Encoded Light Pattern,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 12, No. 2, February 1990, which was published in February 1990 and available through IEEE no later than February 1990. I understand that a copy of this publication has been designated as EX1006.

6. I am being compensated by Crealty and Jimuyida at my standard hourly consulting rate of \$525 per hour for my time on this matter. My compensation does not depend on the outcome of this proceeding.

7. In forming my opinions, I have relied on the documents cited in this declaration and the documents further identified in the attached Appendix B. These documents include patents, file histories, printed publications, and other related documents. As discussed further below, each of these documents is a type of document that experts in the field would have reasonably relied on when forming their opinions. Experts in my field would also have had access to each document either through patent offices or well-known libraries or publications in the field. My opinions are further informed by my personal and professional experience.

II. QUALIFICATIONS

8. I obtained my Bachelor's degree in Computer Science and Engineering from the Indian Institute of Technology, Delhi in 2003. I obtained my Master's degree in Computer Science from Stony Brook University in 2005. I then earned a Ph.D. in Robotics from the Robotics Institute, Carnegie Mellon University in 2011.

9. I am an Associate Professor of Computer Sciences at the University of Wisconsin-Madison, where I have been since 2016. After I received my Ph.D. from the Robotics Institute of Carnegie Mellon University in 2011, I was a postdoctoral

research scientist at Columbia University from 2011-2015. I currently direct the WISION Lab at the University of Wisconsin-Madison with research interests broadly in computer vision and computational imaging.

10. My experience and education are detailed in my curriculum vitae (attached), which lists publications on which I am a named author. I have over 17 years of experience working with three-dimensional (“3D”) imaging and scanning. I have worked on many projects that are relevant to the ‘656 patent.

11. I have extensive research experience in 3D imaging. I have performed research on active 3D cameras, including LiDAR and structured light 3D scanning, since 2007, which I started during my Ph.D. program at Carnegie Mellon University’s Robotics Institute.

12. Active 3D cameras consist of a light source which emits coded light on the scene, *i.e.*, its intensity is modulated over space, and/or time. Examples include LiDAR, time-of-flight sensors, structured light laser scanners, and depth from projector defocus/focus. These sensors are mainstream, getting deployed in several applications such as autonomous vehicles, security and surveillance, industrial inspection, medical and biometric imaging, as well as consumer devices. The structured light 3D imaging system presented in the ‘656 patent is an example of an active 3D camera.

13. I have published more than 50 research papers and 15 patents and patent applications in the areas of 3D imaging, computational imaging, and computer vision over the past 15 years. I received the Marr Prize (honorable mention) for best paper at IEEE ICCV 19, a Sony Faculty Innovation Award, and an NSF CAREER award. My research is supported by NSF, ONR, DARPA, Snap, Sony, Cruise, Intel and the Wisconsin Alumni Research Foundation. I am in the process of co-authoring a book on active 3D imaging including methods that use projectors and cameras for 3D scanning, based on structured light 3D imaging.

14. My research has focused on designing active 3D cameras that can transition outside the lab to extreme real-world conditions, including outdoors (*e.g.*, in sunlight and poor weather), and for optically challenging and geometrically intricate objects such as glass and metal (*e.g.*, for an industrial robot sorting machine parts), for high-speed dynamic objects, and under multi-camera interference.

15. Due to its practical relevance, most of my work in these areas has been patented, and some of it has been licensed for deployment in automotive 3D sensing and surveillance applications. One of these imaging techniques based on structured light 3D imaging (called “Micro Phase Shifting,” research paper in IEEE CVPR 2012, patented) was licensed by Omron, a leading manufacturer of industrial automation systems, who recently released a product that uses this technology for robotic inspection and automation

(<https://automation.omron.com/en/us/products/family/VT-S730>). This invention is about designing structured light patterns for 3D scanning in non-ideal imaging conditions such as multiple interreflections.

16. My Ph.D. thesis is titled “Scene Recovery and Rendering Techniques Under Global Light Transport,” and explains research conducted at the Robotics Institute of Carnegie Mellon University between 2005-2011. The overall goal of the thesis was to develop active 3D imaging techniques based on projecting light patterns on scenes of interest. The thesis resulted in several publications at top computer vision venues. The thesis has a chapter (Chapter 3) that describes research on structured light 3D scanning, in particular, designing projected patterns for scanning of optically challenging materials such as translucent materials, and objects with multiple interreflections.

17. I have authored or co-authored the following references (publications and patents) regarding imaging and scanning:

- Mohit Gupta, Qi Yin, and Shree Nayar, “Structured Light in Sunlight,” IEEE International Conference on Computer Vision (ICCV), 2013.
- Mohit Gupta, Srinivasa Narasimhan, and Yoav Schechner, “On Controlling Light Transport in Poor Visibility Environments,” Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2008.

- Ruilin Xu, Mohit Gupta, and Shree Nayar, “Trapping Light for Time-of-Flight,” Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2018.
- Mohit Gupta, Shree Nayar, Matthias Hullin, and Jaime Martin, “Phasor Imaging: A Generalization of Correlation Based Time-of-Flight Imaging,” ACM Transactions on Graphics (ACM TOG 2015).
- Mohit Gupta and Shree Nayar, “Micro Phase Shifting,” Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2012.
- Shree Nayar and Mohit Gupta, “Diffuse Structured Light,” Proc. IEEE International Conference on Computational Photography (ICCP), 2012.
- Mohit Gupta, Amit Agrawal, Ashok Veeraraghavan and Srinivasa Narasimhan, “Structured Light 3D Scanning in the Presence of Interreflections, Subsurface Scattering and Defocus,” International Journal of Computer Vision (IJCV 2012).
- Jinwei Gu, Toshihiro Kobayashi, Mohit Gupta and Shree Nayar, “Multiplexed Illumination for Scene Recovery in the Presence of Global Illumination,” IEEE International Conference on Computer Vision (ICCV), 2011.

- Mohit Gupta, Yuandong Tian, Srinivasa Narasimhan and Li Zhang, “A Combined Theory of Defocused Illumination and Global Light Transport,” International Journal of Computer Vision (IJCV 2011).
- Mohit Gupta, Yuandong Tian, Srinivasa Narasimhan and Li Zhang, “(De) Focusing on Global Light Transport for Active Scene Recovery,” Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2009.
- Nathan Matsuda, Oliver Cossairt, and Mohit Gupta, “MC3D: Motion Contrast 3D Scanning,” IEEE International Conference on Computational Photography (ICCP) 2015.
- Jongho Lee and Mohit Gupta, “Stochastic Exposure Coding for Handling Multi-ToF-Camera Interference,” IEEE International Conference on Computer Vision (ICCV), 2019.
- Varun Sundar, Aswin Sankaranarayanan, and Mohit Gupta, “Single-Photon Structured Light,” Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2022.
- Mohit Gupta and Nikhil Nakhate, “A Geometric Perspective on Structured Light Coding,” Proc. European Conference on Computer Vision (ECCV), 2018.

- Jian Wang, Aswin Sankaranarayanan, Mohit Gupta, and Srinivasa G. Narasimhan, “Dual Structured Light 3D using a 1D Sensor,” Proc. European Conference on Computer Vision (ECCV), 2016.
- Mohit Gupta, “Systems, Methods, and Media for Encoding Structured Light Imaging Patterns and Estimating Depths in a Scene,” Patent granted, October 2020: US 10818023
- Mohit Gupta and Shree Nayar, “Systems, Methods, and Media for Performing Shape Measurement,” Patent granted, May 2017: US 2015/0176982 A1
- Mohit Gupta, “Scene Recovery and Rendering Techniques Under Global Light Transport,” Ph.D. Thesis, Carnegie Mellon University, 2011.

18. I have provided expert testimony earlier in one case. The subject matter was active 3D imaging, involving a projector-camera system for depth estimation using an imaging modality called depth from projector defocus.

19. I have attached a more detailed list of my qualifications as Appendix A.

III. LEGAL UNDERSTANDING

A. My Understanding of Claim Construction

20. I have been informed that patent claims are construed from the viewpoint of a person having ordinary skill in the art of the patent at the time of the invention. I have been informed that patent claims generally should be interpreted consistent with their plain and ordinary meaning as understood by a person having ordinary skill in the art in the relevant time period (*i.e.*, at the time of the purported invention, or the so called “effective filing date” of the patent application), after reviewing the patent claim language, the specification, and the prosecution history (*i.e.*, the intrinsic record).

21. I have further been informed that a person having ordinary skill in the art must read the claim terms in the context of the claim itself, as well as in the context of the entire patent specification. I understand that in the specification and prosecution history, the patentee may specifically define a claim term in a way that differs from the plain and ordinary meaning. I understand that the prosecution history of the patent is a record of the proceedings before the U.S. Patent and Trademark Office and may contain explicit representations or definitions made during prosecution that affect the scope of the patent claims. I understand that an applicant may, during the course of prosecuting the patent application, limit the scope of the claims to overcome prior art or to overcome an examiner’s rejection,

by clearly and unambiguously arguing to overcome or distinguish a prior art reference, or clearly and unambiguously disavowing claim coverage.

22. In interpreting the meaning of the claim language, I understand that a person having ordinary skill in the art may also consider “extrinsic” evidence, including expert testimony, inventor testimony, dictionaries, technical treatises, other patents, and scholarly publications. I understand this evidence is considered to ensure that a claim is construed in a way that is consistent with the understanding of those of ordinary skill in the art at the time of the claimed invention. For example, this can be useful for a technical term whose meaning may differ from its ordinary English meaning. I understand that extrinsic evidence may not be relied on if it contradicts or varies the meaning of claim language provided by the intrinsic evidence, particularly if the applicant has explicitly defined a term in the intrinsic record.

B. My Understanding of Obviousness

23. I understand that a claim may be invalid if the subject matter described by the claim as a whole would have been obvious to a hypothetical person of ordinary skill in the art in view of a prior art reference or in view of a combination of references at the time the claimed invention was made. Therefore, I understand that obviousness is determined from the perspective of a hypothetical person of ordinary skill in the art and that the asserted claims of the patent should

be read from the point of view of such a person at the time the claimed invention was made. I further understand that a hypothetical person of ordinary skill in the art is assumed to know and to have all relevant prior art in the field of endeavor covered by the patent in suit.

24. I have been informed that there are two criteria for determining whether prior art is analogous and thus can be considered prior art: (1) whether the art is from the same field of endeavor, regardless of the problem addressed, and (2) if the reference is not within the field of the patentee's endeavor, whether the reference still is reasonably pertinent to the particular problem with which the patentee is involved. I have also been informed that the field of endeavor of a patent is not limited to the specific point of novelty, the narrowest possible conception of the field, or the particular focus within a given field. I have also been informed that a reference is reasonably pertinent if, even though it may be in a different field from that of the patentee's endeavor, it is one which, because of the matter with which it deals, logically would have commended itself to a patentee's attention in considering their problem.

25. I have also been advised that an analysis of whether a claimed invention would have been obvious should be considered in light of the scope and content of the prior art, the differences (if any) between the prior art and the

claimed invention, and the level of ordinary skill in the pertinent art involved. I understand as well that a prior art reference should be viewed as a whole.

26. I have also been advised that in considering whether a claimed invention could be obvious over a combination of prior art references, I may assess whether there are apparent reasons to combine known elements in the prior art in the manner claimed in view of interrelated teachings of multiple prior art references, the effects of demands known to the design community or present in the marketplace, and/or the background knowledge possessed by a person having ordinary skill in the art. I understand that other principles may be relied on in evaluating whether a claimed invention would have been obvious, and that these principles include the following:

- A combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results;
- When a device or technology is available in one field of endeavor, design incentives and other market forces can prompt variations of it, either in the same field or in a different one, so that if a person having ordinary skill can implement a predictable variation, the variation is likely obvious;
- If a technique has been used to improve one device, and a person having ordinary skill in the art would recognize that it would improve similar

devices in the same way, using the technique is obvious unless its actual application is beyond their skill;

- An explicit or implicit teaching, suggestion, or motivation to combine two prior art references to form the claimed combination may demonstrate obviousness, but proof of obviousness does not depend on or require showing a teaching, suggestion, or motivation to combine;
- Market demand, rather than scientific literature, can drive design trends and may show obviousness;
- In determining whether the subject matter of a patent claim would have been obvious, neither the particular motivation nor the avowed purpose of the named inventor controls whether the claim is obvious;
- One of the ways in which a patent's subject can be proved obvious is by noting that there existed at the time of invention a known problem for which there was an obvious solution encompassed by the patent's claims;
- Any need or problem known in the field of endeavor at the time of invention and addressed by the patent can provide a reason for combining the elements in the manner claimed;
- "Common sense" teaches that familiar items may have obvious uses beyond their primary purposes, and in many cases a person having ordinary skill will

be able to fit the teachings of multiple patents together like pieces of a puzzle;

- A person having ordinary skill in the art is also a person having ordinary creativity, and is not an automaton;
- A patent claim can be proved obvious by showing that the claimed combination of elements was “obvious to try,” particularly when there is a design need or market pressure to solve a problem and there are a finite number of identified, predictable solutions such that a person having ordinary skill in the art would have had good reason to pursue the known options within his or her technical grasp; and
- One should be cautious of using hindsight in evaluating whether a claimed invention would have been obvious.

27. I further understand that, in making a determination as to whether the claimed invention would have been obvious to a person having ordinary skill, the Board may consider certain objective factors if they are present, such as: commercial success of products practicing the claimed invention; long-felt but unsolved need; teaching away; unexpected results; copying; and praise by others in the field. These factors are generally referred to as “secondary considerations” or “objective indicia” of nonobviousness. I understand, however, that for such objective evidence to be relevant to the obviousness of a claim, there must be a

causal relationship (called a “nexus”) between the claim and the evidence, and that this nexus must be based on a novel element of the claim rather than something in the prior art. I also understand that even when they are present, secondary considerations may be unable to overcome primary evidence of obviousness (such as motivation to combine with predictable results) that is sufficiently strong.

28. I have been asked to consider the validity of the Challenged Claims (claims 1-4, 6-15, and 17-22) of the ‘656 patent. I understand that for *inter partes* reviews, invalidity must be shown under a preponderance of the evidence standard. I have concluded that each of the Challenged Claims is obvious in view of the prior art based on the references described and explained further below.

IV. BACKGROUND OF THE TECHNOLOGY

29. As discussed in Section V (below), the purported invention of the ‘656 patent is a system and method for the three-dimensional measurement of an object. Specifically, the Challenged Claims are directed to a system and method that includes a projector that uses a slide with a structured light pattern that is projected on an object, a camera for capturing an image of the structured light pattern on the object, and a computer that calculates correspondence between points in the slide pattern and points in the captured image, and then uses the calculated correspondences for estimating the three-dimensional geometry of the

object via a triangulation algorithm. In addition, the claimed structured light pattern includes coded elements that may be grouped along epipolar lines that correspond to the spatial location of the projector and camera lens vertices, and orientation of the projector and camera lens' optical axes.

30. Based on my experience in the field, the system and methods described in the Challenged Claims were well-known in the art prior to the filing date of the '656 patent. One example of such prior art is U.S. Patent Application 2004/0005092, which identifies Tomasi as its sole inventor. I understand that a copy of Tomasi has been designated as EX1004. Tomasi discloses a system and method for the three-dimensional measurement of an object using a projector that projects a structured light pattern onto an object using a slide with a pattern, using a camera to capture an image of the object, and using a computer to calculate correspondence between points in the slide pattern and points in the captured image, and then using the calculated correspondences for estimating the three-dimensional geometry of the object via a triangulation algorithm. Tomasi also describes that coded elements of the structured light pattern can be grouped along epipolar lines that correspond to the spatial location of the projector and camera lens vertices, and orientation of the projector and camera lens' optical axes.

31. Another relevant prior art reference is WIPO WO 2007/059780, which identifies Vinther as the first named inventor. I understand that a copy of

Vinther has been designated as EX1005. Vinther discloses a system and method for the three-dimensional measurement of an object using a projector that projects a structured light pattern onto an object using a slide with a pattern, using a camera to capture an image of the object, and using a computer to calculate correspondence between points in the slide pattern and points in the captured image, and then using the calculated correspondences for estimating the three-dimensional geometry of the object via a triangulation algorithm. Vinther also describes that coded elements of the structured light pattern can be grouped along lines that correspond to the spatial location of the projector and camera lens vertices, and orientation of the projector and camera lens' optical axes. As explained in greater detail below in Section IX.A, a person having ordinary skill in the art would have been motivated to modify Tomasi with Vinther to advantageously use the structured light pattern of Vinther to achieve correspondence between the structured light pattern and the captured image using the inherent epipolar geometry that exists between the projector and the camera.

32. Another relevant prior art reference is an IEEE article, "Range Image Acquisition with a Single Binary-Encoded Light Pattern," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 12, No. 2, February 1990, which lists Vuylsteke as its first named author. I understand that a copy of Vuylsteke has been designated as EX1006. Vuylsteke discloses a system and method for the

three-dimensional measurement of an object using a projector that projects a structured light pattern onto an object using a slide with a pattern, using a camera to capture an image of the object, and using a computer to calculate correspondence between points in the slide pattern and points in the captured image, and then using the calculated correspondences for estimating the three-dimensional geometry of the object via a triangulation algorithm. Vuylsteke also describes that coded elements of the structured light pattern can be grouped along lines that correspond to the spatial location of the projector and camera lens vertices, and orientation of the projector and camera lens' optical axes. As explained in greater detail below in Section IX.B, a person having ordinary skill in the art would have been motivated to modify Tomasi in view of Vinther with Vuylsteke to advantageously group points of the structured light pattern of Vinther to achieve correspondence between the structured light pattern and the captured image using the inherent epipolar geometry that exists between the projector and camera vertices.

33. None of the features recited in the Challenged Claims were novel at the time of the alleged invention, and there was nothing novel as to the manner in which the '656 patent combined those features. As I discuss further below, the Challenged Claims are obvious over the prior art. There were also no technological barriers to combining these elements to form the claimed invention

and a person having ordinary skill in the art would have been motivated to combine these elements and would have understood that the combination would have yielded predictable results.

V. THE '656 PATENT

A. '656 Patent Overview

34. The Challenged Claims of the '656 Patent generally recite a system and method for the 3D measurement of the shape of an object. *See, e.g.*, '656 at Abstract. An annotated version of claim 1 shows the claimed aspects of the system.

1. A system for the 3D measurement of the shape of a material object, comprising:

a light projector for projecting a structured light pattern onto a surface of said object, wherein said light projector comprises a light source, **a slide** with **a slide pattern located on a slide surface**, and a projector lens characterized by a projector lens vertex;

a device for capturing an image of said **structured light pattern** reflected on said object, wherein said device for capturing an image comprises a device lens characterized by a device lens vertex; and

a **computing device** for determining a measurement relating to the shape of said object using a triangulation algorithm based on a correspondence between points in said **slide pattern** and said image, and

wherein said **slide pattern** comprises a plurality of coded elements, where each of said **coded elements** is characterized by at least one parameter and, where said at least one parameter defines a spatial or temporal distribution of an amplitude or a wavelength of said structured light, and

wherein said **coded elements are assigned to one of at least first group or second group**, each of which first group and second group comprising at least two of said coded elements, and

wherein at least a first slide **virtual line** and a second slide **virtual line** are defined on said **slide** surface, where said first slide **virtual line** is defined by an intersection between said **slide** surface and a first plane passing through said **projector** lens vertex and through said **device** lens vertex, and said second slide **virtual line** is defined by an intersection between said **slide** surface and a second plane passing

through said **projector** lens vertex and through said **device** lens vertex, and

35. An embodiment of claim 1 is shown in an annotated version of Figures 1 and 13 below.

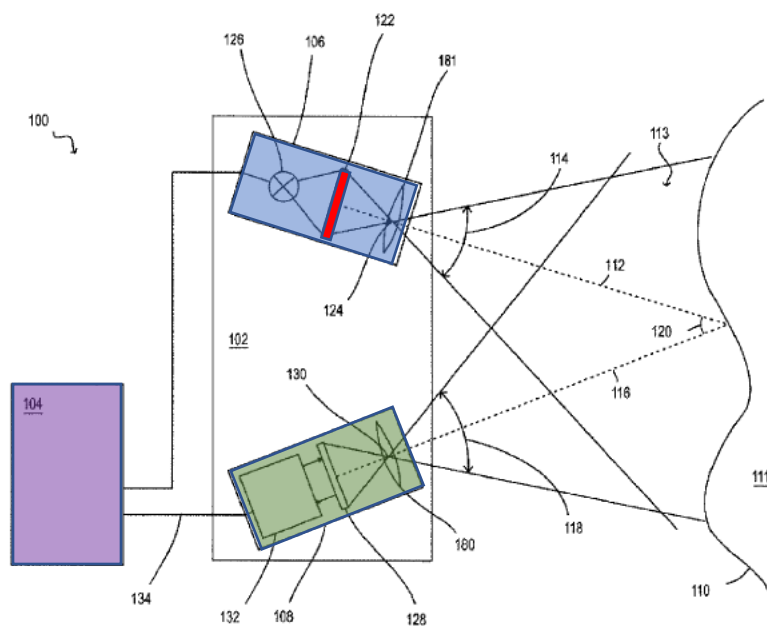


Fig. 1

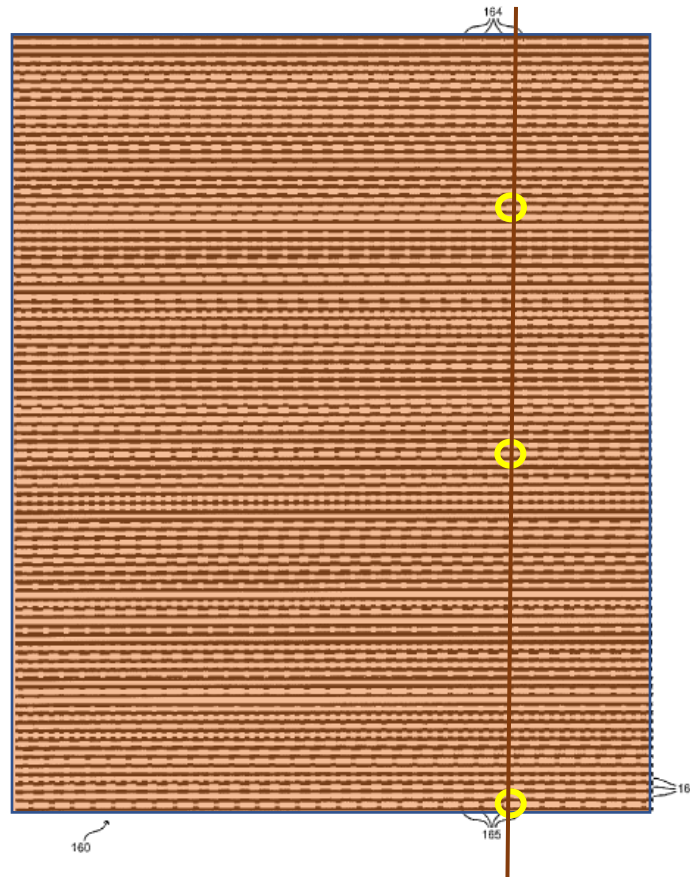


Fig. 13

36. Figure 1 shows a system according to the Challenged Claims. That system includes a **projector** projecting a **structured light pattern** onto the surface of an object, using a **slide** with a **slide pattern**. *See, e.g.*, ‘656 at Fig. 1, 3:4-29. The system also includes a **device for capturing an image** of the structured light pattern reflected on the object. *See, e.g.*, ‘656 at Fig. 1, 3:30-48. The system includes a **computing device** for determining a measurement relating to the shape of the object using a triangulation algorithm. *See, e.g.*, ‘656 at 3:49-56, 3:66-4:15. The system also requires that the slide pattern, as shown in Figure 13, include **coded elements that can be assigned to groups**. *See, e.g.*, ‘656 at 4:40-5:2, 5:11-

7:17. In addition, **virtual lines** (or “meridians” as described in the specification) are defined that pass through the groups of coded elements on the slide pattern and on the image of the object. *See, e.g.*, ‘656 at 5:11-7:17. The virtual line (or “meridians”) are inherent in the epipolar geometry that exists between the projector and the camera and are commonly referred to as “epipolar lines” in the literature. *See, e.g.*, ‘656 at 5:11-19; *see also* 5:20-40; Tomasi at Fig. 3, [0057] – [0061].

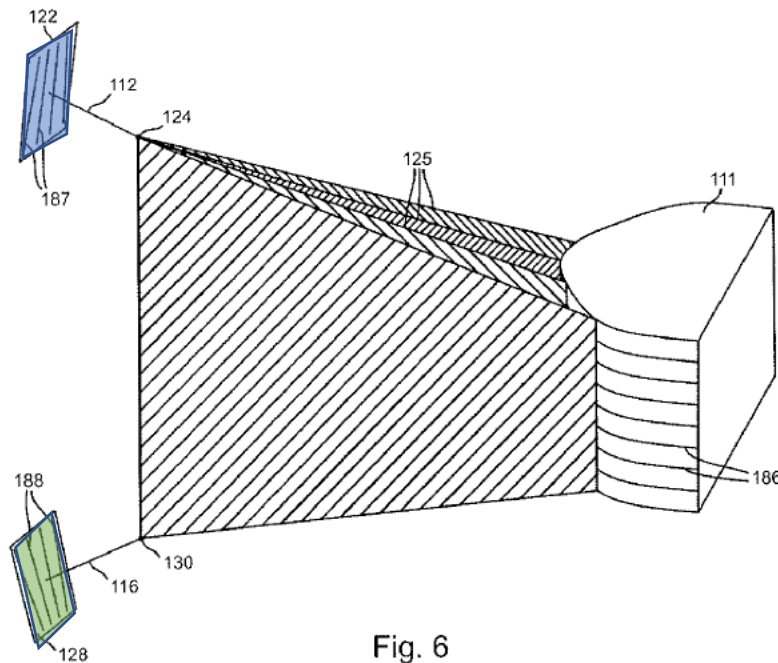


Fig. 6

In describing the nature of these meridians, the specification explains that “[i]n one or more embodiments, the system **100** and associated method for the 3D measurement of the shape of material objects uses the principle that, regardless of the position of the **projector 106** and the **camera 108** in relation to each other, it is

possible to draw a straight line **187** through any point of the **slide 122**, such that, when the projected **pattern in the structured light 113** is projected on the surface **110** of the object **111**, a corresponding straight line **188** exists in the image **140** captured by the **camera 108**, regardless of the shape of the surface **110** being captured. Any pair of such lines **187** and **188** forms a one-to-one correspondence, where such lines will be referred to as ‘**meridians**’ hereafter and, in particular, as ‘camera meridians **188**’ for the captured image by the camera **108** and as ‘projector meridians **187**’ for the projected structured light **113** from the projector **106**, as illustrated by way of example in FIG. 5. In one embodiment, the projector meridians **187** and camera meridians **188** are representative lines that can be represented on the surfaces of the slide **122** and the matrix radiation receiver **128**, but they are not actually part of the pattern that is projected onto the object **111** and captured by the camera **108**.” ‘656 at 5:20-40.

B. Prosecution History of the ‘656 Patent

37. The application from which the ‘656 issued was filed as Ser. No. 11/846,494 on August 28, 2007. In a July 1, 2009 office action, the examiner rejected all of the originally filed claims as unpatentable. Ex. 1002 (“FH”) at 106-115. Claims 1-3, 6-13, and 16-20 were rejected under 35 U.S.C. 102(b) as being anticipated by Geng (U.S. Pat. No. 6,937,348). FH at 109-112. The examiner further found that claims 4-5 and 14-15 were obvious in view of Geng when

combined with the knowledge of a person of ordinary skill in the art. FH at 113-114.

In response to the July 1, 2009 office action, the patent applicant amended the claims to add limitations primarily related to groups of coded elements and virtual lines. FH at 129-139. For example, claim 1 was amended as follows:

1. (Currently Amended) A system for the 3D measurement of the shape of a material object, comprising:

a light projector for projecting a structured light pattern onto a surface of an said object, wherein ~~the said~~ light projector ~~includes~~ comprises a light source, a slide with a slide pattern located on a slide surface, and a projector lens characterized by a projector lens vertex; for the projected structured light pattern;

~~an image detecting~~ a device for capturing an image of ~~the said~~ structured light pattern ~~acting reflected on the surface of the said~~ object, wherein ~~the image capturing said device for capturing an image includes~~ comprises a device lens characterized by a device lens vertex; for a field-of-view of the image detecting device; and

a computing device for determining a measurement relating to the ~~surface~~ shape of the said object using a triangulation algorithm based on a correspondence between points in said slide pattern and said image, ~~the projected structured light pattern and the captured image; and~~

~~wherein the structured light pattern includes at least two coded elements that lie within a plane passing through the vertices of the light projector and the image detecting device and a portion of the object being measured;~~

wherein said slide pattern comprises a plurality of coded elements, where each of said coded elements is characterized by at least one parameter having one of at least two values, and

wherein said coded elements are assigned to one of at least first group or second group, each of which first group and second group comprising at least two of said coded elements, and

wherein at least first slide virtual line and second slide virtual line are defined on said slide surface, where said first slide virtual line is defined by an intersection between said slide

FH at 131-132.

38. In the Patent Owner's Remarks, applicant acknowledged that the specific additional limitations were added to overcome the prior art. FH at 137.

For example, the applicant stated that (1) Geng “fails to teach or suggest a system or method for 3D measurement of a material object where coded elements in the structured light patten are located along virtual lines that are defined by the intersections of the slide surface with a plurality of planes passing through the vertices of the light projector and the camera,” and (2) Geng “fails to teach or suggest a system or method for 3D measurement of a material object where coded elements are always found in the image along virtual lines that are defined by the same virtual planes that define the virtual lines along which the coded elements are located in the structured light pattern, *i.e.*, on the surface of the slide.” FH at 137. Applicant then asserted that the “pending claims, as amended, are not anticipated by Geng.” FH at 138.

39. On March 3, 2010, the applicant has an interview with the examiner where the parties reach an “[a]greement...with respect to the amendment overcoming the prior art of record.” FH at 147. The claims, as amended to get over the prior art of record, were issued on August 3, 2010.

VI. THE ‘656 PATENT PRIORITY DATE

40. I understand the ‘656 patent was filed on August 28, 2007. I further understand that Patent Owner has asserted in its infringement contentions that the ‘656 patent is entitled to a priority date of August 28, 2007.

VII. LEVEL OF ORDINARY SKILL IN THE ART

41. In rendering the opinions set forth in this declaration, I was asked to consider the patent claims and the prior art through the eyes of a person having ordinary skill in the art at the time of the alleged invention. I understand that the factors considered in determining the ordinary level of skill in a field of art the level of education and experience of persons working in the field; the types of problems encountered in the field, the teachings of the prior art, and the sophistication of the technology at the time of the alleged invention. I understand that a person having ordinary skill in the art is not a specific real individual, but rather is a hypothetical individual having the qualities reflected by the factors above. I understand that a person having ordinary skill in the art would also have knowledge from the teachings of the prior art, including the art cited below.

42. I have been asked to assume that the '656 patent is entitled to the priority date of August 28, 2007. Upon consideration of these factors, in my opinion, on or before this priority date, a person having ordinary skill in the art relating to the technology of the '656 patent would have had a minimum of either a bachelor's degree in computer systems, computer science, or the equivalent, and at least two years of experience with 3D scanning or related technology. Additional graduate education could substitute for professional experience, or significant experience in the field could substitute for formal education.

43. Before August 28, 2007, my level of skill in the art was at least that of a person having ordinary skill. I am qualified to opine concerning what a person having ordinary skill in the art would have known and understood at the time of the ‘656 patent’s purported invention. My analysis and conclusions in this declaration are from the perspective of a person having ordinary skill in the art as of August 28, 2007. Even if that priority date were earlier, however, my opinions would not change as long as the identified prior art were still prior art.

VIII. CLAIM CONSTRUCTION

44. All claim terms should generally be construed according to their plain and ordinary meaning as understood by a POSITA. The Challenged Claims all include the claim term “virtual line.” The term “virtual line” is not used anywhere within the context of the specification or prosecution history outside of the context of the claims themselves. As a person of ordinary skill in the art, I have concluded that the term “virtual line” refers to the “meridians” described in the patent specification, which are themselves commonly referred to as epipolar lines inherent in the two-view geometry of a structured light 3D imaging system including a projector and a camera. *See, e.g.*, ‘656 at 5:11-19; *see, also*, Tomasi at [0012], [0057] – [0064], and [0103] – [0104].

IX. GROUNDS OF UNPATENTABILITY

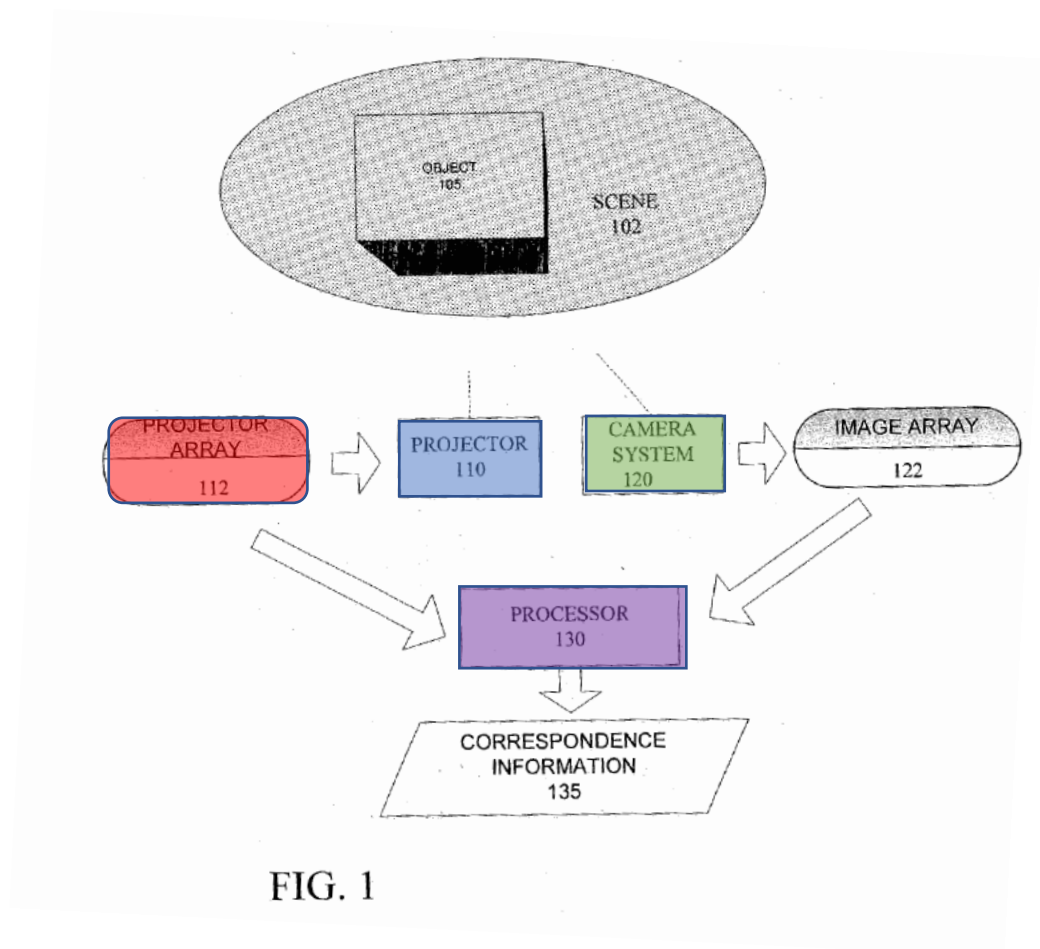
A. Ground 1: Tomasi in View of Vinther Renders Challenged Claims

Obvious

45. Tomasi in view of Vinther renders the Challenged Claims obvious; any purported differences between this art and the claims would have been obvious to a POSITA.

1. Overview of Tomasi

46. Tomasi teaches “an image correspondence system [that] may be used to optically observe an object and determine three dimensional features, characteristics and other information of the object.” Tomasi at [0032]. Tomasi explains that “[t]he components of the system include a **projector** 10, a **camera** 120 and a **processor** 130.” Tomasi at [0033].



Tomasi at Fig. 1.

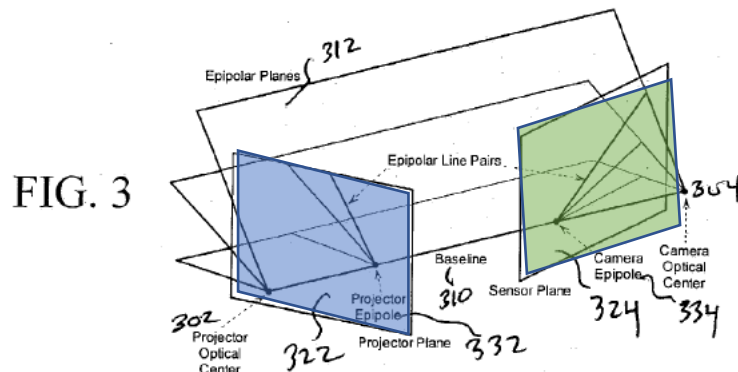
47. Tomasi then explains that “[t]he projector 110 projects an **array 112 of coded light onto the scene 102. Coded light refers to light that is structured or patterned so that it can be represented as propagating from projector 110 as an array with identifiable array elements.** The projector 110 includes a light-emitting source and some mechanism that causes light projecting from it to be coded. For example, projector 110 may include a bulb and a **slide** having a pattern. When the light passes through the slide, the contents of the slide code the

light. In one embodiment, light is projected as a grid when directed at the scene 102, so that grid points are then identifiable on the scene 102. The light may be coded so that the select grid points are identifiable, or otherwise distinguishable from each other.” Tomasi at [0034]. In addition, the coded elements “may be assigned a size from a set of two or more sizes.” Tomasi at [0035].

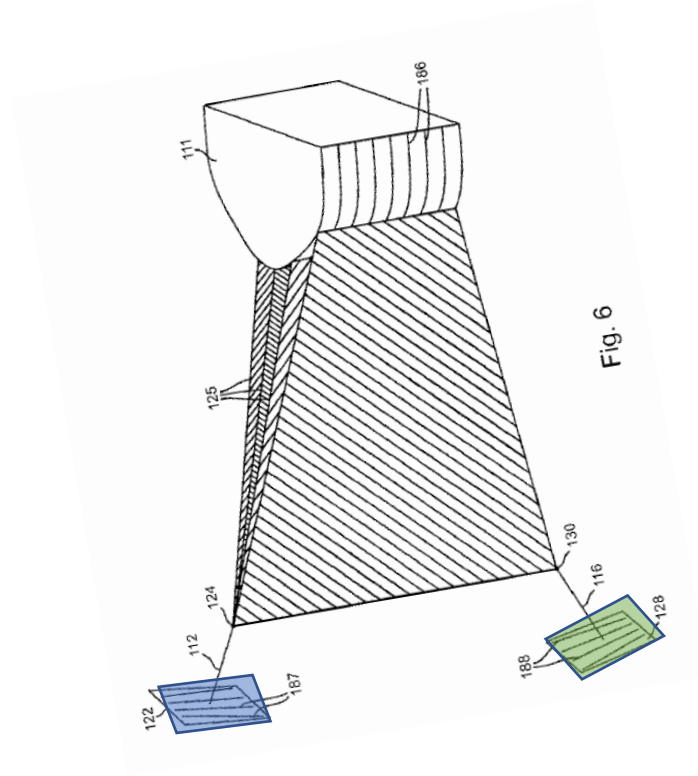
48. Tomasi also explains that these coded elements can be assigned to groups: “a group of contiguous symbols in the image contains, so to speak, its own address: the arrangement of symbols in the group is unique to that particular group in that row of the projected array, and it cannot be confused with any other group. Correspondence between projected and imaged group can therefore be established.” Tomasi at [0092].

49. In addition, Tomasi explains that epipolar geometry can be used to define virtual epipolar lines. “Because of the epipolar geometry (which is described in more detail with FIG. 3), no ambiguity is possible between epipolar lines: the epipolar line to which an image point belongs determines the corresponding array epipolar line uniquely. The position of an array point within a given epipolar line in the image, on the other hand, depends on the geometry of the surface being imaged.” Tomasi at [0057]. Tomasi further explains that “[t]he projector optical center 302 of the projector 110 (FIG. 1) and the camera optical center 304 determine a line in space that is called the baseline 310. Consider the set

of all planes that contain the baseline 310. These are called the epipolar planes 312 of the camera-projector pair. Some of the epipolar planes 312 intersect the image area of the projector 110, as well as the rectangle of the camera 120. For instance, if a standard slide projector and a CMOS camera are used, some of the epipolar planes 312 will intersect the slide, and the same planes intersect the surface of the CMOS camera. The lines formed by these intersections are called epipolar lines in computer vision. The two lines formed by the intersection of a single epipolar plane with the projector plane 322 and camera plane 324 form an epipolar line pair.” Tomasi at [0059].



Tomasi at Fig. 3.



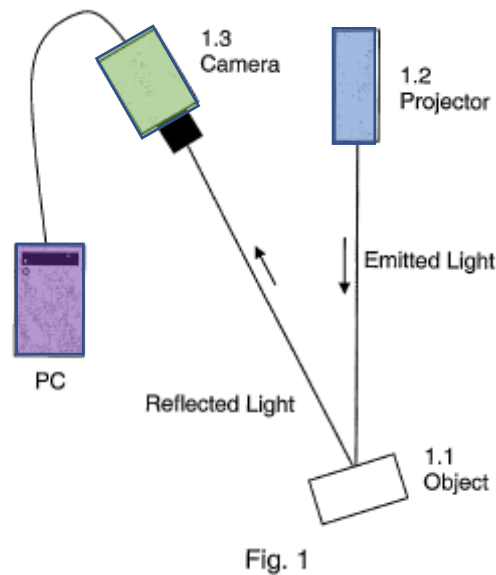
Compare, ‘656 at Fig. 6.

50. Tomasi explains that symbols (or coded elements) are grouped along a given epipolar line for the purpose of aiding correspondence between projected and imaged structured light patterns. “The importance of the epipolar geometry for embodiments described herein is that any point on a given epipolar line in the projector plane 322 must map onto the corresponding epipolar line in the camera plane 324. Thus, when the projector 110 projects an array of symbols onto scene 102, the points in a given row of the array can only move within their epipolar line in the image: no point can ever leave its epipolar line.” Tomasi at [0061].

2. Overview of Vinther and Motivation to Modify Tomasi with Vinther's Teachings

51. In the same field of endeavor, Vinther discloses “a system and method for creating a three-dimensional model of a surface using coded structured light.”

Vinther at 1:3-4.



Vinther at Fig. 1.

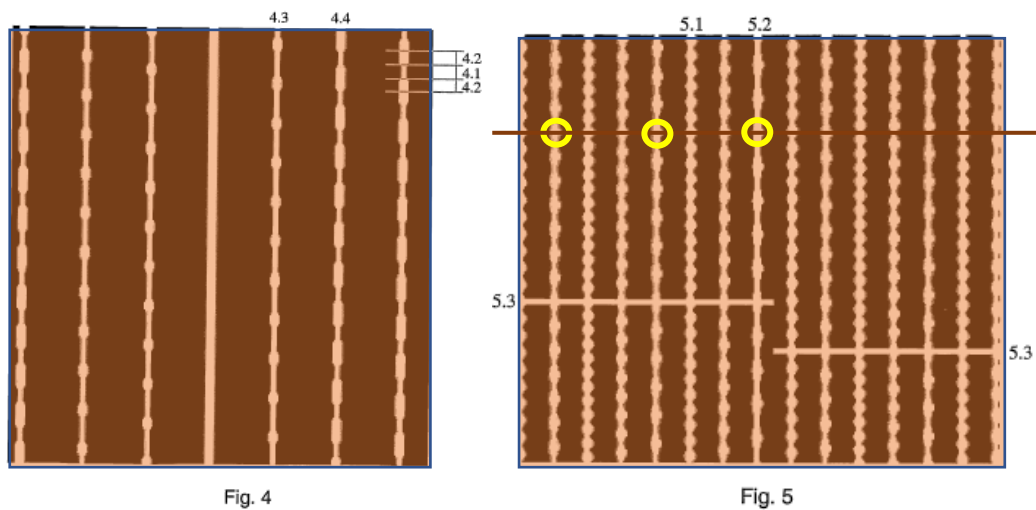
52. Vinther discloses that the system includes a projector, camera, and computer. “The present invention is a system and method for creating a three-dimensional model of a surface comprising a light source 1.2 that projects a pattern of continuous line segments onto the surface, wherein each line segment is coded with a unique pattern along the line segment, a detector 1.3 that records an image of the surface with said projecting pattern, and a computer for

transforming said image to a three-dimensional model of the surface utilizing said projected pattern.” Vinther at Abstract. Vinther discloses that “[t]he projector could be a simple slide projector where the slide contains the coded lines (see Figure 8), it could be a LCD/DMD projector, or the pattern could be generated by one or more lasers.” Vinther at 8:28-30. Vinther discloses that the system includes a camera for capturing images. “The detector according to the present invention may be any suitable detector, such as a digital camera.” Vinther at 7:4-5. Vinther discloses that the computer uses a triangulation algorithm. “When the relative positions of the internal parameters of the projector and the camera are known then the three-dimensional shape of the illuminated part of the object can be computed using triangulation. This is known as structured light scanning and described in the prior art.” Vinther at 1:14-17.

53. In addition, Vinther discloses a structured light pattern that includes coded elements. “Unique pattern: A predetermined recognizable modulation of a line segment identifying said line segment either relative to any other line segment projected by the light source or relative to the proximal line segments. A unique pattern may be repeated in line segments belonging to the same line.” Vinther at 4:11-14. “To be able to distinguish the projected lines in a recorded image the invention proposes using a coding along the lines as e.g. varying line width or

intensity. This could e.g. be a **binary coding** as shown in Figure 4 or a frequency and/ phase coding as shown in Figure 5.” Vinther at 7: 18-21.

54. Vinther then discloses that the coded elements can be grouped along virtual lines. “Determining the linear transformation of the coding and other system parameters needed for obtaining absolute object measurements can be done by recording a number of calibration images with an object of known dimensions. To support the calibration process a number of horizontal lines [5.3] [7.1] can be inserted in the source image.” Vinther at 8:21-25. These **virtual (calibration) lines** pass through a **group of coded elements**.



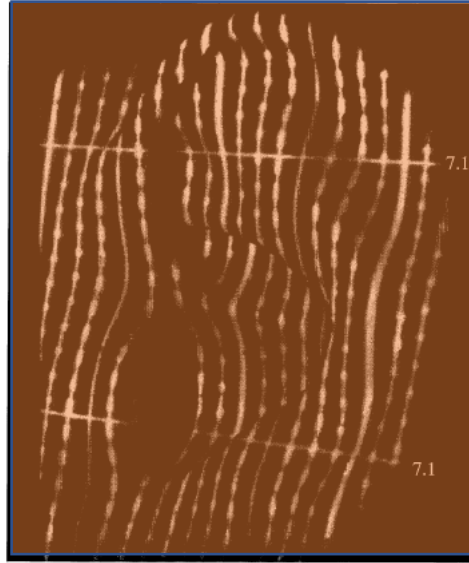


Fig. 7

Vinther at Figs. 4, 5, and 7.

55. Tomasi and Vinther are analogous prior art and in the same field as the '656—three-dimensional modeling of an object surface—and reasonably pertinent to the alleged problems identified in the '656 of correspondence between points in the captured image and the slide pattern. *See, e.g.*, '656 at 4:40-5:19, 5:55-6:2.

56. In light of the above teachings, a POSITA would have had a reasonable expectation of success in modifying Tomasi with Vinther's teachings by using, for example, Vinther's structured light pattern, which is very similar to the one disclosed in the '656.

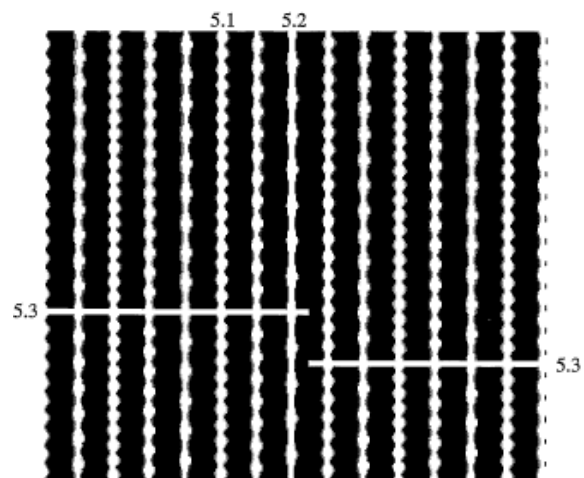


Fig. 5

Vinther at Fig. 5.

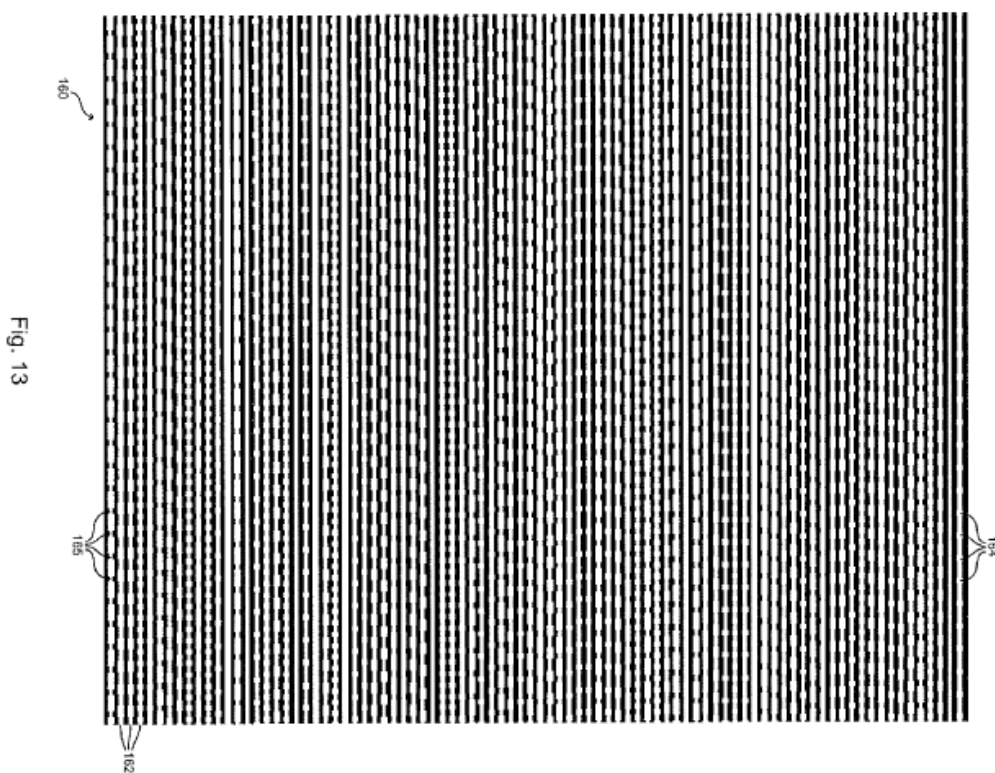


Fig. 13

'656 at Fig. 13.

57. Tomasi already teaches that the coded elements “may be assigned a size from a set of two or more sizes.” Tomasi at [0035]. Consistent with that, Vinther teaches that “[t]o be able to distinguish the projected lines in a recorded image the invention proposes using a coding along the lines as e.g. varying line width or intensity.” Vinther at 7:18-19. Indeed, it was also well understood for a POSITA at the time of the invention to look to other 3D scanning implementations for guidance in how to implement such a system. There is significant technical survey literature in the field of 3D scanning dedicated to reviewing and analyzing various methods and systems for solving issues in 3D scanning. *See, e.g.*, EX1007 (“Battle”); EX1008 (“Salvi 1”); EX1009 (“Salvi 2”). Modifying Tomasi with Vinther’s teachings would have been a straightforward application of those teachings in a manner that advantageously improves the efficiency of a 3D scanning system.

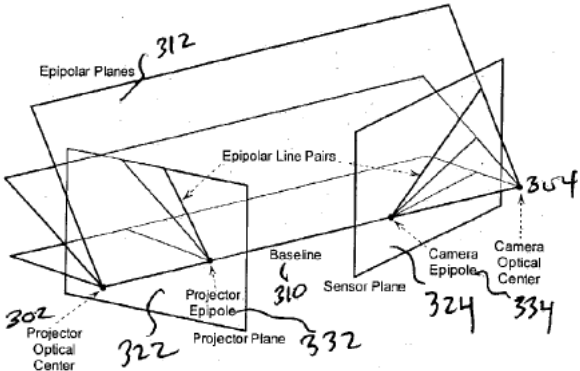
3. Claim Chart

58. The following claim chart shows my invalidity analysis for each of the Challenged Claims.

‘656 Claim	Tomasi in view of Vinther
1. [1.PREAMBLE] A system for the 3D measurement of the shape of a material object, comprising:	Tomasi discloses this claim element. Tomasi discloses constructing a topographical map of three-dimensional scenes.

'656 Claim	Tomasi in view of Vinther
	[0003] (“Three-dimensional sensor systems are increasingly being used in a wide-array of applications. In one general application, a three-dimensional sensor system is used to determine the shape and/or features of an object positioned in a scene of the sensor system's view.”) <i>See also</i>, [0004], [0022], [0032], [0125]. Vinther also discloses this claim element. Vinther discloses using structured light to create a three-dimensional model of a surface. Abstract (“The present invention is a system and method for creating a three-dimensional model of a surface comprising a light source 1.2 that projects a pattern of continuous line segments onto the surface, wherein each line segment is coded with a unique pattern along the line segment, a detector 1.3 that records an image of the surface with said projecting pattern, and a computer for transforming said image to a three-dimensional model of the surface utilizing said projected pattern.”) <i>See also</i>, 1:11-18, 4:8-9, 6:34-7:2, 9:9-19.
[1.A] a light projector for projecting a structured light pattern onto a surface of said object, wherein said light projector comprises a light source, a slide with a slide pattern located on a slide surface, and a projector lens	Tomasi discloses this claim element. Tomasi discloses a projector that projects a structured light pattern onto the surface of an object, including a bulb (light source), a slide having a pattern, and a projector optical center (lens vertex).

'656 Claim	Tomasi in view of Vinther
characterized by a projector lens vertex;	<pre> graph TD PA[PROJECTOR ARRAY 112] --> P[PROJECTOR 110] P --> S([SCENE 102]) S --- O[OBJECT 105] CS[CAMERA SYSTEM 120] --> IA([IMAGE ARRAY 122]) PA --> PR[PROCESSOR 130] IA --> PR PR --> CI[/CORRESPONDENCE INFORMATION 135/] </pre> FIG. 1 [0004] (“Structured-light methods have had success because of their superior accuracy and resolution.”) [0034] (“The projector 110 projects an array 112 of coded light onto the scene 102. Coded light refers to light that is structured or patterned so that it can be represented as propagating from projector 110 as an array with identifiable array elements. The projector 110 includes a light-emitting source and some mechanism that causes light projecting from it to be coded. For example, projector 110 may include a bulb and a slide having a pattern. When the light passes through the slide, the contents of the slide code the light. In one embodiment, light is projected as a grid when directed at the scene 102, so that grid points are then identifiable on the scene 102. The light may be coded so that the select grid points are identifiable, or otherwise distinguishable from each other. . . . In another embodiment, the projection array 112 may correspond to a tangible medium, such as a slide, that includes a grid pattern for producing the coded light structure.”)

'656 Claim	Tomasi in view of Vinther
	[0036] (“The projector 110 may be similar to a slide projector in applications where electrical power is readily available. The coding may be provided by a slide containing a pattern, which in turn causes the projected light to have a pattern. In this case, the projection array 112 may correspond to a specific pattern formed on the slide.”) FIG. 3  [0059] (“FIG. 3 is a diagram illustrating the concept of epipolar geometry, as it applies to embodiments of the invention. The projector optical center 302 of the projector 110 (FIG. 1) and the camera optical center 304 determine a line in space that is called the baseline 310.”) <i>See also</i>, [0007], [0033], [0038], [0061], [0075], [0089], claim 35. Vinther also discloses this claim element. Vinther discloses a projector that projects a structured light pattern onto the surface of an object, including a light source, a slide having a pattern, and a projector optical center (lens vertex).

'656 Claim	Tomasi in view of Vinther
	The diagram illustrates a structured light scanning setup. A Personal Computer (PC) is connected via a cable to a Camera (labeled 1.3) and a Projector (labeled 1.2). The Projector emits a beam of light (labeled 1.1 Object) onto a surface. The light reflects off the surface (labeled Reflected Light) and is captured by the Camera. The Camera then sends data back to the PC. The entire setup is labeled Fig. 1. Fig. 1 6:31-7:2 (“The light source used according to the present invention may be any suitable light source. Accordingly, any structured light may be used, such as the light source in a conventional projector, or a laser light, or a blitz light. The light source may emit visible light, near-visible or invisible light as is suitable for the image and the surface. In particular, for creating a three-dimensional model of a surface of a human being or an animal it may be preferred to use invisible light.”) 1:14-17 (“When the relative positions of the internal parameters of the projector and the camera are known then the three-dimensional shape of the illuminated part of the object can be computed using triangulation. This is known as structured light scanning and described in the prior art.”) 2:1-2 (“... different angles of refraction in the camera and projector lenses. . . .”) 2:31-32 (“... (a) a light source that projects a pattern of continuous line segments onto the surface, wherein each

'656 Claim	Tomasi in view of Vinther
	line segment is coded with a unique pattern along the line segment") 8:28-30 ("The projector could be a simple slide projector where the slide contains the coded lines (see Figure 8), it could be a LCD/DMD projector or the pattern could be generated by one or more lasers.")
[1.B] a device for capturing an image of said structured light pattern reflected on said object, wherein said device for capturing an image comprises a device lens characterized by a device lens vertex; and	Tomasi discloses this claim element. Tomasi discloses a camera for capturing images, including a lens having an optical center (lens vertex). FIG. 1 [0038] ("The camera 120 captures an image of the scene 102. When coded light is cast on the scene 102, the resulting image has a representation of the projection array 112. The image of the projection array 112 is at least partially captured in image array 122. The camera 120 may include a lens (not shown) and a frame grabber which obtains data corresponding to image array 122. In one embodiment, the image array is a digital

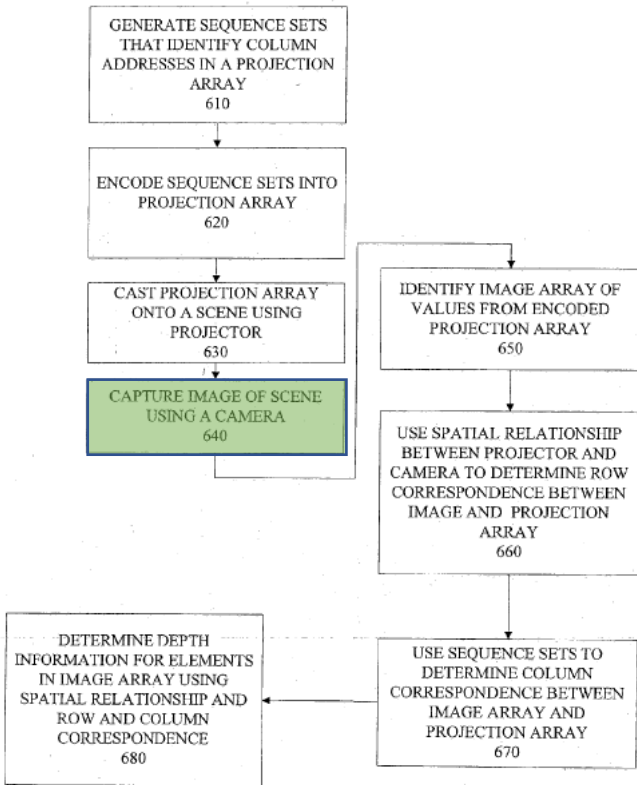
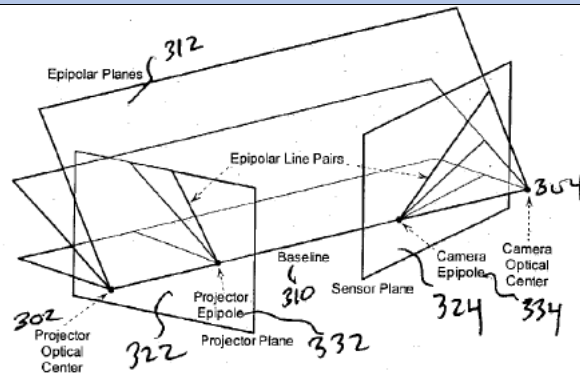
'656 Claim	Tomasi in view of Vinther
	representation of the coded light on the scene 102 and the object 105. The depth of field of the camera should be sufficient to distinguish the different types of code in the light coding emitted from projector 110. . . . Enough depth of field in turn requires a sufficient amount of light for a camera lens with a relatively small aperture. . . . In one embodiment, the camera 120 is of a charged couple device (CCD) or complimentary metal-oxide semiconductor (CMOS) design.”)  <pre> graph TD 610[GENERATE SEQUENCE SETS THAT IDENTIFY COLUMN ADDRESSES IN A PROJECTION ARRAY 610] --> 620[ENCODE SEQUENCE SETS INTO PROJECTION ARRAY 620] 620 --> 630[CAST PROJECTION ARRAY ONTO A SCENE USING PROJECTOR 630] 630 --> 640[CAPTURE IMAGE OF SCENE USING A CAMERA 640] 640 --> 650[IDENTIFY IMAGE ARRAY OF VALUES FROM ENCODED PROJECTION ARRAY 650] 650 --> 660[USE SPATIAL RELATIONSHIP BETWEEN PROJECTOR AND CAMERA TO DETERMINE ROW CORRESPONDENCE BETWEEN IMAGE AND PROJECTION ARRAY 660] 660 --> 670[USE SEQUENCE SETS TO DETERMINE COLUMN CORRESPONDENCE BETWEEN IMAGE ARRAY AND PROJECTION ARRAY 670] 670 --> 680[DETERMINE DEPTH INFORMATION FOR ELEMENTS IN IMAGE ARRAY USING SPATIAL RELATIONSHIP AND ROW AND COLUMN CORRESPONDENCE 680] </pre> FIG. 6

FIG. 3



[0059] (see [1.A])

See also, [0007], [0024], [0033], [0077], claim 35.

Vinther also discloses this claim element.

Vinther discloses a camera for capturing images, comprising a lens with a focal point (lens vertex).

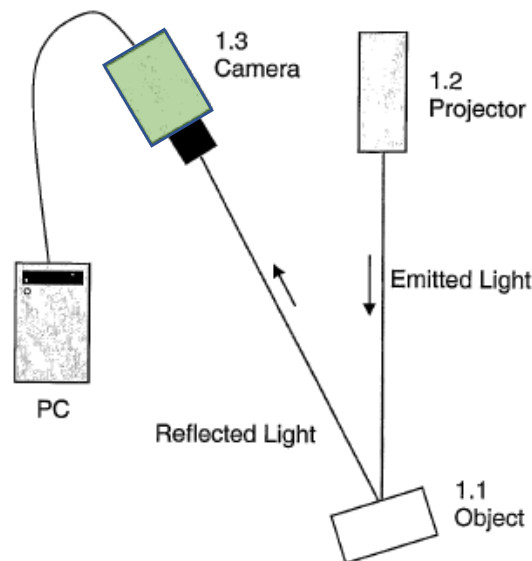


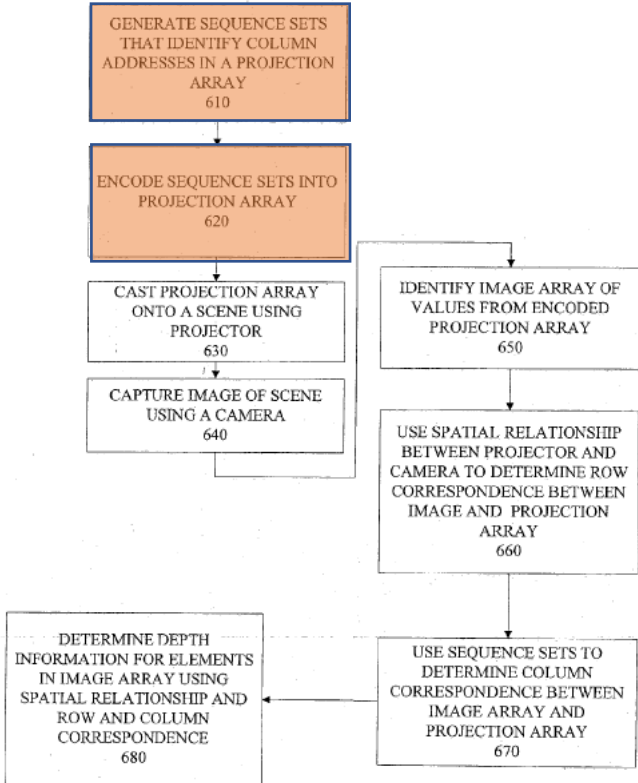
Fig. 1

Abstract (see [1.PREAMBLE])

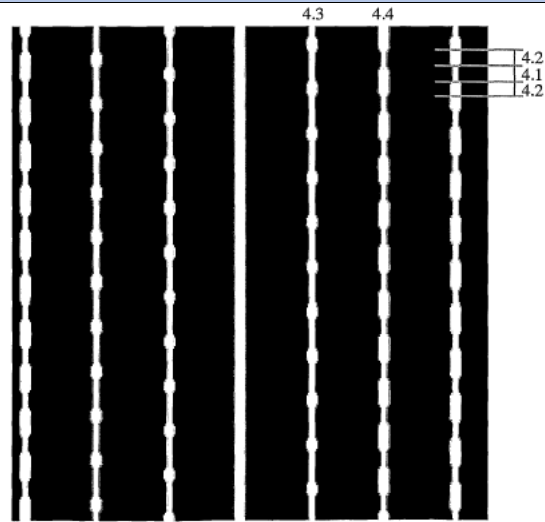
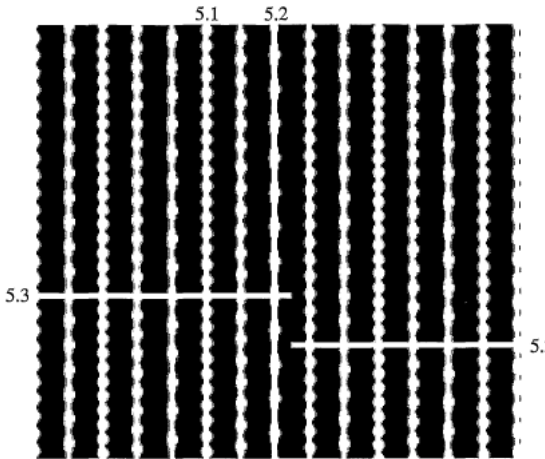
7:4-5 (“The detector according to the present invention may be any suitable detector, such as a **digital camera**.”)

'656 Claim	Tomasi in view of Vinther
	8:5-6 (“This is true if the coded lines in the light source image in [1.2] are perpendicular to the axis between the focal line of the camera and the projector.”) 8:30-31 (“A TV-camera or digital camera (typically CCD or CMOS based) connected to a computer supplies the images.”) See also, 1:9-18, 1:35-2:3, claim 1.
[1.C] a computing device for determining a measurement relating to the shape of said object using a triangulation algorithm based on a correspondence between points in said slide pattern and said image, and	Tomasi discloses this claim element. Tomasi discloses computing a 3-D surface using a triangulation algorithm based on computing correspondences between points in the slide pattern and the image. [0039] (“Embodiments of the invention provide that processor 135 receives data representing image array 122 and projection array 112. Using techniques such as described in FIGS. 2 and 3, the processor 130 determines a correspondence between an element of the image array 122 and an element of the projection array 112. This correspondence is referred to as correspondence information 135.”) FIG. 5 [0081] (“In step 680, depth information is determined for elements in the image array 112 using the row and column correspondence determined in step 660 and step 670. In

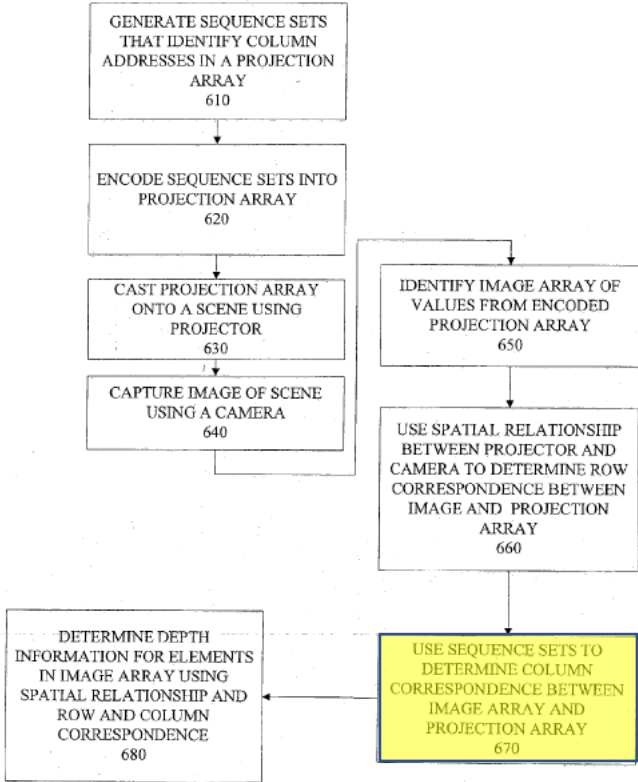
'656 Claim	Tomasi in view of Vinther
	one embodiment, triangulation techniques such as described in FIG. 5 may be employed to determine how far a region on the surface represented by an element of the image array 122 is from the camera 120. This distance may be determined by determining how the column coordinate of the image element differs from its corresponding projector element, as well as knowing a spatial relationship between the camera 120 and the projector 110.”) <i>See also</i>, [0007], [0008], [0025], [0026], [0092]. Vinther also discloses this claim element. Vinther discloses computing 3-D coordinates using a triangulation algorithm based on computing correspondences between points in the slide pattern and the image. Abstract (<i>see</i> [1.PREAMBLE]) 1:14-17 (<i>see</i> [1.A]) 8:30-32 (“A TV-camera or digital camera (typically CCD or CMOS based) connected to a computer supplies the images. A number of algorithms for detecting lines in digital images are known in the prior art.”) 9:2-7 (“Once the lines are found they must be identified based on the coding as described above, and at last the three dimensional position of each pixel along each line can be computed using triangulation. Algorithms for connecting the points in space to a continuous surface are also described in the prior art. One way to do this is to connect neighbouring points with triangles as shown in Figure 9.”) <i>See also</i>, 3:1-2, 10:10-11.

'656 Claim	Tomasi in view of Vinther
[1.D] wherein said slide pattern comprises a plurality of coded elements, where each of said coded elements is characterized by at least one parameter and, where said at least one parameter defines a spatial or temporal distribution of an amplitude or a wavelength of said structured light, and	Tomasi discloses this claim element. Tomasi discloses a spatially distributed binary coded pattern comprising a plurality of grid points (coded elements). Each grid point is characterized by parameters including color defining a spatial distribution of wavelength, and/or size defining a spatial distribution of amplitude.  <pre> graph TD 610[GENERATE SEQUENCE SETS THAT IDENTIFY COLUMN ADDRESSES IN A PROJECTION ARRAY 610] --> 620[ENCODE SEQUENCE SETS INTO PROJECTION ARRAY 620] 620 --> 630[CAST PROJECTION ARRAY ONTO A SCENE USING PROJECTOR 630] 630 --> 640[CAPTURE IMAGE OF SCENE USING A CAMERA 640] 620 --> 650[IDENTIFY IMAGE ARRAY OF VALUES FROM ENCODED PROJECTION ARRAY 650] 650 --> 660[USE SPATIAL RELATIONSHIP BETWEEN PROJECTOR AND CAMERA TO DETERMINE ROW CORRESPONDENCE BETWEEN IMAGE AND PROJECTION ARRAY 660] 660 --> 670[USE SEQUENCE SETS TO DETERMINE COLUMN CORRESPONDENCE BETWEEN IMAGE ARRAY AND PROJECTION ARRAY 670] 640 --> 680[DETERMINE DEPTH INFORMATION FOR ELEMENTS IN IMAGE ARRAY USING SPATIAL RELATIONSHIP AND ROW AND COLUMN CORRESPONDENCE 680] 670 --> 680 </pre> FIG. 6 [0035] (“In one embodiment, the scheme for coding the light provides that each grid point is assigned a value, and a sequence of values from a set of congruent grid points identifies one individual grid point amongst the set. The particular manner in which light can be coded to reflect Sequence values for individual elements of an array is described in with FIGS. 7-12. In addition, the manner in which the light may be coded may vary. In one

'656 Claim	Tomasi in view of Vinther
	embodiment, the light is structured so that each grid point is assigned one symbol or geometric identifier from a set of two or more such identifiers. In another embodiment, grid points are colored to have one color from a set of two or more colors. Still further, grid points may be assigned a size from a set of two or more sizes. Other variations and identifiers are possible. In the end, the coding scheme selected assigns values to specific characteristics of light propagated from the projector 110. In a binary scheme, two or three values (0,1 and parity) are utilized.”) [0089] (“Coding the light from the projector 110 requires assigning an optically distinguishable attribute to each element of the projection array 112. For purpose of description, each element of the projection array 112 is said to be assigned a symbol representing a binary value.”) [0090] (“To address these difficulties, the array of symbols projected onto the scene 102 may be endowed with two properties. The first property ensures that examination of a small pattern from the array allows computing the position or address of the pattern within the array itself. This may be achieved by designing the symbols in the array so that groups of symbols within the same row in the array are never repeated.”) <i>See also, [0006], [0021], [0024], [0038], [0075], [0076], [0091], [0103], claims 1, 12, 16, 35.</i> Vinther also discloses this claim element. Vinther discloses a binary coded pattern comprising lines (coded elements). Each line is characterized by parameters including line width or intensity defining a spatial distribution of amplitude.

'656 Claim	Tomasi in view of Vinther
	 Fig. 4  Fig. 5 6:4-5 (“As described below in greater detail, the continuous line segments may be coded using a binary or n-ary sequence or by changing frequency and/or phase.”) 7:18-27 (“To be able to distinguish the projected lines in a recorded image the invention proposes using coding along the lines as e.g. varying line width or intensity. This could e.g. be a binary coding as shown in Figure 4 or a frequency and/ phase coding as shown in Figure 5.

'656 Claim	Tomasi in view of Vinther
	With a binary coding one could define the length of a bit [4.1]/[4.2] to be e.g. 1/100 of the total height of the projected image and a thin line [4.1] as 0 and a wide line [4.2] as 1. This would give the line [4.3] the code 010010010 ... (top-down) and the line [4.4] the code 110110110 With just a short segment of a line, in this case at least corresponding to the length of 3 bits, one is able to identify the segment.”) <i>See also, claim 9.</i>
[1.E] wherein said coded elements are assigned to one of at least first group or second group, each of which first group and second group comprising at least two of said coded elements, and	Tomasi discloses this claim element. Tomasi discloses groups of grid points (coded elements), each group containing at least two coded elements. [0061] (“The importance of the epipolar geometry for embodiments described herein is that any point on a given epipolar line in the projector plane 322 must map onto the corresponding epipolar line in the camera plane 324. Thus, when the projector 110 projects an array of symbols onto scene 102, the points in a given row of the array can only move within their epipolar line in the image: no point can ever leave its epipolar line.”) [0092] (“If these two properties are satisfied, a group of contiguous symbols in the image contains, so to speak, its own address: the arrangement of symbols in the group is unique to that particular group in that row of the projected array, and it cannot be confused with any other group. Correspondence between projected and imaged group can therefore be established. Standard triangulation, such as described in FIG. 5, may then be applied between individual points within the group of symbols in order to compute a high-resolution depth map of the scene 102.”)

'656 Claim	Tomasi in view of Vinther
	 <pre> graph TD 610[GENERATE SEQUENCE SETS THAT IDENTIFY COLUMN ADDRESSES IN A PROJECTION ARRAY 610] --> 620[ENCODE SEQUENCE SETS INTO PROJECTION ARRAY 620] 620 --> 630[CAST PROJECTION ARRAY ONTO A SCENE USING PROJECTOR 630] 630 --> 640[CAPTURE IMAGE OF SCENE USING A CAMERA 640] 640 --> 650[IDENTIFY IMAGE ARRAY OF VALUES FROM ENCODED PROJECTION ARRAY 650] 650 --> 660[USE SPATIAL RELATIONSHIP BETWEEN PROJECTOR AND CAMERA TO DETERMINE ROW CORRESPONDENCE BETWEEN IMAGE AND PROJECTION ARRAY 660] 660 --> 670[USE SEQUENCE SETS TO DETERMINE COLUMN CORRESPONDENCE BETWEEN IMAGE ARRAY AND PROJECTION ARRAY 670] 670 --> 680[DETERMINE DEPTH INFORMATION FOR ELEMENTS IN IMAGE ARRAY USING SPATIAL RELATIONSHIP AND ROW AND COLUMN CORRESPONDENCE 680] </pre> FIG. 6 <i>See also, [0074], [0075], [0090].</i> Vinther also discloses this claim element. Vinther discloses groups of lines (coded elements), each group containing at least two coded elements.

'656 Claim

Tomasi in view of Vinther

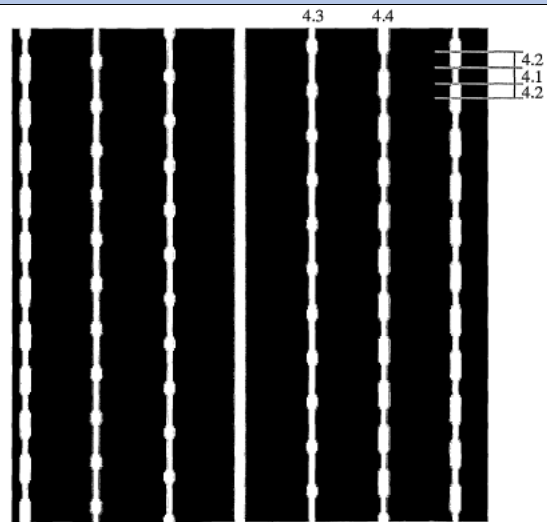


Fig. 4

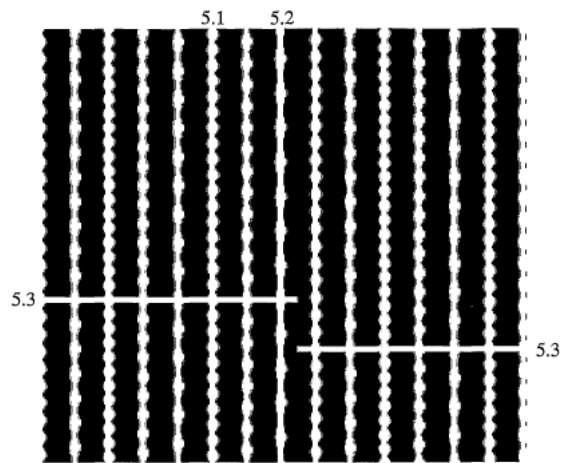
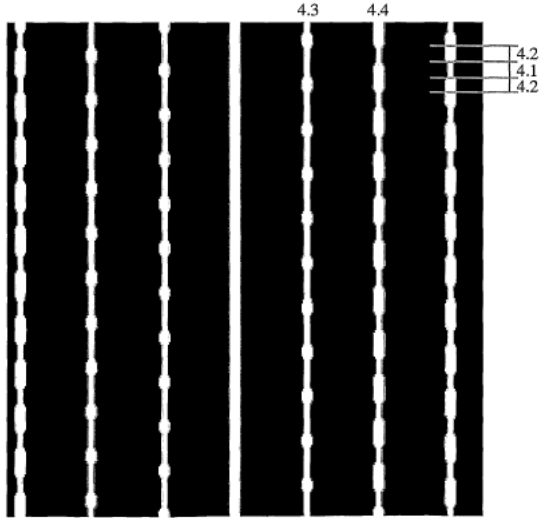


Fig. 5

'656 Claim	Tomasi in view of Vinther
	Fig. 7 7:18-35 (“To be able to distinguish the projected lines in a recorded image the invention proposes using a coding along the lines as e.g. varying line width or intensity. This could e.g. be a binary coding as shown in Figure 4 or a frequency and/ phase coding as shown in Figure 5. With a binary coding one could define the length of a bit [4.1]/[4.2] to be e.g. 1/100 of the total height of the projected image and a thin line [4.1] as 0 and a wide line [4.2] as 1. This would give the line [4.3] the code 010010010 ... (top-down) and the line [4.4] the code 110110110 With just a short segment of a line, in this case at least corresponding to the length of 3 bits, one is able to identify the segment. In another embodiment of the invention the line width could change as a sinusoidal function of the distance from the top with different frequency and phase for each line. In the example in Figure 5 one can see that the line [5.1] has a higher frequency than the line [5.2]. A Fourier transform of a band of pixel values along a line segment in the recorded image will give the frequency that identifies the line. The length of a line segment should preferably be at

'656 Claim	Tomasi in view of Vinther
	least as long as the cycle of the sinusoidal for certain identification.”) 8:21-25 (“Determining the linear transformation of the coding and other system parameters needed for obtaining absolute object measurements can be done by recoding a number of calibration images with an object of known dimensions. To support the calibration process a number of horizontal lines [5.3] [7.1] can be inserted in the source image.”)
[1.F] wherein at least a first slide virtual line and a second slide virtual line are defined on said slide surface, where said first slide virtual line is defined by an intersection between said slide surface and a first plane passing through said projector lens vertex and through said device lens vertex, and said second slide virtual line is defined by an intersection between said slide surface and a second plane passing through said projector lens vertex and through said device lens vertex, and	Tomasi discloses this claim element. Tomasi discloses multiple epipolar planes passing through the projector lens vertex and the device lens vertex. Further, Tomasi discloses epipolar line pairs related to each of the projector optical center (lens vertex) and the camera optical center (lens vertex) that exist along the same epipolar plane. Tomasi also discloses that multiple epipolar planes and epipolar line pairs define virtual lines on the slide surface. [0059] (<i>see</i> [1.A]) [0060] (“The importance of the epipolar geometry for embodiments described herein is that any point on a given epipolar line in the projector plane 322 must map onto the corresponding epipolar line in the camera plane 324. Thus, when the projector 110 projects an array of symbols onto scene 102, the points in a given row of the

'656 Claim	Tomasi in view of Vinther
	array can only move within their epipolar line in the image: no point can ever leave its epipolar line.”) <i>See also</i>, [0061], [0074], [0075], [0090], [0092]. Vinther also discloses this claim element. Vinther discloses using multiple virtual lines to resolve the correspondence between points of the slide pattern and points in the captured image. Vinther discloses defining virtual lines on the slide pattern. These virtual lines relate to planes inherent in the epipolar geometry (called epipolar planes) that exists between the projector and the camera.  The diagram shows a series of vertical black bars (slide pattern) with white dots. To the right, there are four horizontal lines labeled 4.1, 4.2, 4.3, and 4.4 from bottom to top. Above the bars, there are labels 4.3 and 4.4. The diagram illustrates the relationship between the slide pattern and the captured image in the context of epipolar geometry. Fig. 4

'656 Claim	Tomasi in view of Vinther
	Fig. 5 Fig. 7 7:18-35 (<i>see</i> [1.E]) 8:21-25 (<i>see</i> [1.E])
[1.G] wherein said coded elements of	Tomasi discloses this claim element.

'656 Claim	Tomasi in view of Vinther
said first group are located along said first virtual line and said coded elements of said second group are located along said second virtual line.	Tomasi discloses groups of coded elements located along each of the epipolar lines that are inherent in the epipolar geometry. [0060] (<i>see</i> [1.F]) [0092] (<i>see</i> [1.E]) <pre> graph TD 610[GENERATE SEQUENCE SETS THAT IDENTIFY COLUMN ADDRESSES IN A PROJECTION ARRAY 610] --> 620[ENCODE SEQUENCE SETS INTO PROJECTION ARRAY 620] 620 --> 630[CAST PROJECTION ARRAY ONTO A SCENE USING PROJECTOR 630] 630 --> 640[CAPTURE IMAGE OF SCENE USING A CAMERA 640] 640 --> 650[IDENTIFY IMAGE ARRAY OF VALUES FROM ENCODED PROJECTION ARRAY 650] 650 --> 660[USE SPATIAL RELATIONSHIP BETWEEN PROJECTOR AND CAMERA TO DETERMINE ROW CORRESPONDENCE BETWEEN IMAGE AND PROJECTION ARRAY 660] 660 --> 670[USE SEQUENCE SETS TO DETERMINE COLUMN CORRESPONDENCE BETWEEN IMAGE ARRAY AND PROJECTION ARRAY 670] 670 --> 680[DETERMINE DEPTH INFORMATION FOR ELEMENTS IN IMAGE ARRAY USING SPATIAL RELATIONSHIP AND ROW AND COLUMN CORRESPONDENCE 680] </pre> FIG. 6 <i>See also</i>, [0059], [0074], [0075], [0090], [0092]. Vinther also discloses this claim element. Vinther discloses multiple virtual lines passing through groups of coded elements.

'656 Claim	Tomasi in view of Vinther
	Fig. 4 Fig. 5

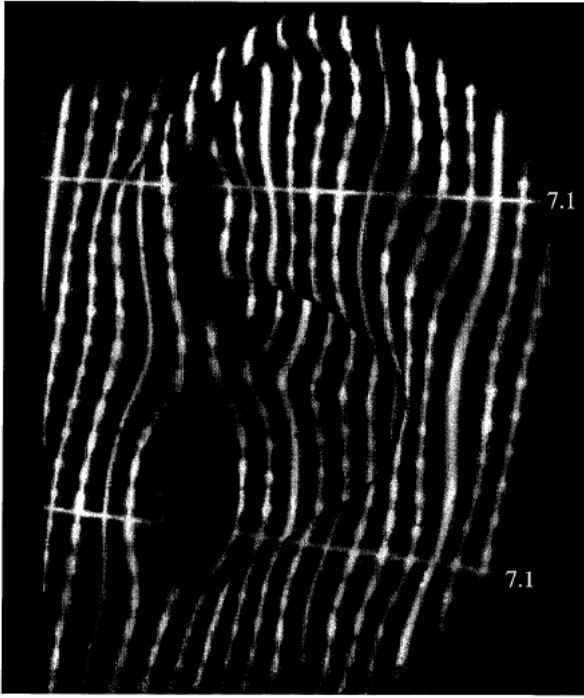
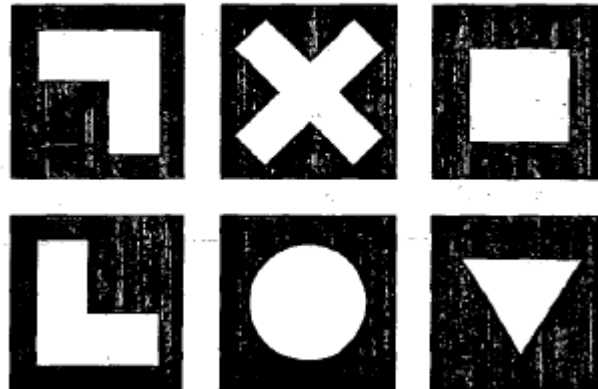
'656 Claim	Tomasi in view of Vinther
	 Fig. 7 7:18-35 (<i>see</i> [1.E]) 8:21-25 (<i>see</i> [1.E])
2. The system of claim 1, wherein each of said coded elements having at least three points that do not lie on a straight line.	Tomasi discloses this claim element. Tomasi discloses that coded elements consist of varying symbols having vertices that do not lie on a straight line, <i>e.g.</i> square, triangle, etc.

FIG. 10



[0035] (*see* [1.D])

[0089] (*see* [1.D])

Vinther also discloses this claim element.

Vinther discloses that coded elements consist of squares or rectangles of light. The vertices of a square or rectangle do not lie on a straight line.

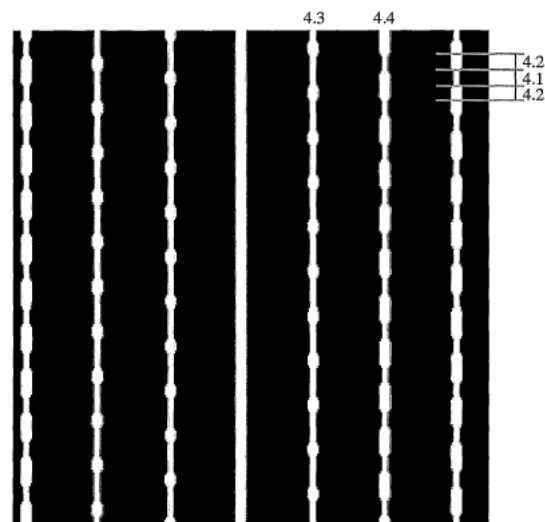
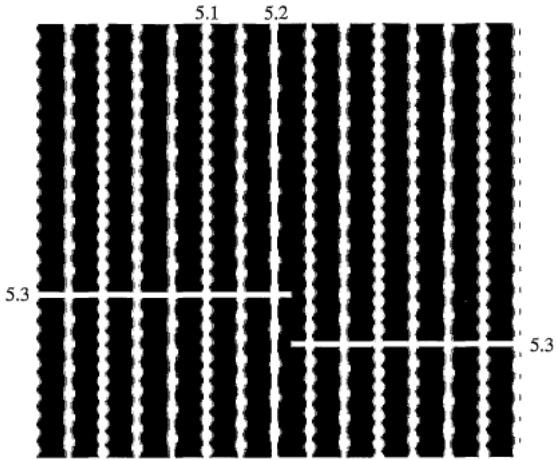
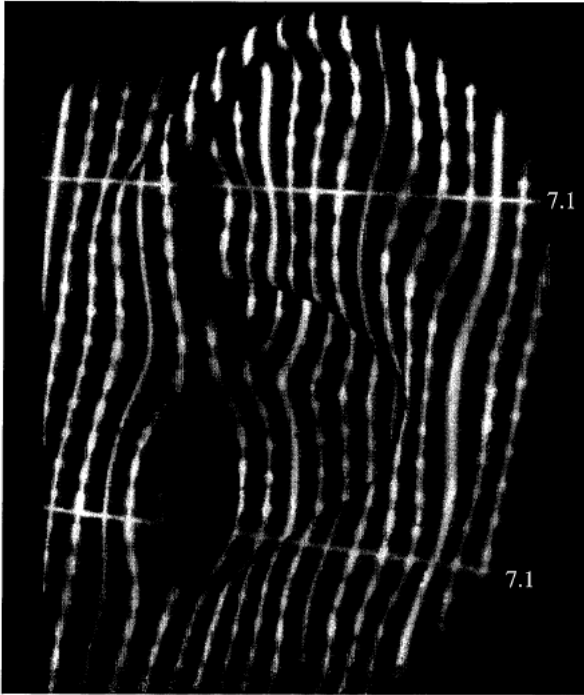


Fig. 4

'656 Claim	Tomasi in view of Vinther
	 Fig. 5  Fig. 7 7:18-35 (see [1.E])
3. The system of claim 1, wherein at	Tomasi discloses this claim element.

'656 Claim	Tomasi in view of Vinther
least first object virtual line and second object virtual line are defined on the surface of said object, where said first object virtual line is defined by an intersection between said surface of said object and said first plane and where said second object virtual line is defined by an intersection between said surface of said object and said second plane.	Tomasi discloses that there are multiple epipolar planes intersecting an object and thereby defining virtual lines on an object. FIG. 3 [0059] (<i>see</i> [1.A]) [0060] (<i>see</i> [1.F]) <i>See also</i>, [0061], [0074], [0075], [0090], [0092]. Vinther also discloses this claim element. Vinther also discloses that virtual lines can be defined on the surface of the object. These virtual lines relate to epipolar planes inherent in the epipolar geometry that exists between the projector lens vertex and the camera lens vertex. These light planes are projected onto an object.

'656 Claim

Tomasi in view of Vinther

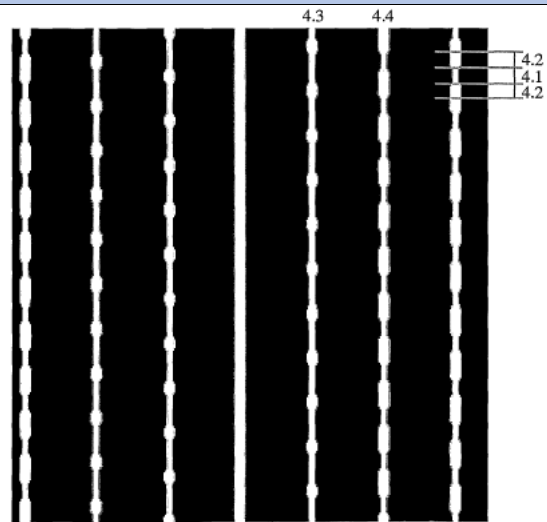


Fig. 4

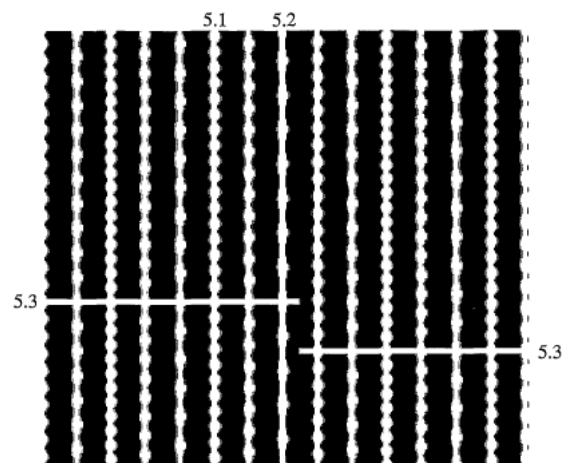
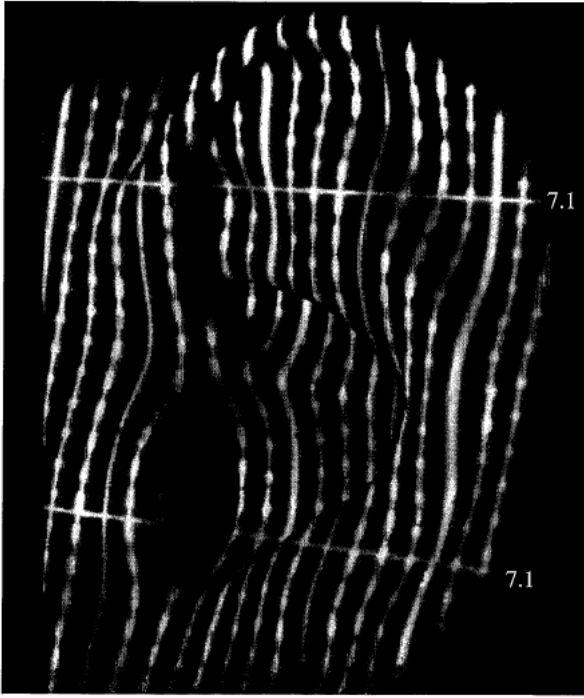
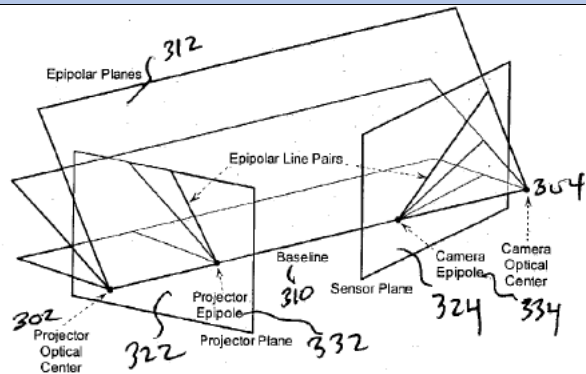


Fig. 5

'656 Claim	Tomasi in view of Vinther
	 Fig. 7 7:18-35 (<i>see</i> [1.E]) 8:21-25 (<i>see</i> [1.E])
4. The system of claim 1, wherein the light projector is further characterized by a central optical axis, further wherein the light projector and the device for capturing an image are arranged such that a line extending between the projector vertex and the device vertex is	Tomasi discloses this claim element. Tomasi discloses that a line extending between the optical center of the projector and the optical center of the camera could be perpendicular to the central optical axis.

'656 Claim	Tomasi in view of Vinther
perpendicular to the central optical axis of the light projector.	FIG. 1 [0033] (“The components of such a system include a projector 10, a camera 120 and a processor 130. The projector 110 and the camera 120 are each aligned in a direction of a scene 102, where an object 105 is provided. In an embodiment, a known spatial or geometric relationship exists between the camera 120 and the projector 110. Specifically, the camera 120 and the projector 110 may be placed in a side-by-side orientation with respect to the scene 102. To simplify computations, an optical center of the projector 110 and an optical center of the camera 120 may have parallel optical axes.”)

FIG. 3



[0059] (see [1.A])

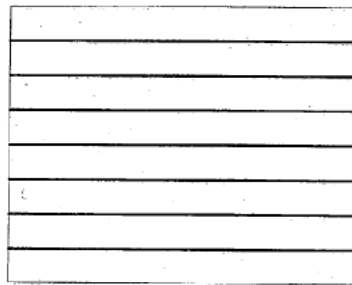


FIG. 4A

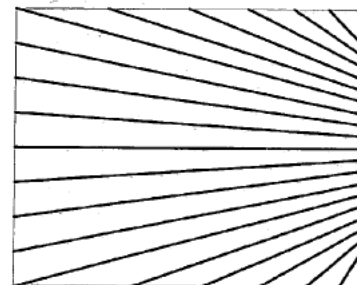


FIG. 4B

[0060] (see [1.F])

See also, [0061].

Vinther also discloses this claim element.

Vinther discloses that a line extending between the optical center of the projector and the optical center of the camera could be perpendicular to the central optical axis.

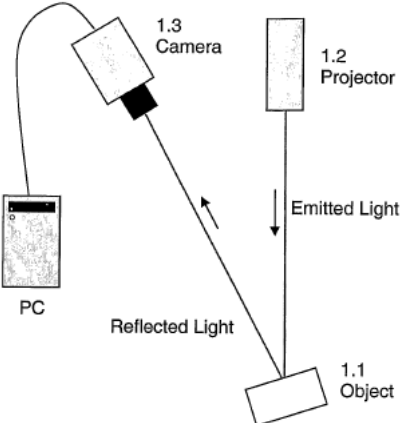
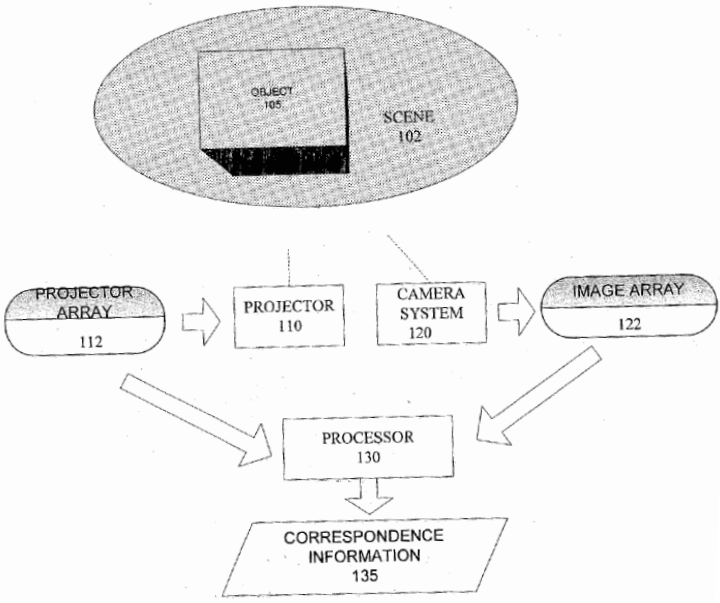
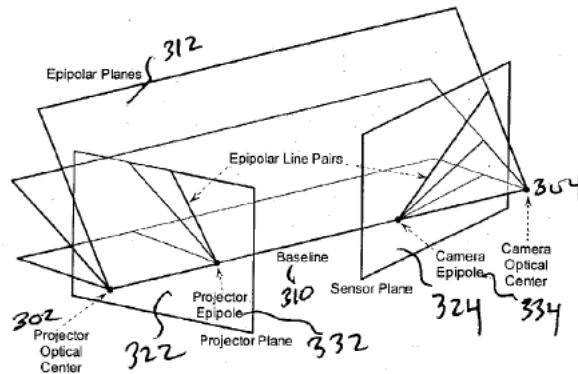
'656 Claim	Tomasi in view of Vinther
	 Fig. 1
6. The system of claim 1, wherein the light projector is characterized by a projector central optical axis and wherein the device for capturing an image is characterized by a device central optical axis, further wherein the light projector and the device for capturing an image are arranged such that a line extending between the projector vertex and the device vertex is not perpendicular to either the projector optical axis or the device optical axis.	Tomasi discloses this claim element. Tomasi discloses that a line extending between the optical center of the projector and the optical center of the camera may not be perpendicular to the camera optical axis.  FIG. 1 [0033] (see [4])

FIG. 3



[0059] (see [1.A])

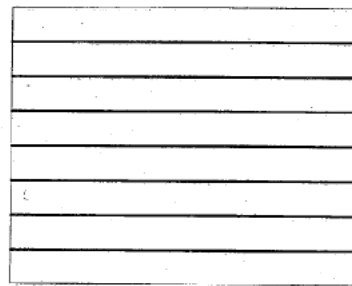


FIG. 4A

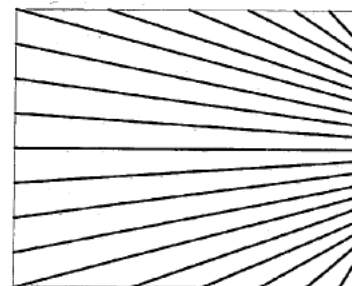


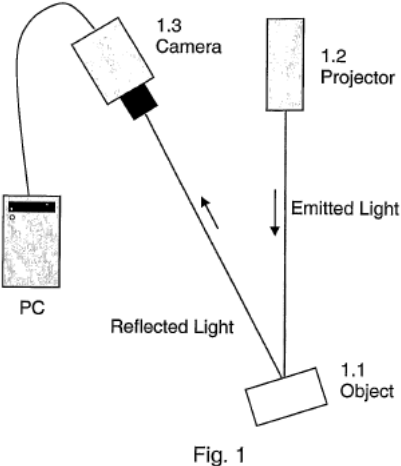
FIG. 4B

[0060] (see [1.F])

See also, [0062], [0074].

Vinther also discloses this claim element.

Vinther discloses that a line extending between the optical center of the projector and the optical center of the camera may not be perpendicular to the camera optical axis.

'656 Claim	Tomasi in view of Vinther
	 Fig. 1
7. The system of claim 1, wherein the light projector projects structured light in a wavelengths selected from optical, visible and infrared wavelengths.	Tomasi discloses this claim element. Tomasi discloses the use of visible and invisible structured light. [0034] (<i>see</i> [1.A]) [0036] (<i>see</i> [1A]) [0037] (“The pattern projected on the scene 102 may be visible, or it could be formed with invisible light when it is undesirable to reveal the array. For example, infrared light may be used when the infrared spectrum is easier to distinguish from ambient light. The projected light may be pulsed in synchrony with a shutter in the camera 120, so as to optimize the ratio of projected versus ambient light.”) <i>See also</i>, [0004], [0006], [0024], [0025], [0026], [0027], [0028], [0038]. Vinther also discloses this claim element. Vinther discloses the use of visible or invisible structured light.

'656 Claim	Tomasi in view of Vinther
	6:31-7:2 (<i>see</i> [1.A]) <i>See also, 1:14-17, 2:1-2, 2:31-32, 8:28-30.</i>
8. The system of claim 1, wherein the light projector is a flashlight source.	Tomasi discloses this claim element. Tomasi discloses a projector that projects light using a bulb. [0034] (<i>see</i> [1.A]) [0037] (<i>see</i> [7]) <i>See also, [0004], [0006], [0024], [0025], [0026], [0027], [0028], [0038].</i> Vinther also discloses this claim element. Vinther discloses a light source in a conventional projector. A POSITA would know that such conventional light source could be a bulb (flashlight source). 6:31-7:2 (<i>see</i> [1.A]) <i>See also, 1:14-17, 2:1-2, 2:31-32, 8:28-30.</i>
9. The system of claim 1, wherein the structured light pattern comprises a plurality of coded elements that can be variably grouped together such that all of the coded elements in each group form a unique sequence relative to the sequences of	Tomasi discloses this claim element. Tomasi discloses groups of unique sequences of coded elements located along varying virtual lines.

'656 Claim

coded elements in adjacent groups of coded elements.

Tomasi in view of Vinther

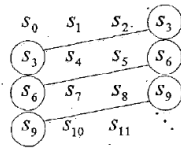


FIG. 7

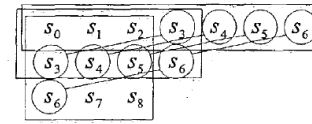


FIG. 8

$s_0 \ s_1 \ s_2 \ b_0 \ s_3 \ s_4 \ s_5 \ b_6 \dots$
 $s_3 \ s_4 \ s_5 \ b_1 \ s_6 \ s_7 \ s_8 \ b_7 \dots$
 $s_6 \ s_7 \ s_8 \ b_2 \ s_9 \ s_{10} \ s_{11} \ b_8 \dots$
 $b_3 \ b_4 \ b_5 \ d \ b_9 \ b_{10} \ b_{11} \ d \dots$

FIG. 9

[0060] (see [1.F])

[0092] (see [1.E])

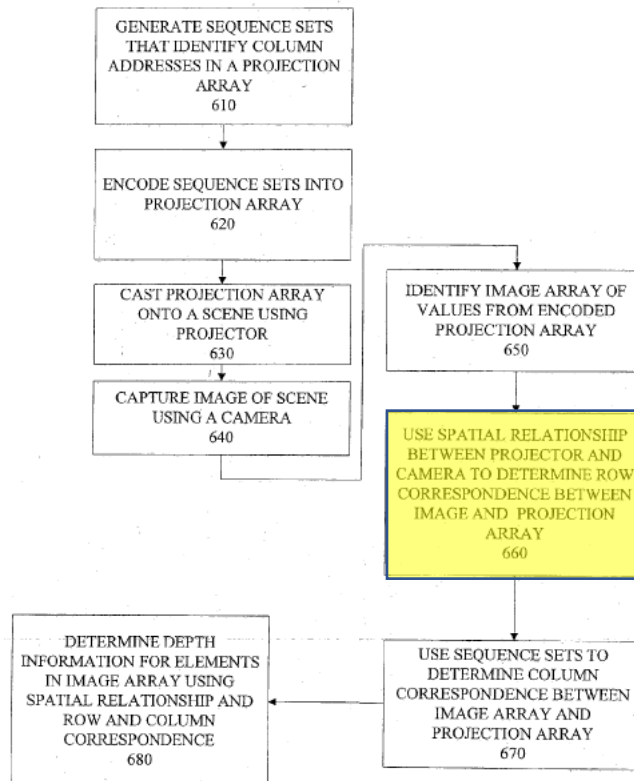
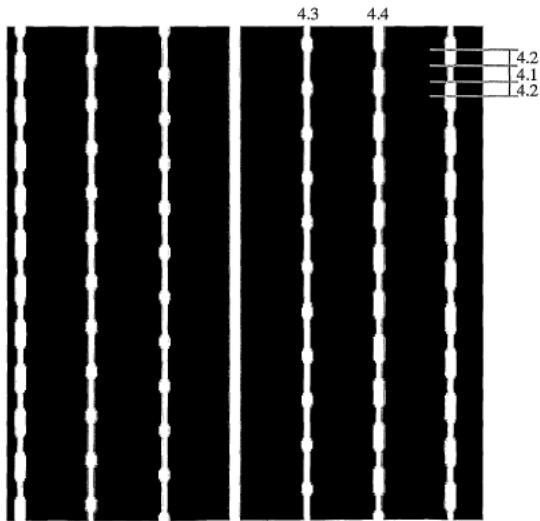
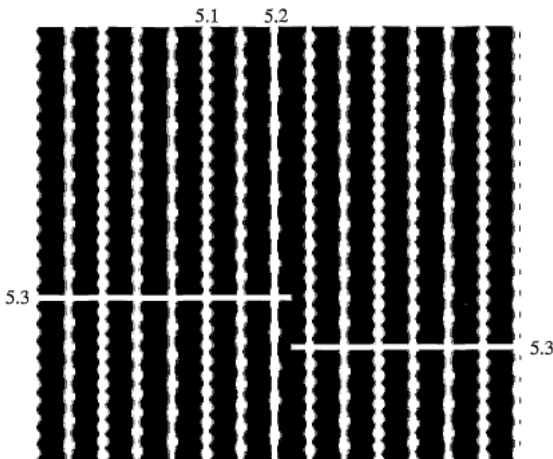
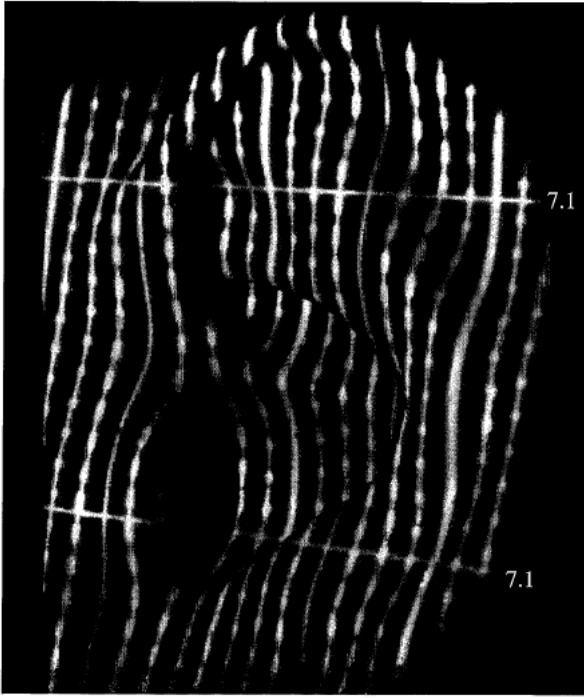


FIG. 6

'656 Claim	Tomasi in view of Vinther
	<i>See also, [0059], [0074], [0075], [0090].</i> Vinther also discloses this claim element. Vinther discloses groups of unique sequences of coded elements located along varying virtual lines.  Fig. 4  Fig. 5

'656 Claim	Tomasi in view of Vinther
	 Fig. 7 7:18-35 (<i>see</i> [1.E]) 8:21-25 (<i>see</i> [1.E])
10. The system of claim 1, wherein the computing device determines a three-dimensional shape of the surface of said object.	Tomasi discloses this claim element. Tomasi discloses the use of structured light to determine the shape of a three-dimensional surface. [0003] (<i>see</i> [1.PREAMBLE])

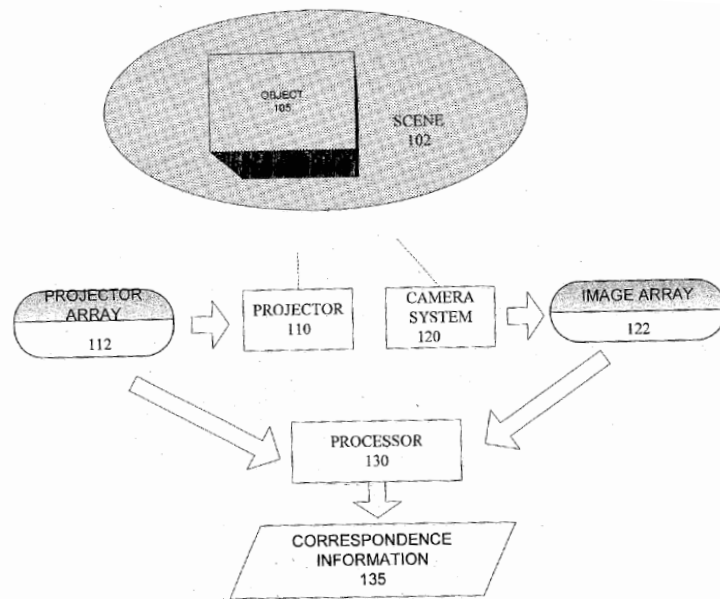


FIG. 1

[0032] (“FIG. 1 describes an image correspondence system, under an embodiment of the invention. As will be described, an image correspondence system may be used to optically observe an object and **determine three dimensional features, characteristics and other information of the object.**”)

See also, [0004], [0022], [0125].

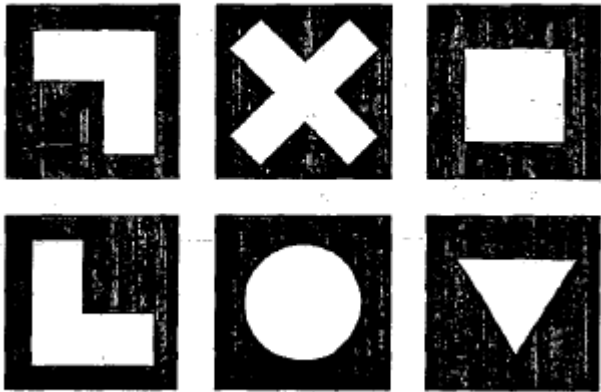
Vinther also discloses this claim element.

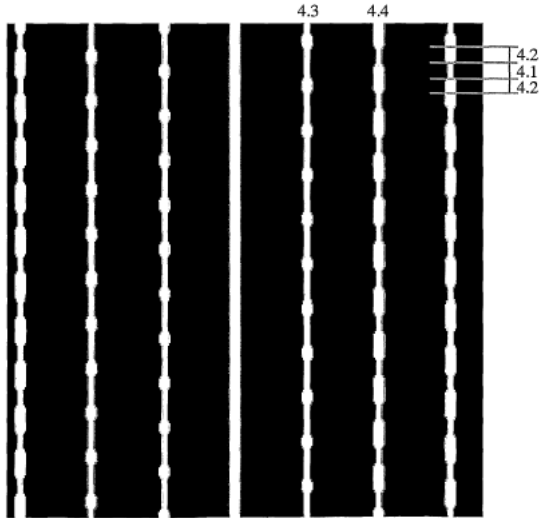
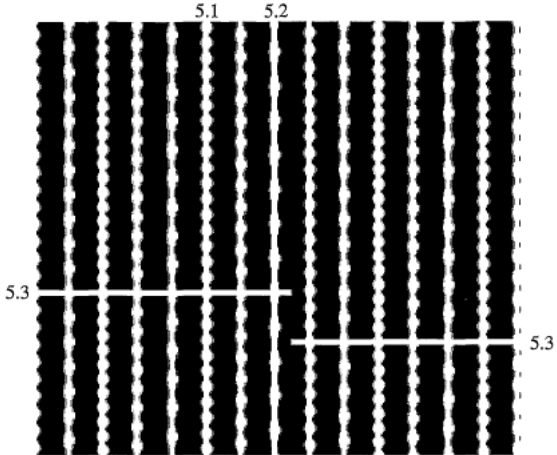
Vinther discloses the use of structured light to determine the shape of a three-dimensional surface.

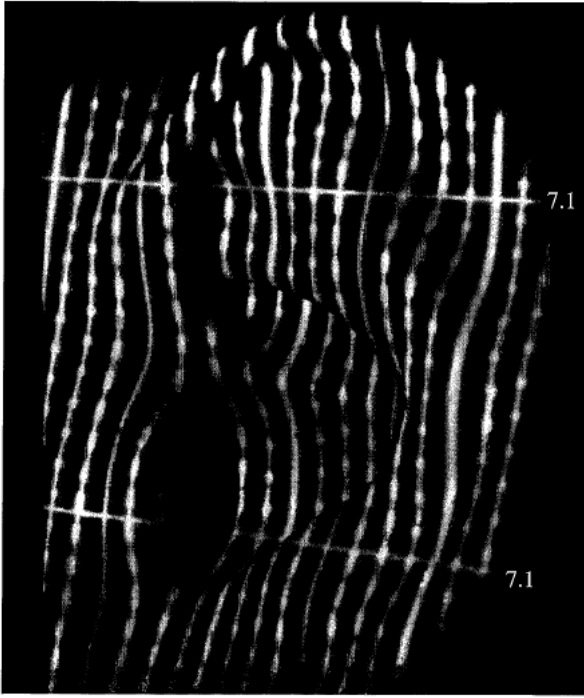
Abstract (see [1.PREAMBLE])

1:14-17 (see [1.C])

8:30-32 (see [1.C])

'656 Claim	Tomasi in view of Vinther
	9:2-7 (<i>see</i> [1.C])
11. The system of claim 1, wherein said at least one parameter defines a shape, size, or color or a change thereof in time for at least one of said coded elements.	Tomasi discloses that at least one parameter defines a shape, size, or color or a change thereof in time for at least one of said coded elements. Tomasi discloses a size and shape of the coded elements. FIG. 10  [0035] (<i>see</i> [1.D]) [0089] (<i>see</i> [1.D]) [0090] (<i>see</i> [1.D]) [0091] (<i>see</i> [1.D]) <i>See also</i>, [0006], [0021], [0024], [0038], [0075], [0076], [0103], claims 1, 12, 16, 35. Vinther also discloses this claim element. Vinther discloses a plurality of coded elements of a predetermined size that are spatially distributed and have varying amplitude.

'656 Claim	Tomasi in view of Vinther
	 Fig. 4  Fig. 5

'656 Claim	Tomasi in view of Vinther
	 Fig. 7 7:18-35 (<i>see</i> [1.E]) 8:21-25 (<i>see</i> [1.E])
12. A method for the 3D measurement of the shape of a material object, comprising:	Tomasi in view of Vinther discloses this claim element. <i>See</i> claim [1.Preamble].
projecting a structured light pattern from a light projector onto a surface of an object, wherein the light projector comprises a light source, a slide with a slide pattern located on a	Tomasi in view of Vinther discloses this claim element. <i>See</i> claim [1.A].

'656 Claim	Tomasi in view of Vinther
slide surface, and a projector lens characterized by a projector lens vertex;	
capturing an image of the structured light pattern reflected on the surface of the object with a device for capturing an image, wherein said device for capturing an image comprises a device lens characterized by a device lens vertex;	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.B].</i>
determining a measurement relating to the surface of the object using a triangulation algorithm based on a correspondence between points in said slide pattern and said image, and	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.C].</i>
wherein said slide pattern comprises a plurality of coded elements, where each of said coded elements is characterized by at least one parameter and, where said at least one parameter	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.D].</i>

'656 Claim	Tomasi in view of Vinther
defines a spatial or temporal distribution of an amplitude or a wavelength of said structured light, and	
wherein said coded elements are assigned to one of at least first group or second group, each of which first group and second group comprising at least two of said coded elements, and	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.E].</i>
wherein at least a first slide virtual line and a second slide virtual line are defined on said slide surface, where said first slide virtual line is defined by an intersection between said slide surface and a first plane passing through said projector lens vertex and through said device lens vertex, and said second slide virtual line is defined by an intersection between said slide surface and a	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.F].</i>

'656 Claim	Tomasi in view of Vinther
second plane passing through said projector lens vertex and through said device lens vertex, and	
wherein said coded elements of said first group are located along said first virtual line and said coded elements of said second group are located along said second virtual line.	Tomasi in view of Vinther discloses this claim element. <i>See claim [1.G].</i>
13. The method of claim 12, wherein each of said coded elements having at least three points that do not lie on a straight line.	Tomasi in view of Vinther discloses this claim element. <i>See claim 2.</i>
14. The method of claim 12, wherein at least first object virtual line and second object virtual line are defined on said surface of said object, where said first object virtual line is defined by an intersection between said surface of said	Tomasi in view of Vinther discloses this claim element. <i>See claim 3.</i>

'656 Claim	Tomasi in view of Vinther
object and said first plane and where said second object virtual line is defined by an intersection between said surface of said object and said second plane.	
15. The method of claim 12, wherein the light projector is further characterized by a central optical axis, further comprising arranging the light projector and the device for capturing an image such that a line extending between the light projector vertex and the device vertex is perpendicular to the central optical axis of the light projector.	Tomasi in view of Vinther discloses this claim element. <i>See claim 4.</i>
17. The method of claim 12, wherein the light projector is characterized by a projector central optical axis and wherein the device for capturing an	Tomasi in view of Vinther discloses this claim element. <i>See claim 6.</i>

'656 Claim	Tomasi in view of Vinther
image is characterized by a device central optical axis, further comprising arranging the light projector and the device for capturing an image such that a line extending between the projector vertex and the device vertex is not perpendicular to either the projector central optical axis or the device central optical axis.	
18. The method of claim 12, further comprising projecting structured light in a wavelengths selected from optical, visible and infrared wavelengths.	Tomasi in view of Vinther discloses this claim element. <i>See claim 7.</i>
19. The method of claim 12, further comprising projecting the structured light from a flashlight source.	Tomasi in view of Vinther discloses this claim element. <i>See claim 8.</i>

'656 Claim	Tomasi in view of Vinther
20. The method of claim 12, wherein the structured light pattern comprises a plurality of coded elements that can be variably grouped together such that all of the coded elements in each group form a unique sequence relative to the sequences of coded elements in adjacent groups of coded elements.	Tomasi in view of Vinther discloses this claim element. <i>See claim 9.</i>
21. The method of claim 12, further comprising determining a three-dimensional shape of the surface of said object.	Tomasi in view of Vinther discloses this claim element. <i>See claim 10.</i>
22. The method of claim 1, wherein said at least one parameter defines a shape, size, or color or a change thereof in time for at least one of said coded elements.	Tomasi in view of Vinther discloses this claim element. <i>See claim 11.</i>

B. Ground 2: Tomasi in View of Vinther and Vuylsteke

1. Overview of Vuylsteke and Motivation to Modify Tomasi (in view of Vinther) with Vuylsteke's Teachings

59. Vuylsteke discloses a system and method for the 3D measurement of the shape of a three-dimensional scene. Vuylsteke at 148. Vuylsteke further seeks to solve the correspondence problem between points in a captured image and in the slide pattern. Vuylsteke at 148-149.

60. Vuylsteke discloses a system using a projector, a camera, and a computer for 3D imaging.

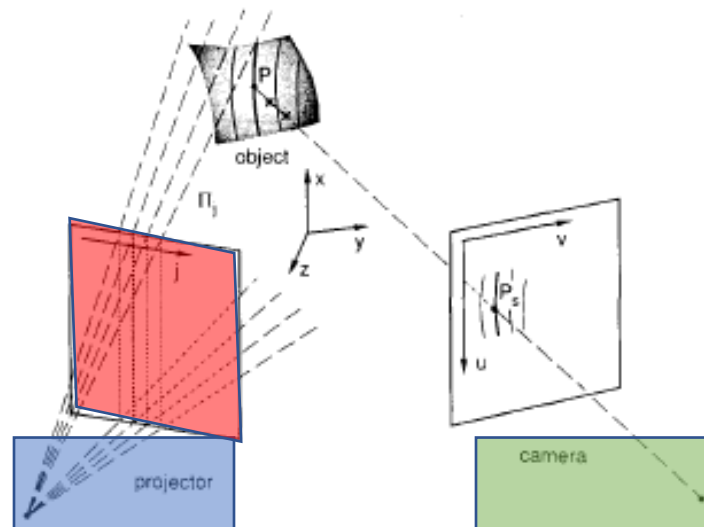


Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_z on a light stripe may correspond to any of the projected light sheets Π_j . The index value j is required to compute the coordinates of the actual object point P .



Fig. 2. Detail of the projected binary pattern.

Vuylsteke at 149. For example, Vuylsteke discloses that “[t]he **illumination pattern depicted in Fig. 2** has been recorded on a **24 X 36 mm Ortho-negative** and is projected on the scene with **a standard slide projector** equipped with a 250 W xenon bulb and a 90 mm/f 1:2.5 objective.” Vuylsteke at 153. In addition, Vuylsteke discloses that a camera is used to capture an image. “The **camera** (High Technology Holland, MX type) has a MOS-CCD frame transfer image sensor of 604(H) x 576(V) pixels. It delivers a 625-line CCIR video signal (linear response, constant gain), which is sampled and digitized to a 512 X 512 by 8 bit digital picture with 1:1 aspect ratio. The focal length of the camera objective (16 mm/f 1:1.8) has been matched to the projection optics, such that approximately the entire illumination pattern is visible when it is projected on a frontal surface at nominal depth.” Vuylsteke at 153.

61. Vuylsteke further describes that a computer is used to execute a triangulation algorithm that uses corresponding points in the slide pattern and the captured image for measuring 3D object geometry. “The digitized picture is processed by **a VAX-750 minicomputer**. Demodulating and decoding an

illumination-encoded image comprise the following steps: 1) detecting the grid points, estimating their precise location in the image, determining their appearance (“sign”) in the chess-board, and their individual codebit indicated by a bright or dark spot; 2) searching for the closest N-, S-, W-, and eastern neighbors of every detected grid point, i.e., recovering the local grid context in the image; and 3) identifying grid points by their local signature, using dynamic windows of some specified minimal size, and checking for signature consistency. Identified points are next spatially located by triangulation.” Vuylsteke at 153.

62. Vuylsteke also discloses that coded elements can be grouped along virtual lines.

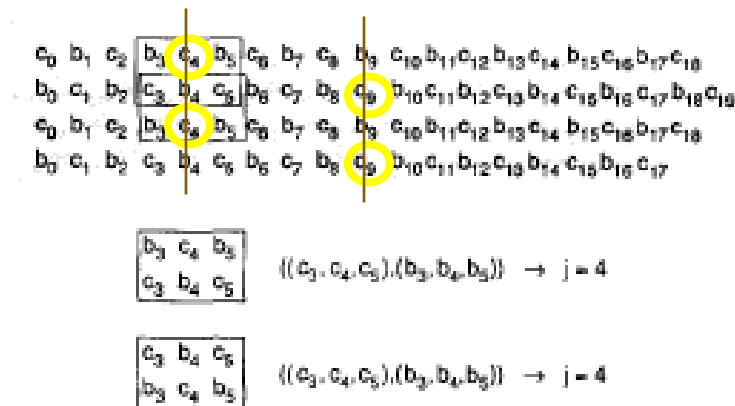


Fig. 4. Two binary sequences are bit-wise assigned to the grid such that every window of 2×3 bits has a unique signature in every position when it is shifted horizontally. Points of the “+” type are marked with a bit of the $\{c_k\}$ sequence, and those of the “-” type with a bit of $\{b_k\}$. The assignment is repeated every second row.

Vuylsteke at 150. “In general, if the identification should be based on a $t \times b$ window format, then the bit map must be organized such that any t consecutive

rows provide for independent information. This requirement may be achieved by repeating the bit assignment every t rows. In the simplest case when the bit map is composed of equal rows ($t = 1$) the appropriate identification window format would be very elongated (covering at least 6 adjacent grid points in horizontal direction, if 63 column positions have to be identified).” Vuylsteke at 151. In addition, Vuylsteke discloses that epipolar geometry can be used to resolve correspondence ambiguity. “If a point grid (or an orthogonal line grid) is projected instead of a parallel line grid, then the ambiguity may be alleviated by taking into account the discrete nature of the projected grid [14], [15], or it may even be eliminated by applying the epipolar constraint several times in a dynamic configuration where the projector is successively rotated [16].” Vuylsteke at 148.

63. Tomasi, Vinther, and Vuylsteke are analogous prior art and in the same field as the ‘656—three-dimensional modeling of an object surface—and reasonably pertinent to the alleged problems identified in the ‘656 of determining correspondence between points in the captured image and the slide pattern. *See, e.g.,* ‘656 at 4:40-5:19, 5:55-6:2.

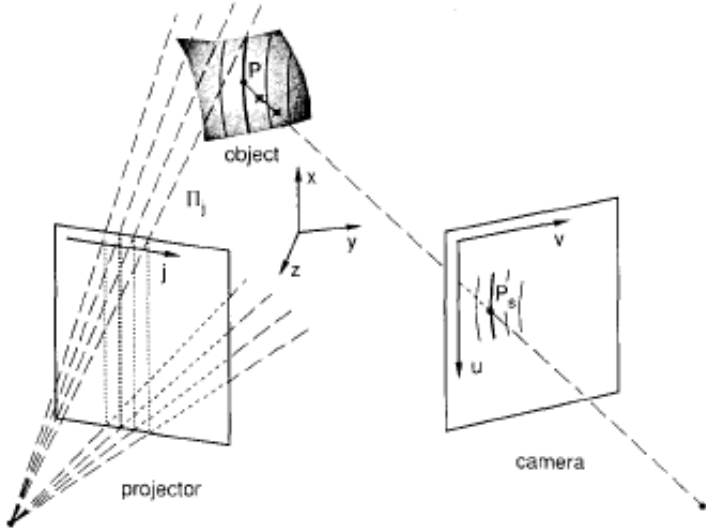
64. In light of the above teachings, a POSITA would have had a reasonable expectation of success in modifying Tomasi with Vinther’s teachings by using, for example, Vuylsteke’s grouping of coded light symbols within the structured light pattern. As previously discussed in Section IX.A, Tomasi and

Vinther teach using structured light patterns having varying coded bits that can be grouped. Tomasi at [0035], Vinther at 7:18-19. Vuylsteke also discloses coded elements that can be grouped. Vuylsteke at 150. Indeed, it was also well understood for a designer of a system at the time of the invention to look to other 3D scanning implementations for guidance. *See, e.g.*, Section IX.A.2. Modifying Tomasi in view of Vinther with Vuylsteke’s teachings would have been a straightforward application of those teachings in a manner that advantageously improves the efficiency of a 3D scanning system.

2. Claim Chart

65.The following claim chart shows my invalidity analysis for each of the Challenged Claims.

‘656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
1. [1.PREAMBLE] A system for the 3D measurement of the shape of a material object, comprising:	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.PREAMBLE]. Vuylsteke discloses this claim element. Vuylsteke discloses using structured light to acquire range pictures of three-dimensional scenes. p. 148 (“Triangulation with structured light is a well established technique for acquiring range pictures of three-dimensional scenes. The spatial position of a point is uniquely determined as the intersection of a straight line with a plane, of three planes, or as the intersection of two straight lines within a plane. These geometric principles have been applied in wide

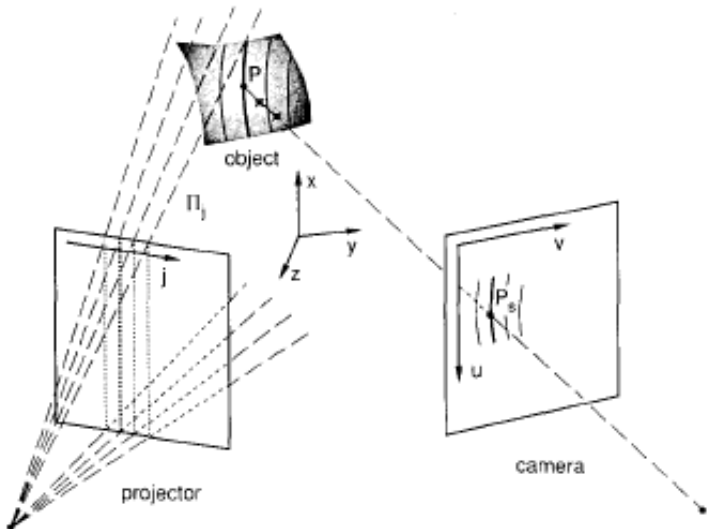
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	range of simple triangulation techniques, using a directional illumination device (a projector), and a directional sensor (a TV-camera). The basic schemes use a directed light beam to indicate a single object point [1]-[3], or a light sheet to indicate a cross-section of the visible scene surface [4]-[6].")
[1.A] a light projector for projecting a structured light pattern onto a surface of said object, wherein said light projector comprises a light source, a slide with a slide pattern located on a slide surface, and a projector lens characterized by a projector lens vertex;	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.A]. Vuylsteke discloses this claim element. Vuylsteke discloses a projector that projects a structured light pattern onto the surface of an object.  Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_j on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149 Vuylsteke explains that the projector includes a light source. p. 149 ("It is therefore essential to restrict the encoding process to a single instance (e.g., by means of a flash light source), such that all the information required for

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	identifying the indicated scene points is available in a single camera picture.”) Vuylsteke discloses a projector having a slide with slide pattern on the slide and a lens, which has a lens vertex. p. 153 (“We realized a prototype based on this binary encoding principle. The measurement setup is very simple and it involves no moving parts. The basic geometry is sketched in Fig. 1. The illumination pattern depicted in Fig. 2 has been recorded on a 24 X 36 mm Ortho-negative and is projected on the scene with a standard slide projector equipped with a 250 W xenon bulb and a 90 mm/f 1:2.5 objective. The entire pattern consists of 64 rows by 63 columns.”)
[1.B] a device for capturing an image of said structured light pattern reflected on said object, wherein said device for capturing an image comprises a device lens characterized by a device lens vertex; and	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.B]. Vuylsteke discloses this claim element. Vuylsteke discloses a camera for capturing images. It further describes that the focal length is designed to match that of the projector optics. p. 153 (“The camera (High Technology Holland, MX type) has a MOS-CCD frame transfer image sensor of 604(H) x 576(V) pixels. It delivers a 625-line CCIR video signal (linear response, constant gain), which is sampled and digitized to a 512 X 512 by 8 bit digital picture with 1:1 aspect ratio. The focal length of the camera objective (16 mm/f 1:1.8) has been matched to the projection optics, such that approximately the entire illumination pattern is visible when it is projected on a frontal surface at nominal depth. In that case the observed grid period roughly corresponds to 8 pixels in both directions.”)
[1.C] a computing device for	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.C].

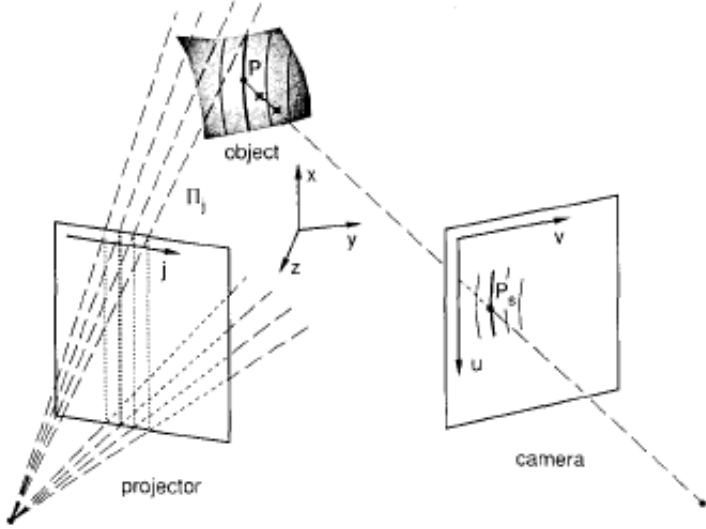
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
determining a measurement relating to the shape of said object using a triangulation algorithm based on a correspondence between points in said slide pattern and said image, and	Vuylsteke discloses this claim element. Vuylsteke discloses that triangulation with structured light is a well-established technique. p. 148 (<i>see</i> [1.PREAMBLE]) Vuylsteke describes the computer used to execute the triangulation algorithm. p. 153 (“The digitized picture is processed by a VAX-750 minicomputer. Demodulating and decoding an illumination-encoded image comprise the following steps: 1) detecting the grid points, estimating their precise location in the image, determining their appearance (‘sign’) in the chess-board, and their individual codebit indicated by a bright or dark spot; 2) searching for the closest N-, S-, W-, and eastern neighbors of every detected grid point, i.e., recovering the local grid context in the image; and 3) identifying grid points by their local signature, using dynamic windows of some specified minimal size, and checking for signature consistency. Identified points are next spatially located by triangulation.”)
[1.D] wherein said slide pattern comprises a plurality of coded elements, where each of said coded elements is characterized by at least one parameter and, where said at least one parameter defines a spatial or temporal distribution of an amplitude or a	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.D]. Vuylsteke discloses this claim element. Vuylsteke discloses that it was known to use a slide pattern with varying wavelength. p. 148 (“Tajima used a single monochromatic illumination pattern with gradually increasing wavelength (i.e., a rainbow pattern), in combination with a two-channel color camera [18].”)

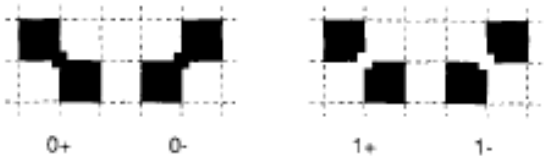
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
wavelength of said structured light, and	Vuylsteke discloses a slide pattern with a plurality of coded elements, spatially distributed and having varying amplitude. p. 150 (“An appropriate illumination pattern with only two intensity levels which 1) indicates a grid of points and 2) marks each grid point individually with a single codebit, is depicted in Fig. 2. Note the basic chess-board appearance. By definition, the grid points to be indicated on the scene are located at the intersection of the horizontal and vertical chess-board edges, i.e., where four squares meet. Upon projection every column generates a plane Π, the index j of which must be known for locating the indicated object points by triangulation. In our experimental measurement system the entire pattern consists of 63 columns of 64 points each (only 10 rows are shown). For the purpose of identification every grid point is individually marked with a bright or a dark spot, representing a binary “1” or “0”, respectively. Additionally the chess-board naturally exhibits two basic appearances of the grid points, which alternate both in horizontal and vertical direction. We denote them as either “+” or “-”. Hence one may think of the complete pattern to be composed of the four primitives depicted in Fig. 3.”)

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	 Fig. 2. Detail of the projected binary pattern.  Fig. 3. The entire illumination pattern is composed of four primitives.
[1.E] wherein said coded elements are assigned to one of at least first group or second group, each of which first group and second group comprising at least two of said coded elements, and	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.E]. Vuylsteke discloses this claim element. Vuylsteke discloses groups of coded elements, containing at least two coded elements. p. 151 (“For any arbitrary identification window format one may always define an equivalent <i>n</i>-tuple with a specified order of c_k- and b_k-bits, n being the total number of bits in the window. The window even need not be rectangular. For some specified window format the corresponding n-tuple may be regarded as a codeword, and the set of all the codewords which are obtained by considering the window at every horizontal position on the bit map defines a code. Every window format defines a distinct code. If the identification is to be performed with a window of some specified format, say $2 \times b$ bits, then a pair of binary sequences $\{c_k\}$ and $\{b_k\}$ should be found such that the corresponding code is optimal, in the sense that it has the largest possible minimal Hamming distance.”)
[1.F] wherein at least a first slide virtual line	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.F].

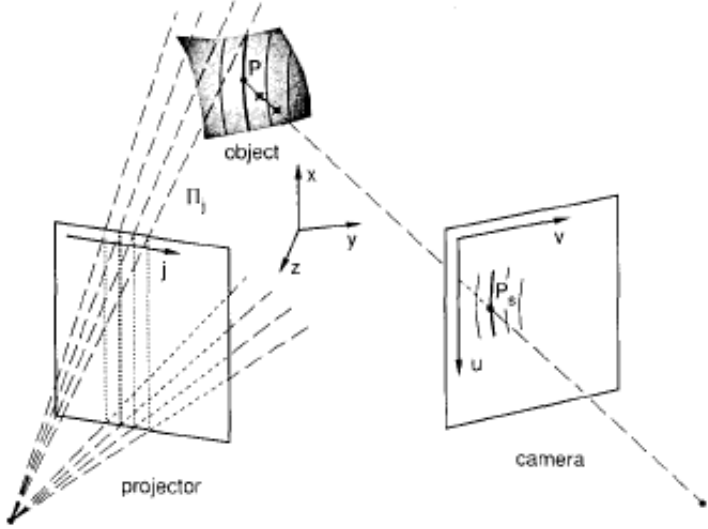
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
and a second slide virtual line are defined on said slide surface, where said first slide virtual line is defined by an intersection between said slide surface and a first plane passing through said projector lens vertex and through said device lens vertex, and said second slide virtual line is defined by an intersection between said slide surface and a second plane passing through said projector lens vertex and through said device lens vertex, and	Vuylsteke discloses this claim element. Vuylsteke discloses light sheets (planes) projected through the projector lens vertex, and virtual planes passing through the projector lens vertex and the camera lens vertex. The structured light pattern is designed in a grid-like fashion such that defined rows and columns intersect with the light sheets.  Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_s on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149 Vuylsteke describes how it performs decoding by using grid points along certain virtual rows and/or columns. p. 148 (see [1.PREAMBLE]) p. 155 (“We estimated the precision of this subpixel location technique by means of the following experiment. If the illumination pattern is projected on a flat target then ideally every set of grid points belonging to the same row or column should be

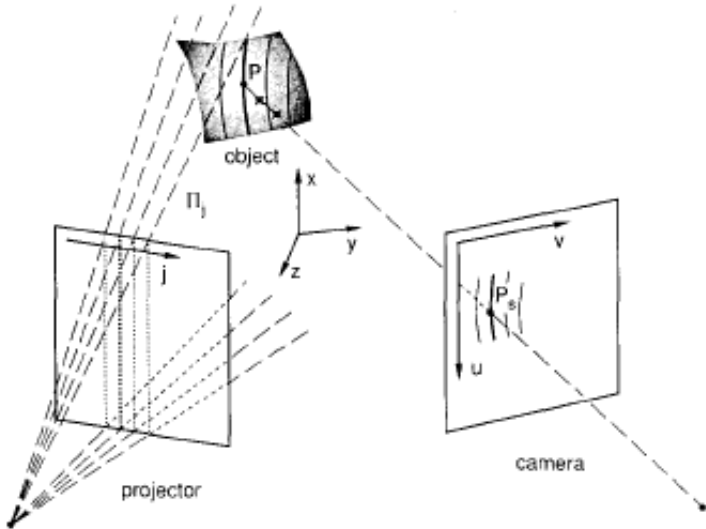
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	collinear in the camera image. In our test procedure collinearity is examined by fitting lines to the rows and columns of located grid points in the image, according to the least squared error criterion.” “The previous steps served to characterize every detected grid point by its image coordinates, its “sign,” and its corresponding codebit. For the purpose of identification, however, windows of adjacent grid points are to be considered instead of isolated grid points. The actual configuration of codebits in a window determines a signature by which the enclosed grid points can be identified. Hence the first decoding step consists of locally recovering the original grid topology in the observed image, i.e., finding the natural N-, S-, W-, and E-neighbors of any detected grid point. A directed graph, with a node for every detected grid point, and branches to the immediate 4-neighbors, is very convenient to represent these relational data.” “Finding neighboring grid points may be facilitated by invoking some heuristics, which follow from geometrical considerations. The geometry of our experimental system (depicted in Fig. 1) is subject to some weak restrictions, which we denote by a “usual” triangulation setup: 1) the projector and the camera point to some common point so as to optimally cover the working space; 2) their mutual separation (base length) is small compared to the nominal object distance; 3) the focal length/image size ratios of the projector and the camera are nearly equal and relatively large; and 4) the <i>j</i>-axis does not deviate very much from the base line direction (i.e., the line through both lens centers). Under these circumstances the grid rows will be observed as nearly parallel and equidistant in the camera image. In other words, the direction and vertical separation of the grid

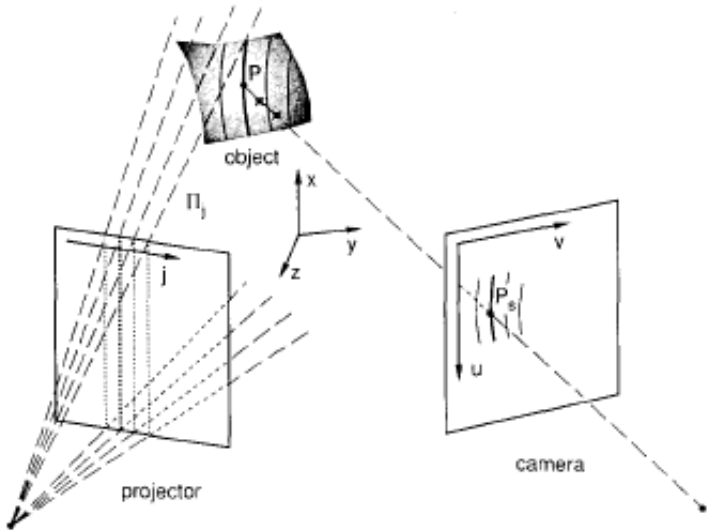
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	rows is only to a small extent modulated by the scene geometry.”)
[1.G] wherein said coded elements of said first group are located along said first virtual line and said coded elements of said second group are located along said second virtual line.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, [1.G]. Vuylsteke discloses this claim element. Vuylsteke discloses groups of coded elements located along varying virtual lines.  Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_s on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149 Vuylsteke discloses how triangulation with structured light involves the intersection of lines and planes. p. 148 (<i>see</i> [1.PREAMBLE]) Vuylsteke shows how codebits exist within the context of columns and planes. p. 150 (<i>see</i> [1.D])

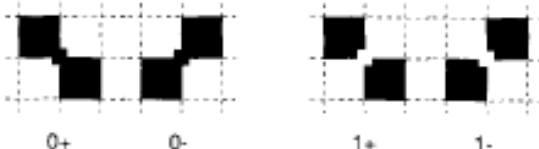
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	 Fig. 2. Detail of the projected binary pattern.  Fig. 3. The entire illumination pattern is composed of four primitives. Vuylsteke discloses groups of coded elements, containing at least two coded elements. p. 151 (<i>see</i> [1.E]) Vuylsteke describes how coded elements exist in the context of a grid topology. p. 155 (<i>see</i> [1.F])
2. The system of claim 1, wherein each of said coded elements having at least three points that do not lie on a straight line.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 2. Vuylsteke discloses this claim element. Vuylsteke shows that codes elements consist of squares of light at intersections of a checkerboard layout. The vertices of a square do not lie on a straight line. p. 150 (<i>see</i> [1.D])

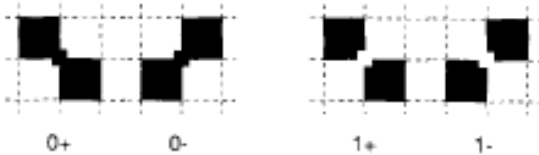
'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	 Fig. 2. Detail of the projected binary pattern.  Fig. 3. The entire illumination pattern is composed of four primitives.
3. The system of claim 1, wherein at least first object virtual line and second object virtual line are defined on the surface of said object, where said first object virtual line is defined by an intersection between said surface of said object and said first plane and where said second object virtual line is defined by an intersection between said surface of said object and said second plane.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 3. Vuylsteke discloses this claim element. Vuylsteke discloses light sheets (planes) projected through the projector lens vertex, and virtual planes passing through the projector lens vertex and the camera lens vertex. The structured light pattern is designed in a grid-like fashion such that defined rows and columns intersect with the light sheets.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
	 Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_s on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149 Vuylsteke discloses how triangulation with structured light involves the intersection of lines and planes with an object. p. 148 (see [1.PREAMBLE])
4. The system of claim 1, wherein the light projector is further characterized by a central optical axis, further wherein the light projector and the device for capturing an image are arranged such that a line extending between the projector vertex and the device vertex is	Tomasi in view of Vinther discloses this element. See section IX.A.3, claim 4. To the extent this claim element is not explicitly disclosed in Vuylsteke, one of ordinary skill in the art would have considered it an obvious addition to or modification of the disclosure. A person of ordinary skill in the art would have been motivated to combine the disclosure with other disclosures, such as those in Tomasi and Vinther, to arrive at this claim.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
perpendicular to the central optical axis of the light projector.	
6. The system of claim 1, wherein the light projector is characterized by a projector central optical axis and wherein the device for capturing an image is characterized by a device central optical axis, further wherein the light projector and the device for capturing an image are arranged such that a line extending between the projector vertex and the device vertex is not perpendicular to either the projector optical axis or the device optical axis.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 6. Vuylsteke discloses this claim element. Vuylsteke discloses projector and camera orientations such that the projector and camera optical axes are at acute angles with respect to the line between the optical centers.  Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_s on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149
7. The system of claim 1, wherein the light projector projects structured light in a wavelengths selected from optical,	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 7. Vuylsteke discloses this claim element. Vuylsteke discloses the use of visible structured light.

‘656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
visible and infrared wavelengths.	p. 148 (<i>see</i> [1.PREAMBLE])
8. The system of claim 1, wherein the light projector is a flashlight source.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 8. Vuylsteke discloses this claim element. Vuylsteke shows a projector that projects a structured light pattern onto the surface of an object.  Fig. 1. The identification problem with multiple stripe triangulation. An observed image point P_j on a light stripe may correspond to any of the projected light sheets Π_j. The index value j is required to compute the coordinates of the actual object point P. p. 149 Vuylsteke explains that the projector includes a flashlight source. p. 149 (<i>see</i> [1.A])
9. The system of claim 1, wherein the structured light pattern comprises a plurality of coded	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 9. Vuylsteke discloses this claim element.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
elements that can be variably grouped together such that all of the coded elements in each group form a unique sequence relative to the sequences of coded elements in adjacent groups of coded elements.	Vuylsteke discloses groupings of coded elements that are unique from other groups. p. 150 (<i>see</i> [1.D])  Fig. 2. Detail of the projected binary pattern.  Fig. 3. The entire illumination pattern is composed of four primitives. p. 151 (<i>see</i> [1.E])
10. The system of claim 1, wherein the computing device determines a three-dimensional shape of the surface of said object.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 10. Vuylsteke discloses this claim element. Vuylsteke discloses the use of structured light to determine the shape of a three-dimensional surface. p. 148 (<i>see</i> [1.PREAMBLE])
11. The system of claim 1, wherein said at least one parameter defines a shape, size, or color or a change thereof in time for at	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 11. Vuylsteke discloses this claim element.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
least one of said coded elements.	Vuylsteke discloses a plurality of coded elements of a predetermined size that are spatially distributed and having varying amplitude. p. 150 (<i>see</i> [1.D])  Fig. 2. Detail of the projected binary pattern.  Fig. 3. The entire illumination pattern is composed of four primitives.
12. A method for the 3D measurement of the shape of a material object, comprising:	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke also discloses this claim element. <i>See</i> claim [1.PREAMBLE].
projecting a structured light pattern from a light projector onto a surface of an object, wherein the light projector comprises a light source, a slide with a slide pattern located on a slide surface, and a projector lens	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.A].

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
characterized by a projector lens vertex;	
capturing an image of the structured light pattern reflected on the surface of the object with a device for capturing an image, wherein said device for capturing an image comprises a device lens characterized by a device lens vertex;	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.B].
determining a measurement relating to the surface of the object using a triangulation algorithm based on a correspondence between points in said slide pattern and said image, and	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.C].
wherein said slide pattern comprises a plurality of coded elements, where each of said coded elements is characterized by at least one parameter and, where said at least one parameter defines a spatial or temporal distribution of an amplitude or a	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.D].

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
wavelength of said structured light, and	
wherein said coded elements are assigned to one of at least first group or second group, each of which first group and second group comprising at least two of said coded elements, and	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.E].
wherein at least a first slide virtual line and a second slide virtual line are defined on said slide surface, where said first slide virtual line is defined by an intersection between said slide surface and a first plane passing through said projector lens vertex and through said device lens vertex, and said second slide virtual line is defined by an intersection between said slide surface and a second plane passing through said projector lens vertex and through said device lens vertex, and	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12. Vuylsteke discloses this claim element. <i>See</i> claim [1.F].
wherein said coded elements of said first	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 12.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
group are located along said first virtual line and said coded elements of said second group are located along said second virtual line.	Vuylsteke discloses this claim element. <i>See</i> claim [1.G].
13. The method of claim 12, wherein each of said coded elements having at least three points that do not lie on a straight line.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 13. Vuylsteke discloses this claim element. <i>See</i> claim 2.
14. The method of claim 12, wherein at least first object virtual line and second object virtual line are defined on said surface of said object, where said first object virtual line is defined by an intersection between said surface of said object and said first plane and where said second object virtual line is defined by an intersection between said surface of said object and said second plane.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 14. Vuylsteke discloses this claim element. <i>See</i> claim 3.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
15. The method of claim 12, wherein the light projector is further characterized by a central optical axis, further comprising arranging the light projector and the device for capturing an image such that a line extending between the light projector vertex and the device vertex is perpendicular to the central optical axis of the light projector.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 15. <i>See</i> claim 4.
17. The method of claim 12, wherein the light projector is characterized by a projector central optical axis and wherein the device for capturing an image is characterized by a device central optical axis, further comprising arranging the light projector and the device for capturing an image such that a line extending between the projector vertex and the device vertex is not perpendicular to	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 17. Vuylsteke discloses this claim element. <i>See</i> claim 6.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
either the projector central optical axis or the device central optical axis.	
18. The method of claim 12, further comprising projecting structured light in a wavelengths selected from optical, visible and infrared wavelengths.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 18. Vuylsteke discloses this claim element. <i>See</i> claim 7.
19. The method of claim 12, further comprising projecting the structured light from a flashlight source.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 19. Vuylsteke discloses this claim element. <i>See</i> claim 8.
20. The method of claim 12, wherein the structured light pattern comprises a plurality of coded elements that can be variably grouped together such that all of the coded elements in each group form a unique sequence relative to the sequences of coded elements in adjacent groups of coded elements.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 20. Vuylsteke discloses this claim element. <i>See</i> claim 9.

'656 Claim	Tomasi in view of Vinther further in view of Vuylsteke
21. The method of claim 12, further comprising determining a three-dimensional shape of the surface of said object.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 21. Vuylsteke discloses this claim element. <i>See</i> claim 10.
22. The method of claim 1, wherein said at least one parameter defines a shape, size, or color or a change thereof in time for at least one of said coded elements.	Tomasi in view of Vinther discloses this element. <i>See</i> section IX.A.3, claim 22. Vuylsteke discloses this claim element. <i>See</i> claim 11.

X. SECONDARY CONSIDERATIONS

66. I have not seen any evidence of any arguments regarding the existence of secondary considerations in the prosecution history of the '656 patent. *See generally*, FH. I have also not seen any evidence that any such evidence would have a nexus to any of the Challenged Claims. In addition, as shown above with respect to the prior art referenced in Section IX, any alleged solutions to problems or unexpected results in the '656 patent were already well known.

XI. CONCLUSION

67.I have concluded that the Challenged Claims are rendered obvious over the prior art references as discussed above.

68.Specifically, it is my opinion that for at least the reasons above, the Challenged Claims are rendered obvious over Tomasi in view of Vinther and further over Tomasi in view of Vinther and Vuylsteke.

69.To the extent it is argued that any further disclosure is required for an element in the Challenged Claims that I have identified as being disclosed, a person having ordinary skill in the art would have found that element obvious to include based on the same explicit disclosure or inherent disclosures and analysis I have identified above.

70.To the extent necessary, I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner or its expert(s) may raise and to take into account new information as it becomes available to me.

71.In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

72.I hereby declare that all statements made in this declaration of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that my statements were made with the knowledge that willful false statements are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed on this 26th day of June in 2023.

Respectfully submitted,



Prof. Mohit Gupta, Ph.D.

MOHIT GUPTA

Computer Sciences Department, University of Wisconsin-Madison

Lab website: <http://wisionlab.cs.wisc.edu/>

Research Interests

Computer Vision, Computational Imaging

Education

Ph.D. in Robotics, Carnegie Mellon University	2005 - 2011
M.S. in Computer Science, Stony Brook University	2003 – 2005
B.Tech. in Computer Science, Indian Institute of Technology, Delhi	1999 – 2003

Work Experience

Associate Professor, University of Wisconsin-Madison	2022 -
Assistant Professor, University of Wisconsin-Madison	2016 - 2022
Post-doctoral Research Scientist, Columbia University	2011 - 2015
Research Intern, Mitsubishi Electric Research Labs	Summer 2009, 2010

Awards and Honors

Sony Faculty Innovation Award	2022, 21, 20
Marr Prize Honorable Mention, IEEE Int. Conf. on Computer Vision (ICCV)	2019
NSF CAREER Award	2019
Finalist, Most Influential Research Category, AutoSens Conference Awards	2019
Paper Selected for IJCV Special Issue on Best Papers of ECCV	2018
Keynote Talk, Workshop on Visual Odometry and Applications, IEEE CVPR	2023

Keynote Talk, Workshop on Computational Cameras and Displays, IEEE CVPR	2022
Keynote Talk, Workshop on Mobile Intelligent Photography and Imaging, ECCV	2022
Plenary Talk, Int. Conf. on Quality Control by Artificial Vision (Tokyo)	2017
Keynote Talk, Workshop on Computational Cameras and Displays, IEEE CVPR	2014
Best Paper Honorable Mention, IEEE Int. Conf. on Computational Photography	2014

Professional Activities

Organization

Program Chair: IEEE International Conf. on Computational Photography (ICCP) 2023, Madison

Program Chair: IEEE International Conf. on Computational Photography (ICCP) 2019, Tokyo

Workshops Chair: IEEE CVPR 2022

Program Chair: Workshop on Computational Cameras and Displays (with IEEE CVPR 2017, 2018)

Finance Chair: IEEE ICCP 2018, Demos and Posters Chair, IEEE ICCP 2016

Program Committees and Editorial Boards

Best Paper Award Committee: IEEE CVPR 2022

Area Chair (Program Committee): CVPR 2024, ICCV 2023, CVPR 2023, WACV 2023, ECCV 2022, ICCV 2021, CVPR 2021, SIGGRAPH Asia 2018, Pacific Graphics 2018

Guest Editor: IJCV Special Issue on Computational Photography (2017-2018)

Professional Service Awards

Outstanding reviewer award, ECCV 2020

Tutorials

Co-organized (invited) tutorial on computational imaging at ICIP 2015, ICIP 2016

Co-organized tutorial on time-of-flight (ToF) imaging at ICCV 2015

Co-organized tutorial on compressive sensing of videos at CVPR 2012

Co-organized the symposium on volumetric scattering at CVPR 2007

Reviewing

Reviewer for Nature, Nature Communications, CACM, SIGGRAPH, SIGGRAPH Asia, PAMI, IJCV, TIP, ICCV, CVPR, ECCV, ICCP

Publications

Conference and Journal Publications: ¹ ²

2023

CASPI: Collaborative Photon Processing for Active Single-Photon Imaging
Jongho Lee^S, Atul Ingle^C, Jenu Chacko^C, Kevin Elicieri^C, and **Mohit Gupta**
Nature Communications

Seeing Photons in Color
Sizhuo Ma^S, Varun Sundar^S, Paul Mos^C, Claudio Bruschini^C, Edoardo Charbon^C, and **Mohit Gupta**
ACM Transactions on Graphics (SIGGRAPH 2023)

When Two Cameras Are a Crowd (Understanding Interference Across Multiple Active Cameras)
Jongho Lee^S, **Mohit Gupta**, Bhuvana Krishnaswamy^C, and Suman Banerjee^C
Communications of the ACM

Burst Vision Using Single-Photon Cameras
Sizhuo Ma^S, Paul Mos^C, Edoardo Charbon^C, and **Mohit Gupta**
WACV 2023

Spike-Based Anytime Perception
Matt Dutson^S, Yin Li^C, and **Mohit Gupta**
WACV 2023

QFaR: Location-Guided Scanning of Visual Codes from Long Distances
Sizhuo Ma^S, J. Wang^C, W. Chen^C, S. Banerjee^C, **Mohit Gupta**, S. Nayar^C
ACM MobiCom 2023

2022

Event Neural Networks
Matt Dutson^S, Yin Li^C, and **Mohit Gupta**
ECCV 2022

3D Scene Inference from Transient Histograms
Sacha Jungerman^S, Atul Ingle^C, Yin Li^C, and **Mohit Gupta**
ECCV 2022

¹Collaborators are denoted by^C, thesis and post-doc advisors by^a, students and post-docs under my supervision by^S, and students/post-docs under the supervision of others by^O.

²ICCV, ECCV and CVPR are the top three conferences in computer vision, with acceptance rates typically around 25%. A few selected papers (typically 2 – 4%) are awarded an oral presentation. ACM Transactions on Graphics (TOG) and ACM SIGGRAPH are the top journal/conference in computer graphics, with an acceptance rate around 20%. IEEE PAMI, IJCV, and IEEE TIP are the top journals in computer vision and image processing. 3DV and ICCP are smaller conference for 3D vision and computational imaging and photography. Acceptance rates are typically around 30 – 40%.

Mitigating AC and DC Interference in Multi-ToF-Camera Environments

Jongho Lee^S, and **Mohit Gupta**

IEEE Trans. on Pattern Analysis and Machine Intelligence (conditionally accepted)

Robust Scene Inference under Noise-Blur Dual Corruptions

Bhavya Goyal^S, JF Lalonde^C, Yin Li^C, and **Mohit Gupta**

ICCP 2022

Geometric Calibration of Single-Pixel Distance Sensors

Carter Sifferman^S, Dev Mehrotra^S, **Mohit Gupta**, and Michael Gleicher^C

IEEE Robotics and Automation Letters (RAL); Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2022

Single-Photon Structured Light

Varun Sundar^S, Sizhuo Ma^S, Aswin Sankaranarayanan^C, and **Mohit Gupta**

CVPR 2022

Compressive Single-Photon 3D Cameras

Felipe Gutierrez-Barragan^S, Atul Ingle^C, Trevor Seets^C, **Mohit Gupta**, and Andreas Velten^C

CVPR 2022

Single-Photon Camera Guided Extreme Dynamic Range Imaging

Yuhao Liu^C, Felipe Gutierrez-Barragan^S, Atul Ingle^C, **Mohit Gupta**, and Andreas Velten^C

WACV 2022

iToF2dToF: A Robust and Flexible Representation for Data-driven Time-of-Flight Imaging

Felipe Gutierrez-Barragan^S, Huaijin Chen^C, **Mohit Gupta**, Andreas Velten^C, Jinwei Gu^C

IEEE Transactions on Computational Imaging 2022

2021

Photon-Starved Scene Inference using Single Photon Cameras

Bhavya Goyal^S, and **Mohit Gupta**

ICCV 2021

Blocks-World Cameras

Jongho Lee^S, and **Mohit Gupta**

CVPR 2021, * oral presentation

Passive Inter-Photon Imaging

Atul Ingle^S, T Seets^C, M Buttafava^C, Shantanu Gupta^S, A Tosi^C, Andreas Velten^C, and **Mohit Gupta**

CVPR 2021, * oral presentation

Invisible Perturbations: Physical Adversarial Examples Exploiting the Rolling Shutter Effect

Athena Sayles^C, Ashish Hooda^C, **Mohit Gupta**, Rahul Chatterjee^C, and Earlene Fernandes^C

CVPR 2021

2020

Quanta Burst Photography

Sizhuo Ma^S, Shantanu Gupta^S, Arin Ulku^C, Claudio Bruschini^C, Edoardo Charbon^C, and **Mohit Gupta**
ACM Transactions on Graphics (SIGGRAPH 2020)

Smart Time-Multiplexing of Quads Solves the Multicamera Interference Problem

Tomislav Pribanic^C, Tomislav Petkovi^C, David Bojani^C, Kristijan Bartol^C, and **Mohit Gupta**
International Conference on 3D Vision (3DV) 2020

Inertial Safety from Structured Light

Sizhuo Ma^S, and **Mohit Gupta**
ECCV 2020

2019

Asynchronous Single-Photon 3D Imaging

Anant Gupta^S, Atul Ingle^S, and **Mohit Gupta**
ICCV 2019, * oral presentation, * Marr Prize Honorable Mention

Stochastic Exposure Coding for Handling Multi-ToF-Camera Interference

Jongho Lee^S, and **Mohit Gupta**
ICCV 2019, * oral presentation

Micro-Baseline Structured Light

Viswa Venkata^{SC}, Jian Wang^C, **Mohit Gupta**, and Shree Nayar^C
ICCV 2019

Practical Coding Function Design for Time-of-Flight Imaging

Felipe Gutierrez-Barragan^S, Syed Reza^C, Andreas Velten^C, and **Mohit Gupta**
CVPR 2019

Photon-Flooded Single Photon 3D Cameras

Anant Gupta^S, Atul Ingle^S, Andreas Velten^C, and **Mohit Gupta**
CVPR 2019, * oral presentation

Passive High Flux Imaging with Single Photon Cameras

Atul Ingle^S, Andreas Velten^C and **Mohit Gupta**
CVPR 2019, * oral presentation

Differential Scene Flow from Light-Field Gradients

Sizhuo Ma^S, Brandon Smith^S, and **Mohit Gupta**
International Journal of Computer Vision (IJCV 2019)
Special Issue on Best Papers of ECCV 2018

Coding Scheme Optimization for Fast Fluorescence Lifetime Imaging

Jongho Lee^s, JV Chacko^o, B Dai^o, SA Reza^o, AK Sagar^o, K Eliceiri^c, A Velten^c, and **Mohit Gupta**
ACM Transactions on Graphics (ACM TOG 2019), presented at SIGGRAPH 2019

2018

A Geometric Perspective on Structured Light Coding

Mohit Gupta, and Nikhil Nakhate^s
ECCV 2018

3D Scene Flow from 4D Light Field Gradients

Sizhuo Ma^s, Brandon Smith^s, and **Mohit Gupta**
ECCV 2018, * oral presentation; * Selected for IJCV Special issue on 'Best of ECCV'

Tracking Multiple Objects Outside the Line of Sight using Speckle Imaging

Brandon Smith^s, Matt O'Toole^c, and **Mohit Gupta**
CVPR 2018, * spotlight oral presentation

Trapping Light for Time-of-Flight

Ruilin Xu^o, **Mohit Gupta**, and Shree Nayar^c
CVPR 2018, * oral presentation

What are Optimal Coding Functions for Time-of-Flight Imaging?

Mohit Gupta, Andreas Velten^c, Shree Nayar^c, and Eric Breitbach^c
ACM Transactions on Graphics (ACM TOG 2018), presented at SIGGRAPH 2018

SH-ToF: Micro Resolution Time-of-Flight Imaging with Superheterodyne Interferometry

Fengqiang Li^o, F Willomitzer^o, P Rangarajan^c, **Mohit Gupta**, Andreas Velten^c, Oliver Cossairt^c
ICCP 2018

2016-17

CoLux: Multi-Object 3D Micro-Motion Analysis Using Speckle Imaging

Brandon Smith^s, Pratham Desai^s, Vishal Agrawal^s, and **Mohit Gupta**
ACM Transactions on Graphics (SIGGRAPH 2017)

High-depth-resolution Range Imaging with Multiple-wavelength Superheterodyne Interferometry using 1550-nm Lasers

Fengqiang Li^o, Joshua Yablon^o, Andreas Velten^c, **Mohit Gupta**, and Oliver Cossairt^c
Applied Optics 2017

Dual Structured Light 3D using a 1D Sensor

Jian Wang^o, Aswin Sankaranarayanan^c, **Mohit Gupta**, and Srinivasa Narasimhan^c
ECCV 2016, * oral presentation

DisCo: Display-Camera Communication Using Rolling Shutter Sensors

Kensei Jo^o, **Mohit Gupta**, and Shree Nayar^a

ACM Transactions on Graphics (ACM TOG 2016), presented at SIGGRAPH 2016

2015 and Earlier

SpeDo: 6 DOF Ego-Motion Sensor Using Speckle Defocus Imaging

Kensei Jo^o, **Mohit Gupta**, and Shree Nayar^a

ICCV 2015

Phasor Imaging: A Generalization of Correlation Based Time-of-Flight Imaging

Mohit Gupta, Shree Nayar^a, Matthias Hullin^c, and Jaime Martin^c

ACM Transactions on Graphics (ACM TOG 2015), presented at SIGGRAPH 2015

LiSens: A Scalable Architecture for Video Compressive Sensing

Jian Wang^o, **Mohit Gupta**, and Aswin Sankaranarayanan^c

ICCP 2015

MC3D: Motion Contrast 3D Scanning

Nathan Matsuda^o, Oliver Cossairt^c, and **Mohit Gupta**

ICCP 2015

Digital Refocusing with Incoherent Holography

Oliver Cossairt, Nathan Matsuda and Mohit Gupta

ICCP 2014

*** Best paper honorable mention**

Recovering Scene Geometry Under Wavy Fluid Via Distortion And Defocus Analysis

Mingjie Zhang, Xing Lin, Mohit Gupta, Jinli Suo and Qionghai Dai

ECCV 2014

Fibonacci Exposure Bracketing for High Dynamic Range Imaging

Mohit Gupta, Daisuke Iso and Shree Nayar

ICCV 2013

Structured Light in Sunlight

Mohit Gupta, Qi Yin and Shree Nayar

ICCV 2013

Efficient Space-Time Sampling with Pixel-wise Coded Exposure for High Speed Imaging

Dengyu Liu, Jinwei Gu, Yasunobu Hitomi, Mohit Gupta, Tomoo Mitsunaga and Shree Nayar

IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI 2013)

Micro Phase Shifting

Mohit Gupta and Shree Nayar

CVPR 2012, * oral presentation

Diffuse Structured Light
Shree Nayar and Mohit Gupta
ICCP 2012

3D Scanning in the Presence of Interreflections, Subsurface Scattering and Defocus
Mohit Gupta, Amit Agrawal, Ashok Veeraraghavan and Srinivasa Narasimhan
International Journal of Computer Vision (IJCV 2012)

When Does Computational Imaging Improve Performance?
Oliver Cossairt, Mohit Gupta and Shree Nayar
IEEE Transactions on Image Processing (TIP 2012)

Video from a Single Exposure Coded Photograph using a Learned Over-Complete Dictionary
Yasunobu Hitomi, Jinwei Gu, Mohit Gupta and Shree Nayar
ICCV 2011

Multiplexed Illumination for Scene Recovery in the Presence of Global Illumination
Jinwei Gu, Toshihiro Kobayashi, Mohit Gupta and Shree Nayar
ICCV 2011, * oral presentation

Structured Light 3D Scanning Under Global Illumination
Mohit Gupta, Amit Agrawal, Ashok Veeraraghavan and Srinivasa Narasimhan
CVPR 2011

A Combined Theory of Defocused Illumination and Global Light Transport
Mohit Gupta, Yuandong Tian, Srinivasa Narasimhan and Li Zhang
International Journal of Computer Vision (IJCV 2011)

Flexible Voxels for Motion-Aware Videography
Mohit Gupta, Amit Agrawal, Ashok Veeraraghavan and Srinivasa Narasimhan
ECCV 2010

Optimal Coded Sampling for Temporal Super-Resolution
Amit Agrawal, Mohit Gupta, Ashok Veeraraghavan and Srinivasa Narasimhan
CVPR 2010

(De) Focusing on Global Light Transport for Active Scene Recovery
Mohit Gupta, Yuandong Tian, Srinivasa Narasimhan and Li Zhang
CVPR 2009, * oral presentation

On Controlling Light Transport in Poor Visibility Environments
Mohit Gupta, Srinivasa Narasimhan and Yoav Schechner
CVPR 2008

High Resolution Tracking of Non-Rigid 3D Motion Using Harmonic Maps
Yang Wang, Mohit Gupta, Song Zhang, Sen Wang, Xianfeng Gu, Dimitris Samaras and Peisen Huang
International Journal of Computer Vision (IJCV 2008)

Legendre Fluids: Reduced Space Modeling and Rendering of Participating Media
Mohit Gupta and Srinivasa Narasimhan
Eurographics/ ACM SIGGRAPH Symposium on Computer Animation (SCA 2007)

Acquiring Scattering Properties of Participating Media by Dilution
Srinivasa Narasimhan, Mohit Gupta, Craig Donner, Ravi Ramamoorthi, Shree Nayar, Henrik Wann Jensen
ACM Transactions on Graphics (SIGGRAPH 2006)

High Resolution Tracking of Non-Rigid 3D Motion Using Harmonic Maps
Yang Wang, Mohit Gupta, Song Zhang, Sen Wang, Xianfeng Gu, Dimitris Samaras and Peisen Huang
ICCV 2005, * oral presentation

Multilevel Modeling and Rendering of Architectural Scenes
A. Kushal, G. Chanda, K. Srivastava, M. Gupta, S. Sanyal, T.V.N. Sri Ram, P. Kalra and S. Banerjee
Eurographics 2003

Invited Book Chapters:

Shape From Scatter
Mohit Gupta
Computer Vision: A Reference Guide, 2014, Publisher: Springer

Performance Limits for Motion Deblurring Cameras
Oliver Cossairt and Mohit Gupta
Motion Deblurring: Algorithms and Systems, 2014, Publisher: Cambridge University Press

Patents

Systems, Methods, And Media For Generating And Using Spiking Neural Networks With Improved Efficiency
Inventors: Matthew Dutson and Mohit Gupta
US Patent Application P210141US01, Filing Date: April 2021

Systems, Methods, And Media For Directly Recovering Planar Surfaces In A Scene Using Structured Light
Inventors: Jongho Lee and Mohit Gupta
US Patent Application P200264US01, Filing Date: July 2020

Systems, Methods, And Media For High Dynamic Range Quanta Burst Imaging
Inventors: Sizhuo Ma and Mohit Gupta
US Patent Application P200158US01, Filing Date: April 2020

Systems, Methods, And Media For Stochastic Exposure Coding That Mitigates Multi-Camera Interference In Continuous Wave Time-Of-Flight Imaging
Inventors: Jongho Lee and Mohit Gupta
US Patent Application 16/556119, Filing Date: August 2019

Systems, methods, and media for asynchronous single photon Depth imaging with improved precision in ambient light

Inventors: Anant Gupta, Atul Ingle and Mohit Gupta

US Patent Application P190244US01, Filing Date: June 2019

Systems, Methods, And Media For Single Photon Depth Imaging With Improved Precision In Ambient Light

Inventors: Anant Gupta, Atul Ingle, Andreas Velten and Mohit Gupta

US patent application P190137US01, Filing Date: March 2019

Low Power Light Wave Communication for Mobile and Wearable Devices

Inventors: Shree K. Nayar, Mikhail Fridberg, Mohit Gupta

Patent granted, August 2021: US 11,082,129 B1

Augmented Reality System using Structured Light

Inventors: Mohit Gupta, Shree K. Nayar, Viswanath Saragadam

Patent granted, February 2021: US 10,909,373 B1

Systems, methods, and media for encoding structured light imaging patterns and estimating depths in a scene

Inventor: Mohit Gupta

Patent granted, October 2020: US 10818023

Systems, Methods And, Media For Determining Object Motion In Three Dimensions From Light Field Image Data

Inventors: Mohit Gupta, Sizhuo Ma, Brandon Smith

Patent granted, October 2019: US 10706564

Systems, methods, and media for high dynamic range imaging using dead-time-limited single photon detectors

Inventors: Mohit Gupta, Atul Ingle, Andreas Velten

Patent granted, April 2020: US 10616512

Systems, methods, and media for encoding and decoding signals used in time-of-flight imaging

Inventors: Felipe Gutierrez, Mohit Gupta, Eric Breitbach, Andreas Velten, Shree Nayar

Patent granted, November 2020: US 10,739,447 B2

*** Licensed**

Systems, methods, and media for encoding and decoding signals used in time-of-flight imaging

Inventors: Mohit Gupta, Eric Breitbach, Andreas Velten, Shree Nayar

Patent granted, May 2020: US 10,645,367 B2

*** Licensed**

Systems, methods, and media for determining object motion in 3D using speckle images

Inventors: Mohit Gupta, Brandon Smith, Pratham Desai, Vishal Agarwal

Patent granted, December 2018: US 10,152,798 B2

** Nominated as one of six finalists out of 400 applications in WARF Innovation Awards 2017*

Systems, methods, and media for performing shape measurement

Inventors: Mohit Gupta, Shree Nayar

Patent granted, May 2017: US 2015/0176982 A1

*** Licensed and Productized**

Methods, systems, and media for high dynamic range imaging

Inventors: Mohit Gupta, Tomoo Mitsunaga, Daisuke Iso, Shree Nayar

Patent granted, December 2018: US 9,648,248 B2

Structured Light for 3D Shape Reconstruction Subject to Global Illumination

Inventors: Mohit Gupta, Ashok Veeraraghavan, Amit Agrawal

Patent granted, August 2014: US 8,811,767 B2

Video Camera for Acquiring Images with Varying Spatio-Temporal Resolutions

Inventors: Mohit Gupta, Ashok Veeraraghavan, Amit Agrawal, Srinivasa Narasimhan

Publication number US 2011/0243442 A1

Research Grants

As PI:

Quanta Computational Imaging with Single-Photon Cameras

NSF CAREER Award, 2020-2025

Co-PIs: None

Total Funding: \$550K

Analysis of Single-Photon Sensors for Long-range 3D Imaging

Cruise, 2023-24

Co-PIs: None

Total Funding: \$125K

How many Photons are needed to Recognize an Object?

SONY Faculty Innovation Award, 2020-2024

Co-PIs: None

Total Funding: \$300K

Practical Single-Photon 3D Imaging

WARF (UW-Madison IP Office), 2020-2024

Co-PIs: None

Total Funding: \$325K

Next Generation Time-of-Flight Imaging

ONR, 2016-2019

Co-PIs: Shree Nayar (Columbia University)

Total Funding: \$650K; Gupta's Share: \$450K

Time-of-Flight Cameras

Sony Corp. (Research Gift), 2017-2018

Co-PIs: None

Total Funding: \$70K

Hierarchical Visual Codes
Snap Research (Research Gift), 2020

Co-PIs: None

Total Funding: \$20K

Practical Time-of-Flight Imaging
Draper Technology Innovation Fund (UW Internal) Award, 2020-2021

Co-PIs: None

Total Funding: \$50K

Weak 3D Cameras
UW Internal Fall Competition, 2021-2022

Co-PIs: None

Total Funding: \$40K

Single-Photon 3D Imaging
UW Internal Fall Competition, 2019-2020

Co-PIs: None

Total Funding: \$40K

From One Photon to a Billion: Extreme Dynamic Range Imaging with Single Photon Sensors
Draper Technology Innovation Fund (UW Internal) Award, 2018-2019

Co-PIs: Andreas Velten (U. Wisconsin)

Total Funding: \$50K; Gupta's Share: \$25K

Extreme Motion Cameras
UW Internal Fall Competition, 2018-2019

Co-PIs: None

Total Funding: \$40K

As Co-PI:

Scene Recovery Using an Extended Plenoptic Function
DARPA, 2016-2020

PIs: Srinivasa Narasimhan (CMU) and Andreas Velten (U. Wisconsin)

Total funding: ~ \$5.5 million; Gupta's share: ~\$850K

Characterization, Mitigation, and Management of Active 3D Camera Interference
NSF, 2021-2025

PI: Suman Banerjee (U. Wisconsin)

Total funding: \$1 million; Gupta's share: ~\$350K

Supporting Distributed Machine Learning Applications for the Nomadic Edge
NSF and Intel Research, 2020-2023

PI: Suman Banerjee (U. Wisconsin)

Total funding: \$900K; Gupta's share: ~\$150K

Teaching

A summary of end-of-semester teaching evaluations, based on the following questions:

- **Q1: Did the instructor create a positive, engaging learning environment?**

Range of Available Responses (1–7); 1 - Not at all; 4 - Neutral; 7 - Completely

- **Q2: Would you recommend this instructor to your fellow students?**

Range of Available Responses (1–7); 1 - Not at all; 4 - Neutral; 7 - Completely

Table 1: Summary of teaching evaluations at U. Wisconsin-Madison. The numerical values in the Q1 and Q2 columns indicate the mean values aggregated over the student responses to the corresponding survey question.

Semester	Course	Number of Students	Q1	Q2
Spring 2021	Graduate Computer Vision	70	6.22	6.12
Fall 2020	Ugrad. Computer Vision	50	6.48	6.26
Spring 2020	Graduate Computer Vision	64	5.91	5.64
Spring 2019	Graduate Computer Vision	65	6.33	5.75
Fall 2018	Computational Photography	142	5.65	4.48
Spring 2018	Graduate Computer Vision	82	6.16	6.04
Spring 2017	Graduate Computer Vision	58	6.20	5.85
Spring 2016	Graduate Computer Vision	53	6.45	6.42

Talks

Shedding Light on 3D Cameras

NYU Courant CS Colloquium (October 2022)
Magic Leap Seminar (September 2022)
Cruise Seminar (March 2022)
University of California Berkeley (September 2021)
Georgia Tech. (September 2021)
Cornell University (October 2021)
Google Research (October 2021)

Computational Imaging, One Photon at a Time

SONY Distinguished Engineer Professor Lecture Series (February 2022)
University of Florida (April 2021)
Stanford University SCIEN Seminar Series (October 2020)

Towards Next Generation 3D Cameras

Omron R&D Center, Kyoto, Japan (May 2017)
SONY R&D Center, Atsugi, Tokyo, Japan (May 2017)
Oculus Research, Seattle (March 2016)
University of Washington, Seattle (June 2015)
Amazon, Seattle (June 2015)
Microsoft Research Labs, Seattle (June 2015)
Robotics Institute, Carnegie Mellon University (April 2015)
University of Wisconsin-Madison (December 2014)

Time-of-Flight Revolution

Dagstuhl Seminar on Computational Imaging (May 2015)
Workshop on Computational Photography and Intelligent Cameras, UCLA (February 2015)
MIT Media Labs (November 2014)
Keynote talk, CCD Workshop at IEEE CVPR (June 2014)

Measuring 3D Shape When Light Misbehaves

University of Toronto (June 2011)
Harvard University (June 2011)

Probing Scenes with Programmable Illumination

Intel Research Labs, Seattle (April 2010)
University of California, Berkeley (June 2010)
Columbia University (June 2010)

Scene Recovery in the presence of Global Light Transport

Stony Brook University (July 2009)
Columbia University (July 2009)

APPENDIX B: LIST OF MATERIALS CONSIDERED

EX1001	U.S. Patent No. 7,768,656
EX1002	File History of U.S. Application No. 11/846,494 (“FH”)
EX1004	U.S. Patent Application 2004/0005092 (“Tomasi”)
EX1005	WIPO WO 2007/059780 (“Vinther”)
EX1006	Vuylsteke and Oosterlinck, “Range Image Acquisition with a Single Binary-Encoded Light Pattern,” <i>IEEE Transactions on Pattern Analysis and Machine Intelligence</i> , Vol. 12, No. 2, February 1990 (“Vuylsteke”)
EX1007	Batlle, et al, “Recent Progress in Coded Structured Light as a Technique to Solve the Correspondence Problem: a Survey,” <i>Pattern Recognition</i> , Vol. 31, No. 7, pp. 963-982 (“Batlle”)
EX1008	Salvi, et al., “Pattern codification strategies in structured light systems,” <i>Pattern Recognition</i> 37 (2004) 827 – 849 (“Salvi 1”)
EX1009	Salvi, et al., "An overview of the advantages and constraints of coded pattern projection techniques for autonomous navigation," <i>Proceedings of the 1997 IEEE/RSJ International Conference on Intelligent Robot and Systems. Innovative Robotics for Real-World Applications. IROS '97</i> , Grenoble, France, 1997, pp. 1264-1271 vol.3 (“Salvi 2”)