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3U Vision SRL,

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(54) Title of the Invention: Camera system

Abstract Title: Shortwave infrared camera system comprising at least two different spectral filters

(57) A camera system 1 comprises at least one infrared detector device 2 sensitive to electromagnetic radiation in the shortwave infrared range from approximately 900 nm to approximately 1700 nm and including a plurality of sensor elements arranged next to one another in rows and columns for capturing individual spatial picture elements. The system also comprises at least one optical unit 3 that images electromagnetic radiation incident on the camera system onto the at least one infrared detector device, and at least two different spectral filters 4x, 4y, 4z, 4w disposed or disposable upstream of the at least one infrared detector device and that are each light transmissive in different shortwave infrared spectral regions. A control and processing device 5 captures a picture of at least approximately the same scene using the at least one infrared detector device with the at least two different spectral filters (4x, 4y, 4z, 4w) so that picture signals of the recorded scene are produced in the different shortwave infrared spectral regions, wherein each spatial picture element captured by the at least one infrared detector device is provided with spectral information items corresponding to the at least two different upstream spectral filters (4x, 4y, 4z, 4w).

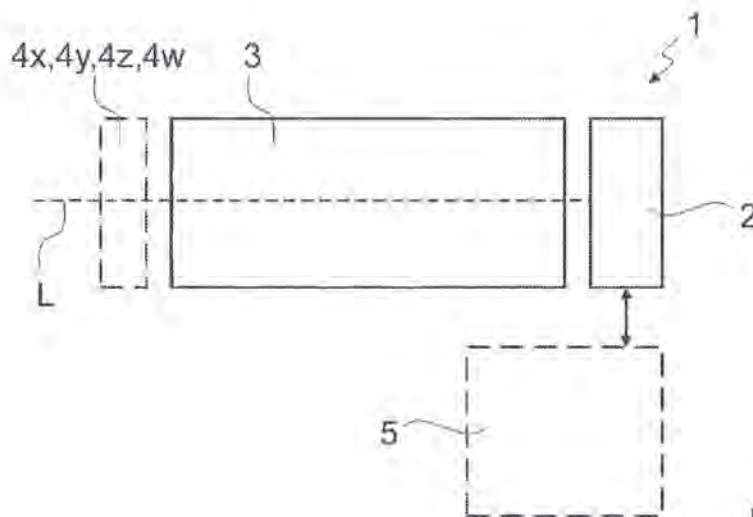


Fig. 1

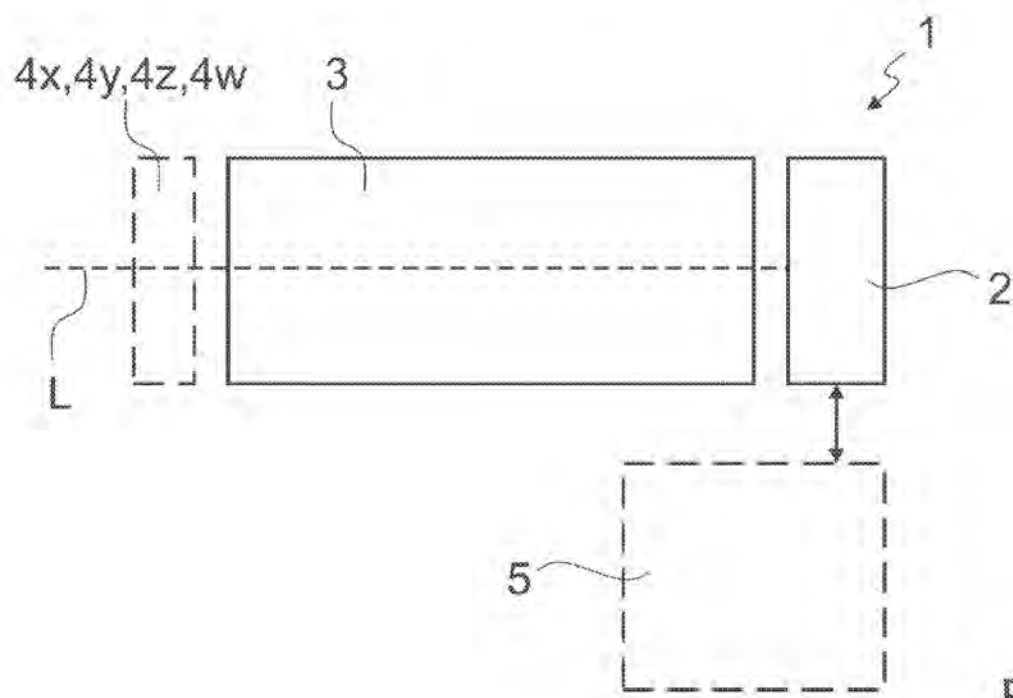


Fig. 1

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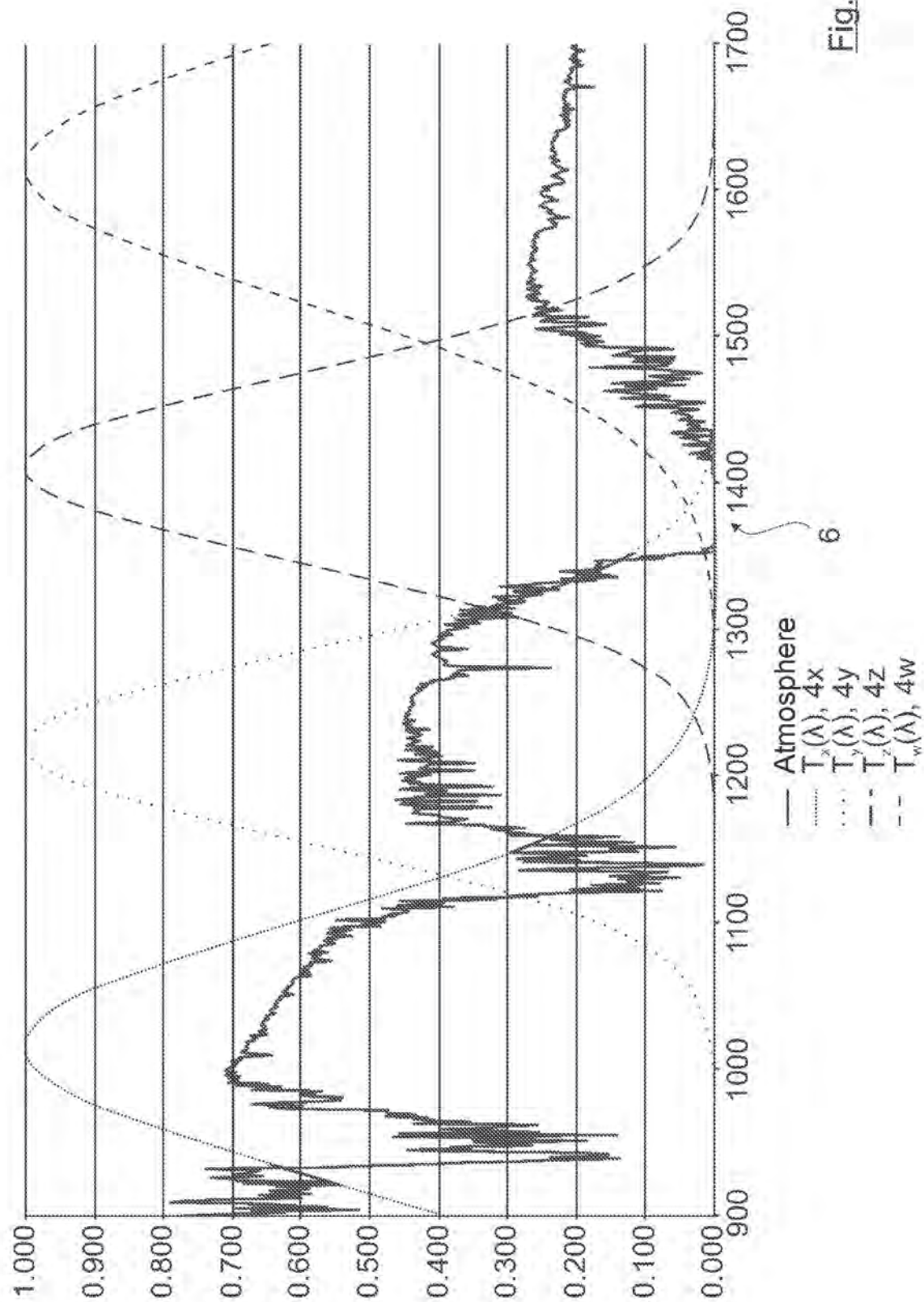
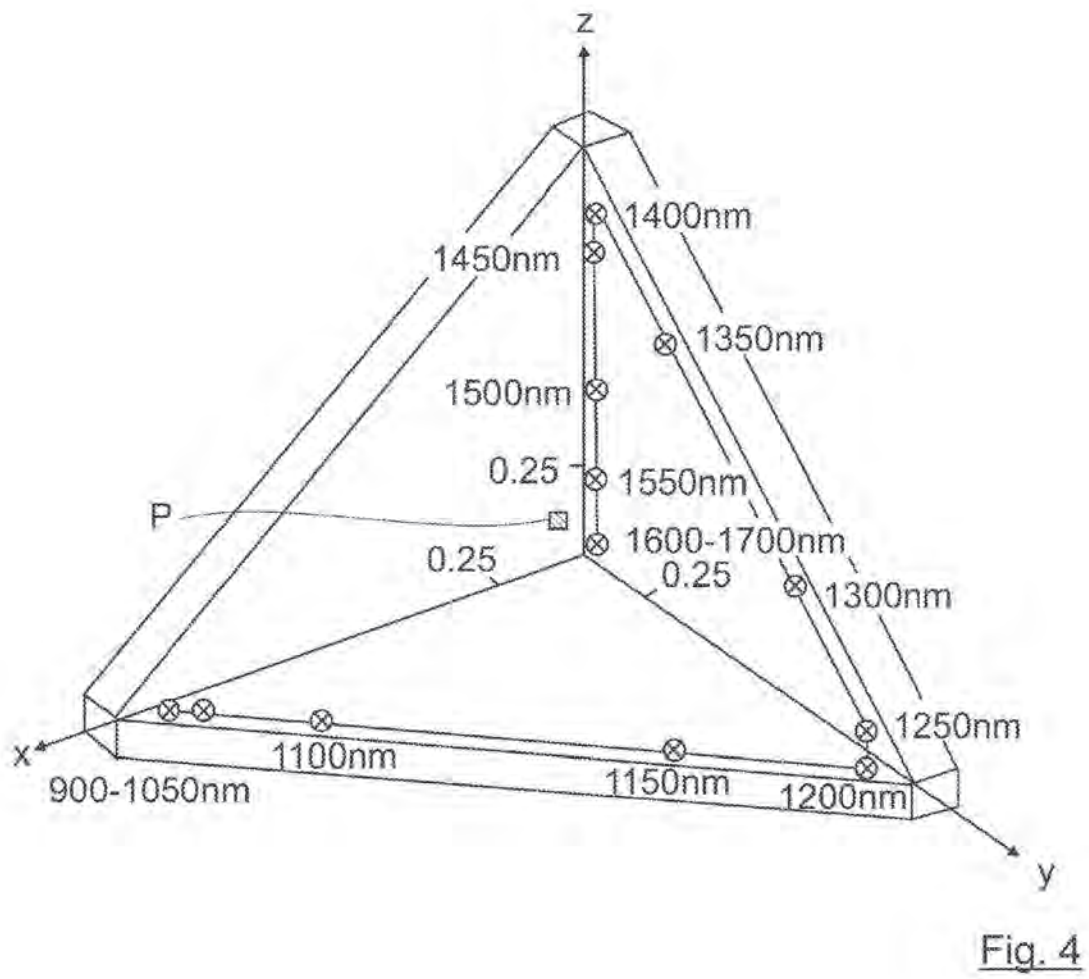
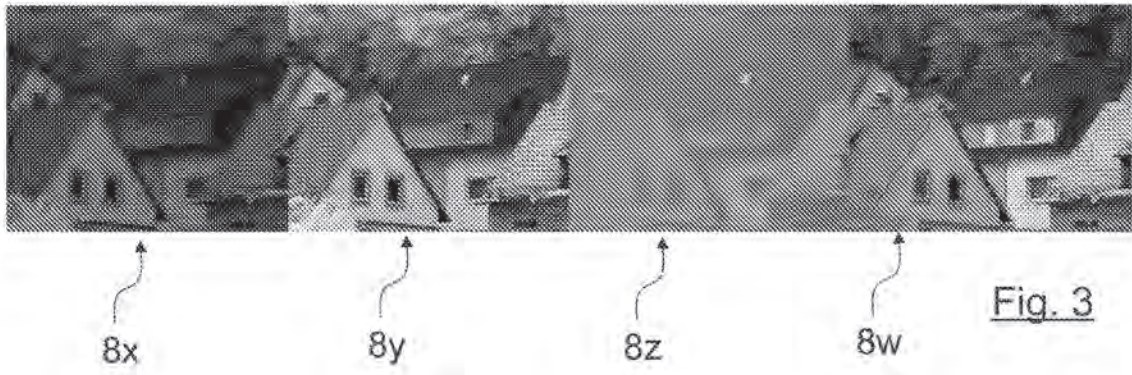
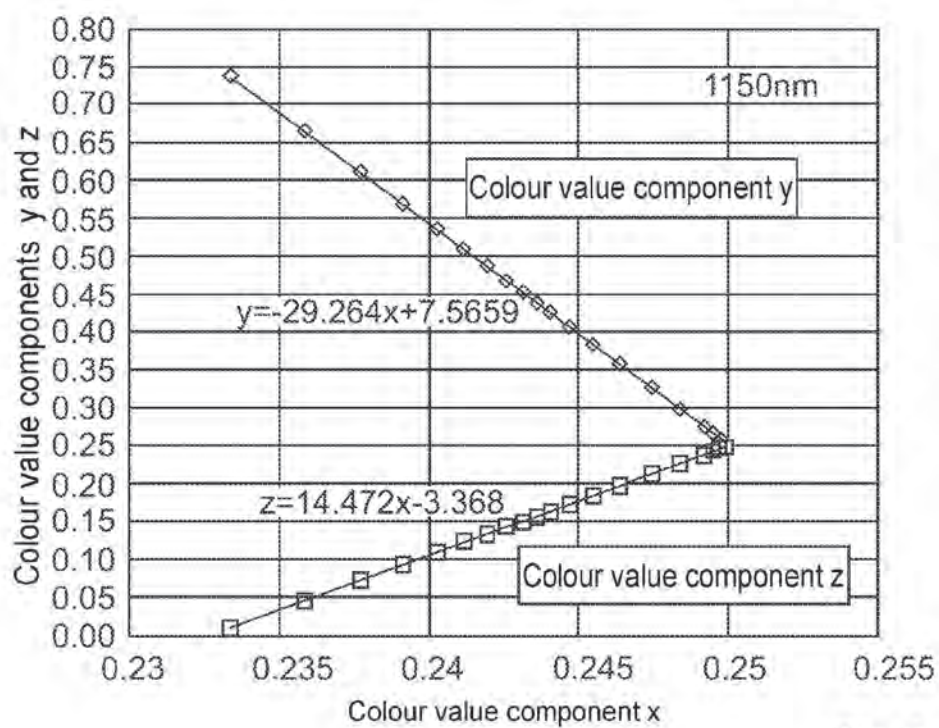
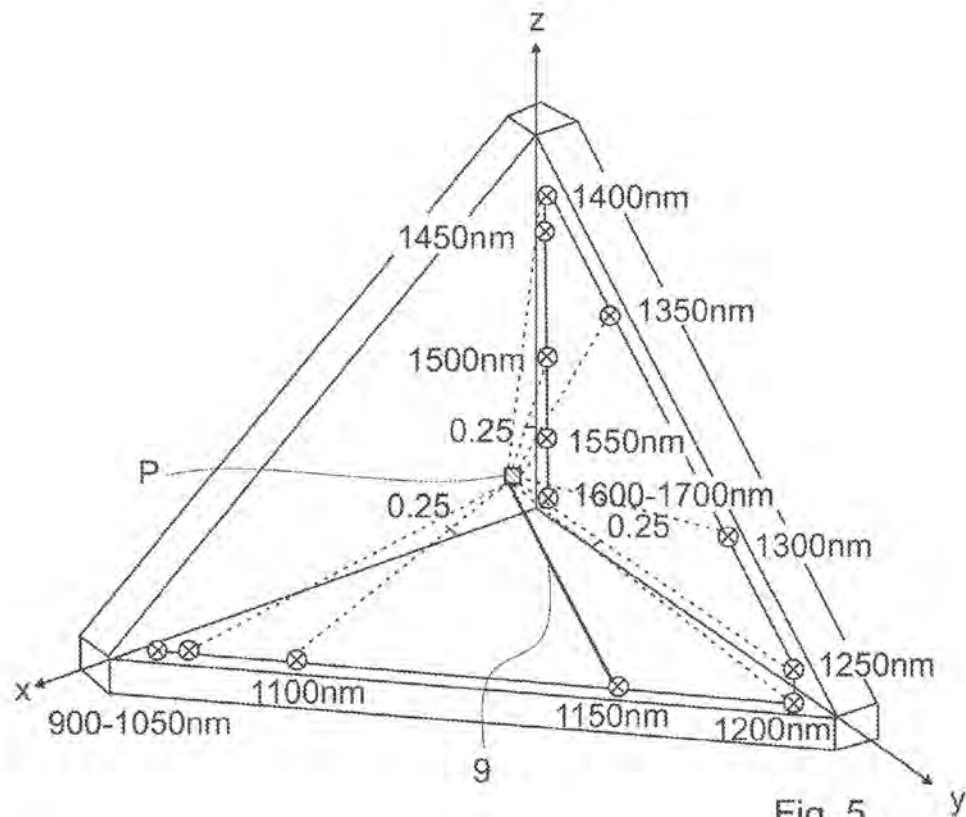


Fig. 2





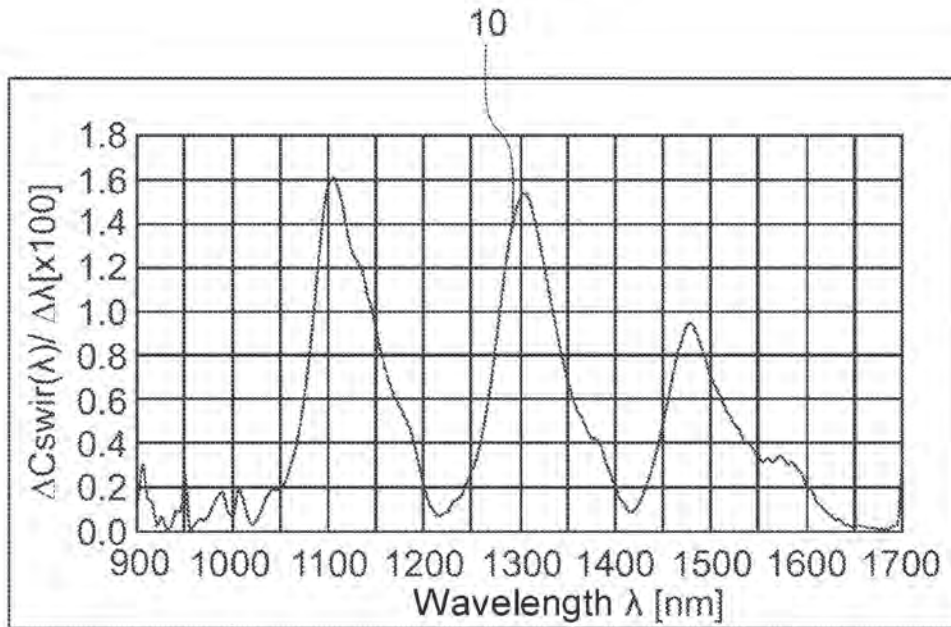


Fig. 7

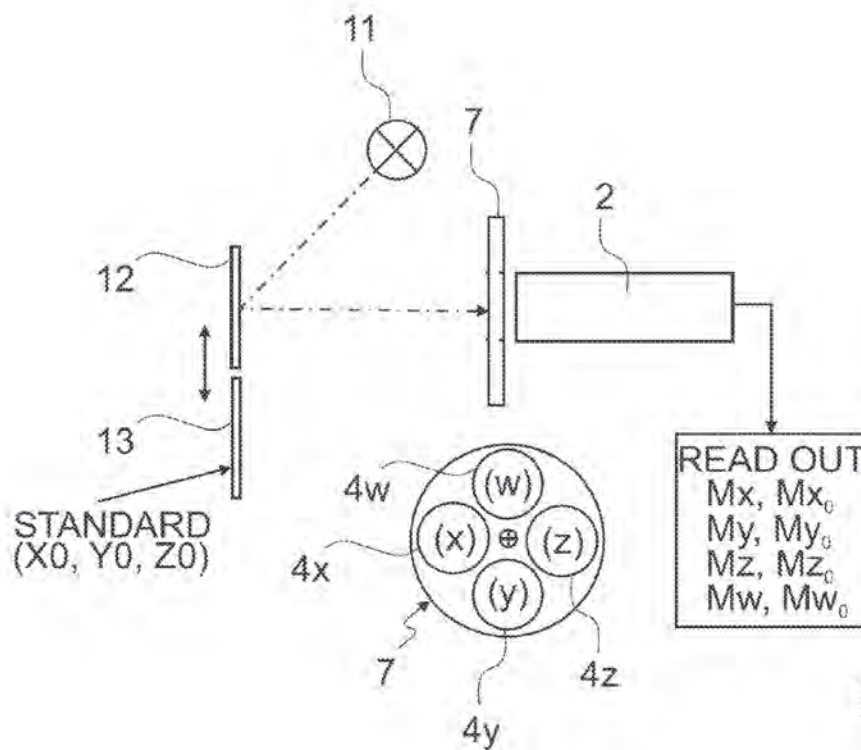


Fig. 8

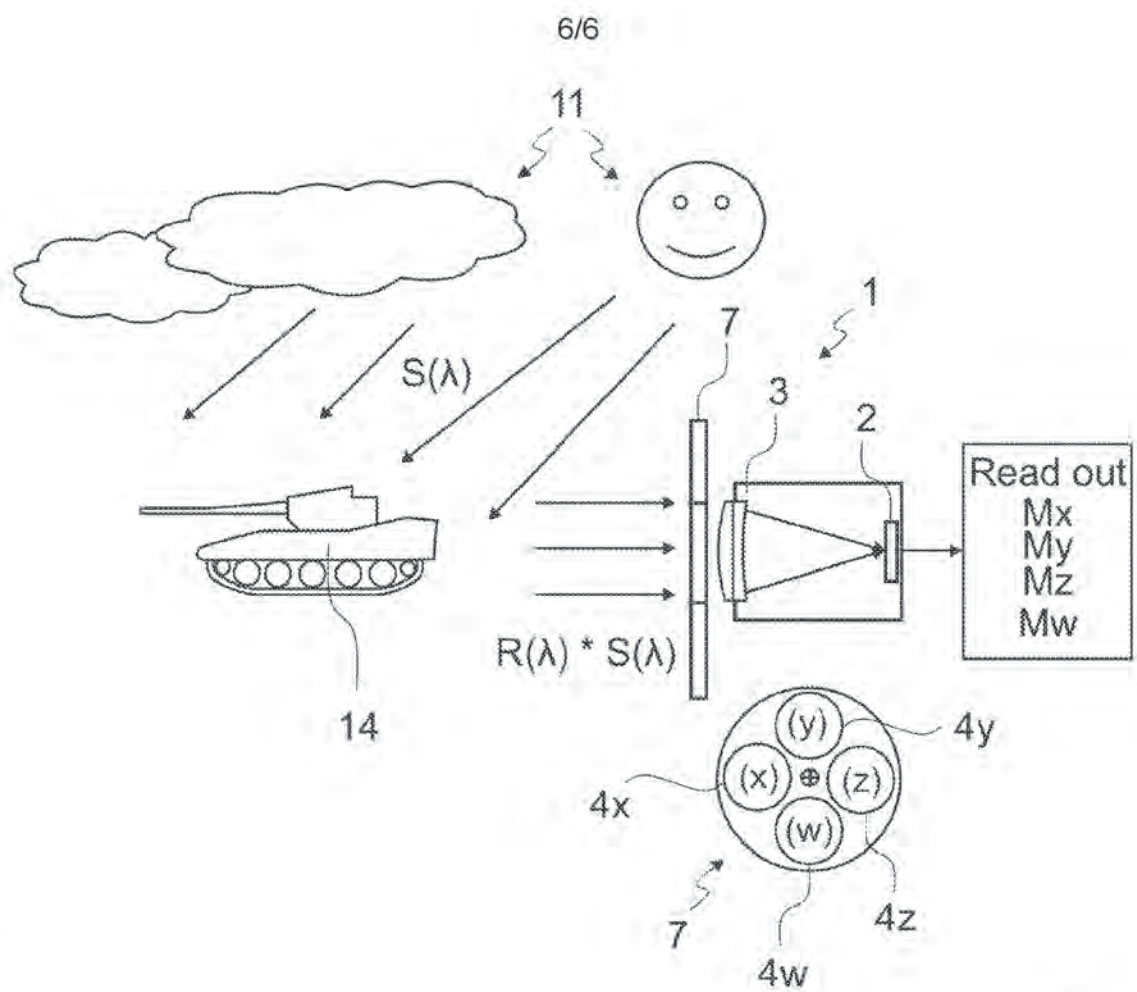


Fig. 9

Description:

Camera system

- 5 The invention relates to camera system, comprising at least one infrared detector device that is sensitive to electromagnetic radiation in the shortwave infrared region from approximately 900 nm to approximately 1700 nm.

- Current camera systems having detectors that are sensitive in the shortwave infrared
- 10 (SWIR/shortwave infrared) region from 900 nm to 1700 nm produce no spectral information items in relation to the recorded pictures or scenes. Even though the spectral range comprises an entire octave in the electromagnetic spectrum in terms of frequency and said spectral region is larger than the visual spectral region, many current applications only use the integrated radiation over the entire spectral region.
- 15 Representations are usually implemented integrated over the wavelength, usually in black/white or greyscale values. Spectral resolutions and coloured representation in this wavelength region previously only existed in the case of remote sensing using spectrometers or complicated spectral filters.
- 20 However, the production of spectral information items or the creation of a colour metric in the shortwave infrared region is very advantageous in conjunction with a less complicated and expensive HDTV camera system. Firstly, improved imaging is possible using the produced spectral information items. By way of example, smoke and fog can be penetrated over short distances. Spectral ranges that are particularly
- 25 impaired by moisture in the atmosphere or by scattering can be not taken into account, or omitted, in the representation. A representation can be implemented both in an RGB space as a so-called false colour representation, or as a greyscale picture.

- A second advantage of using shortwave infrared camera systems lies in the option of
- 30 revealing objects clearly masked for the visual region and the mid-infrared region by using the shortwave infrared. The information about an object to be observed can be significantly increased if the latter is observed or imaged in various spectral regions. The observation of an object in different spectral regions generally allows an

improved analysis of the absorption, reflection, transmission and/or emission characteristics of the object, and so a specific property of the object as such can be identified more easily. By way of example, two objects appearing identical in the visual spectral region may be distinguished from one another in the infrared (IR) spectral region provided they have different temperatures.

Proceeding therefrom, the present invention is based on the object of developing a camera system of the type set forth at the outset, which avoids the disadvantages of the prior art and which, in particular, is able to produce spectral information items relating to a picture recorded in the shortwave infrared.

According to the invention, this object is achieved by Claim 1.

According to the invention, a camera system, in particular a high-resolution camera system, is proposed, comprising:

- at least one infrared detector device, in particular two-dimensional infrared detector device, that is sensitive to electromagnetic radiation in the shortwave infrared range from approximately or exactly 900 nm to approximately or exactly 1700 nm and that has a plurality of sensor elements arranged next to one another in rows and columns for capturing spatial picture elements;
- at least one optical unit that images electromagnetic radiation incident on the camera system onto the at least one infrared detector device;
- at least two different spectral filters that are disposed or disposable upstream of the at least one infrared detector device and that are each light-transmissive in different shortwave infrared spectral regions;
- a control and processing device that is configured to capture a picture of at least approximately the same scene using the at least one infrared detector device with the at least two spectral filters disposed upstream thereof, in such a way that picture signals of the recorded scene are produced in the different shortwave infrared spectral regions of the at least two different spectral filters, wherein each spatial picture element captured by the at least one infrared detector device is provided with spectral information items corresponding to the at least two different upstream

spectral filters.

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The invention pursues the goal of exposing the image sensor with at least two different spectral filters (e.g., in sequence by a filter wheel), like in the case of RGB
5 imaging using CCD or CMOS camera sensors, and of producing the spectral information item by way of a dedicated colour metric for the shortwave infrared region. Specifically developed transformations can adopt the representation in RGB space as a false colour representation (spectral coded false colour). Since many objects have a conspicuous spectral behaviour in the region from 900 nm to
10 1700 nm, an extension to the capabilities can be obtained, especially when revealing these objects. Likewise, the detection of water, for example in the form of humidity or fog, can be improved. Moreover, in the case of infrared spectral bands that are dominated by a water absorption band (e.g., at approximately 1440 nm), the latter can be removed by calculation or can be not taken into account, and so the range
15 can be increased. By defining a colour metric in the shortwave infrared region, the option of a hyperspectral or multispectral resolution and a representation using only one sensor arises. Retrofitting available products is possible with relatively little modification outlay. Moreover, a standardized colour metric allows the comparability of the images. According to the invention, imaging can be implemented at the same
20 time or with a time offset. A corresponding beam splitter arrangement with further infrared detector devices, i.e., a plurality of measurement channels or a type of Bayer filter, are required in the case of simultaneous imaging, like in the case of RGB imaging.

25 By way of the invention, captured spatial picture elements (pixels) in the shortwave infrared region are advantageously provided with spectral information items corresponding to the upstream spectral filters.

The at least two different spectral filters may comprise:

- 30 - at least one first spectral filter that is light-transmissive in a first shortwave infrared spectral region from approximately 900 nm to approximately 1300 nm and preferably is maximally light-transmissive at approximately 1000 nm;

- at least one second spectral filter that is light-transmissive in a second shortwave infrared spectral region from approximately 1000 nm to approximately 1400 nm and preferably is maximally light-transmissive at approximately 1200 nm;
- at least one third spectral filter that is light-transmissive in a third shortwave infrared spectral region from approximately 1200 nm to approximately 1600 nm and preferably is maximally light-transmissive at approximately 1400 nm; and/or
- at least one fourth spectral filter that is light-transmissive in a fourth shortwave infrared spectral region from approximately 1300 nm to approximately 1700 nm and preferably is maximally light-transmissive at approximately 1600 nm.

The shortwave infrared region is completely covered by such a selection of spectral filters. The infrared spectral regions have a sufficient overlap such that the spectral information items are advantageously calculable. The third spectral filter covers a dominant water absorption band at approximately 1440 nm.

Four spectral filters can be present in one configuration of the invention.

It is advantageous if at least one of the different shortwave infrared spectral regions comprises a water absorption band, in particular a dominant water absorption band.

This renders it possible not to take account of a measurement channel that is particularly impaired by scattered light or by humidity, or mist or fog in the atmosphere, when creating the overall picture as, as a rule, only little usable information is present in said measurement channel. Advantageously, the overall resolution can be improved by way of this measure. Consequently, the option of suppressing interference radiation from the water absorption band arises by omitting the corresponding spectral filter; on the other hand, water components in the image can be highlighted accordingly. Consequently, it is likewise possible to detect moisture or to detect water. By way of example, objects camouflaged by dry leaves could be recognized or identified in a forest that otherwise has damp leaves on the trees.

It is advantageous if the different shortwave infrared spectral regions of the at least two different spectral filters partly overlap, in particular by several nanometres, preferably by at least approximately 50%, if they are spectrally adjacent or lie next to one another.

5

As a result of an at least partial overlap of the different shortwave infrared spectral regions, in particular by several nanometres, at least two measurement values can be captured for each wavelength in different measurement channels. As it were, the incident electromagnetic radiation is distributed among a certain number of – at least
10 two – measurement channels. These measurement channels are distinguished by different spectral sensitivities, and the sensitivity curves as a function of the wavelength should be suitably chosen in this case. The wavelength of the respectively incident light is uniquely establishable by calculation, at least by forming a quotient, from the individual measurement values of the different channels. The
15 suitable spectral sensitivity curves can be formed by various spectral filters and/or different infrared detectors. In this respect, reference is made to DE 197 44 565 A1. Different measurement values are obtained in the measurement channels, and the wavelength can be deduced therefrom. This effect is used in similar fashion in the present invention.

20

The at least two different spectral filters can be interchangeable, in particular pivotable or displaceable, and/or arranged in a filter changer with at least two positions, in particular a filter wheel. By way of example, the spectral filters can be configured as multi-layer dielectric interference filters. Further, beam splitter
25 elements, too, e.g., in the form of reflective filters, or the like can be considered as spectral filters.

The at least one infrared detector device can be an InGaAs (indium-gallium-arsenide) detector or an MCT (mercury-cadmium-telluride) detector.

30

Two-dimensional InGaAs detectors for detection in the shortwave infrared region from 900 nm to 1700 nm can be used. Such infrared detector devices have a plurality

of sensor elements arranged next to one another in lines and columns for capturing individual picture element (pixels) (e.g., with a resolution of 640 x 512 pixels).

The control and processing device can be configured to produce a multispectral picture of the recorded scene by superposing or combining or adding the picture signals of the recorded scene in the different shortwave infrared spectral regions. The picture signals of the recorded scene can be stored in a picture memory and can be displayed or output as a summed picture or the like. By way of example, the measurement values in the various management channels, i.e., the spectral information items of the at least two different upstream spectral filters, are added for each picture element or pixel. The control and processing device or the picture processing unit can be configured to combine the picture contents in the different shortwave infrared spectral regions with one another by calculation. If use is made of a plurality of infrared detector devices and sensors, the picture processing unit can be configured to combine the separate picture contents of at least two of the detectors with one another by calculation in real time. To this end, the picture data are electronically superposed and positioned in real time.

It is likewise advantageous if the picture signals of an infrared spectral region that comprises a water absorption band, in particular a dominant water absorption band, is not taken into account when superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions. This can improve the overall resolution of the image if the scattered light resulting from the water absorption band (e.g., at 1440 nm) is not used in the superposition.

The control and processing device can be configured to produce an RGB colour picture of the recorded scene by superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions, wherein one RGB colour channel is assigned in each case to a different shortwave infrared spectral region.

A so-called false colour picture can be produced by these measures, wherein, for

example, a visually red colour is assigned to the region of 900 nm to 1100 nm, a visually green colour is assigned to the region of 1100 nm to 1300 nm, and a visually blue colour is assigned to the region from 1500 nm to 1700 nm.

- 5 The control and processing device can be configured to determine colour value components for at least two spatial picture elements from the picture signals of the different shortwave infrared spectral regions, and compare these by forming a difference, in particular a difference based on the Euclidean metric. Similarly, a colour metric can be introduced for the shortwave infrared spectral region.

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Further, the control and processing device can be configured, for the purposes of object identification in the recorded picture, to compare colour value components of objects and/or object surfaces, which were determined in advance and preferably stored, with colour value components determined in the recorded picture by forming a difference, in particular a difference based on the Euclidean metric.

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To this end, experimental laboratory measurements can be carried out in advance by virtue of spectral camouflaging structures (camouflage material, etc.) or further natural substances (foliage, earth, etc.) being measured. The spectral properties of many surfaces are known and can be determined. As a result, it is possible to uncover synthetic surfaces (uniforms, vehicles), for example. It is also possible to detect changes in the earth, for example, for detecting buried mines. Moreover, it is possible to find natural resources on account of the different surface reflections. The spectral properties or colour value components of the objects can be supplied to a colour metric and they may possibly be recognized again in a recorded image if they lie within tolerance regions of the brightness values of the individual shortwave infrared spectral regions.

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It is very advantageous if there is a beam deflection by approximately $\pm 1/2$ pixel in the horizontal or vertical direction of the electromagnetic radiation incident on the camera system whenever there is a change of the at least two different spectral filters. As a result of this measure, the resolution of the camera system can be

increased further in the style of micro-scanning. To this end, the filter changer can be provided with appropriate means, for example with angled faces. However, prisms or the like may also be used. In the case of four different spectral filters, the sequence of the beam deflection can be carried out, for instance, as follows: 1st filter change
5 +½ pixel horizontal direction; 2nd filter change +½ pixel vertical direction; 3rd filter change -½ pixel horizontal direction; 4th filter change -½ pixel vertical direction.

Advantageous configurations and developments of the invention emerge from the dependent claims.

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Exemplary embodiments of the invention, outlined in principle, are specified below on the basis of the drawing. Here, functionally equivalent elements are provided with the same reference signs.

15 In detail:

Figure 1 shows a much-simplified schematic illustration of a camera system according to the invention;

20 Figure 2 shows a schematic diagram with four different transmission curves in the shortwave infrared spectral regions;

Figure 3 shows representations of greyscale value pictures, which are obtained with four different upstream spectral filters;

25

Figure 4 shows a first chromaticity diagram of spectral colours in the shortwave infrared region;

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Figure 5 shows a second chromaticity diagram of spectral colours in the shortwave infrared region;

Figure 6 shows a representation of colour value components for the same hue

(1150 nm) and different colour saturations in the shortwave infrared region;

5 Figure 7 shows a representation of a change of colour value components of the pure spectral colours depending on the wavelength;

Figure 8 shows a schematic representation of the essential components of a colorimeter for the shortwave infrared region; and

10 Figure 9 shows a schematic representation of an imaging process using a camera system according to the invention.

Figure 1 illustrates a camera system 1 according to the invention, comprising:

- 15 - at least one infrared detector device 2 that is sensitive to electromagnetic radiation in the shortwave infrared range from approximately 900 nm to approximately 1700 nm and that has a plurality of sensor elements, not illustrated in detail in Figure 1, arranged next to one another in rows and columns for capturing individual spatial picture elements;
- 20 - at least one optical unit 3 that images electromagnetic radiation (indicated by a dashed line L) incident on the camera system 1 onto the at least one infrared detector device 2;
- at least two different spectral filters 4x, 4y, 4z, 4w, indicated using dashed lines, that are disposed or disposable upstream of the at least one infrared detector device 2 and that are each light-transmissive in different shortwave infrared spectral regions;
- 25 - a control and processing device 5 that is configured to capture a picture of at least approximately the same scene using the at least one infrared detector device 2 with the at least two different spectral filters 4x, 4y, 4z, 4w disposed upstream thereof, in such a way that picture signals of the recorded scene are produced in the different shortwave infrared spectral regions of the at least two different spectral filters 4x, 4y,
- 30 4z, 4w, wherein each spatial picture element captured by the at least one infrared detector device 2 is provided with spectral information items corresponding to the at least two different upstream spectral filters 4x, 4y, 4z, 4w.

As is clear from Figure 2, four different spectral filters 4x, 4y, 4z, 4w with associated spectral transmission curves $T_x(\lambda)$, $T_y(\lambda)$, $T_z(\lambda)$ and $T_w(\lambda)$ can be present.

5 The four different spectral filters 4x, 4y, 4z, 4w comprise:

- at least one first spectral filter 4x that is light-transmissive in a first shortwave infrared spectral region from approximately 900 nm to approximately 1300 nm and preferably is maximally light-transmissive at approximately 1000 nm;
- at least one second spectral filter 4y that is light-transmissive in a second shortwave infrared spectral region from approximately 1000 nm to approximately 1400 nm and preferably is maximally light-transmissive at approximately 1200 nm;
- at least one third spectral filter 4z that is light-transmissive in a third shortwave infrared spectral region from approximately 1200 nm to approximately 1600 nm and preferably is maximally light-transmissive at approximately 1400 nm; and/or
- 15 - at least one fourth spectral filter 4w that is light-transmissive in a fourth shortwave infrared spectral region from approximately 1300 nm to approximately 1700 nm and preferably is maximally light-transmissive at approximately 1600 nm.

Moreover, the spectral transmission or absorption of the atmosphere is illustrated in Figure 2 using a solid line. In Figure 2, the wavelength λ is plotted along the horizontal axis and the light-transmissivity or transmittance is plotted on the vertical axis. It is further clear from Figure 2 that a water absorption band 6, in particular a dominant water absorption band, covers at least one of the different shortwave infrared spectral regions, specifically the third shortwave infrared spectral region from approximately 1200 nm to approximately 1600 nm. The different shortwave infrared spectral regions of the at least two different spectral filters 4x, 4y, 4z, 4w partly overlap, in particular by several nanometres, preferably by at least 50%, if they are spectrally adjacent. The spectral filters 4x, 4y, 4w are preferably also selected in such a way that the maximum light-transmissivities thereof lie in the regions of maximum illuminance.

30

The at least two different spectral filters 4x, 4y, 4z, 4w can be interchangeable, in particular pivotable or displaceable, and/or arranged in a filter changer with at least

two positions, in particular a filter wheel 7 (see also Figures 7 and 8). By way of example, if 25 multispectral pictures are produced per second for the representation, 100 spectral pictures have to be recorded per second in the case of four different spectral filters 4x, 4y, 4z, 4w; i.e., 100 filter changes per second are necessary.

5

The at least one infrared detector device 2 can be an InGaAs detector, in particular a two-dimensional InGaAs detector, or an MCT detector.

Figure 3 indicates pictures 8x, 8y, 8z and 8w that were recorded with the spectral filters 4x, 4y, 4z, 4w. It is very clear that the image 8z provides substantially worse image information items as a result of the reduction in the illuminance caused by the dominant water absorption band 6.

The control and processing device 5 can be configured to produce a multispectral picture of the recorded scene by superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions.

The picture signals of an infrared spectral region or spectral filter 4z that comprises a water absorption band 6, in particular a dominant water absorption band, is not taken into account when superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions.

The control and processing device 5 can be configured to produce an RGB colour picture of the recorded scene by superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions, wherein one RGB colour channel is assigned in each case to a different shortwave infrared spectral region. As a result, a so-called false colour picture can be produced.

The control and processing device 5 can be configured to determine colour value components for at least two spatial picture elements from the picture signals of the different shortwave infrared spectral regions, and compare these by forming a difference, in particular a difference based on the Euclidean metric.

Further, the control and processing device 5 can be configured, for the purposes of object identification in the recorded picture, to compare colour value components of objects and/or object surfaces, which were determined in advance and preferably stored, with colour value components determined in the recorded picture by forming a difference, in particular a difference based on the Euclidean metric.

There can be a beam deflection by approximately +/- half a pixel in the horizontal or vertical direction of the electromagnetic radiation (L) incident on the camera system 1 whenever there is a change of the at least two different spectral filters 4x, 4y, 4z, 4w.

The employed shortwave infrared spectral region (SWIR region) between 900 nm and 1700 nm is a wavelength range that is spectrally broader than that of visible light. SWIR cameras known from the prior art produce a greyscale value image using the intensity over the entire spectral band. However, objects may have a completely different spectral behaviour in this region. Plants have a high reflectivity at the lower end of the SWIR region and liquid water has a strong absorption band around 1440 nm, for example.

According to the invention, dividing the SWIR region into a suitable number of spectral measurement channels is proposed in order to extract more detailed information items from a recorded picture. In order to obtain these information items, the proposition follows a concept that is similar to that of the colour vision of the human eye. In a manner analogous to the three types of colour receptors of the eye, four spectral measurement channels are defined for the shortwave infrared. Consequently, each picture element is characterized by four colour values instead of a single greyscale value.

A specific SWIR colour measurement is possible for a comprehensive characterization of an object by way of choosing suitable filters with suitable bandwidth and spectral overlap. Spectral sensitivity, algorithms for calculating SWIR colour values, a distinction of SWIR colour values by NEWD (noise equivalent

wavelength difference) and a spectrally encoded false colour picture representation are proposed.

Principles of SWIR colour measurement are proposed below; these may also be part
5 of the subject matter of the invention.

The result of a radiometric measurement implemented by means of four spectral measurement channels in the shortwave infrared region can be processed in a manner similar to a colour stimulus by the human eye, with the difference that a 4-
10 tuple of values is now present.

The imaging process in the SWIR region is also very similar to the visible region in that a radiation source is required for the purposes of illuminating the scene. Typically, an artificial source such as an incandescent lamp can be used in the
15 laboratory, while natural daylight (from the sun or the sky) is required outside.

Therefore, the SWIR radiation reflected by an object of interest is not determined exclusively by the spectral reflectance $R(\lambda)$ of the object but also by the spectral distribution $S(\lambda)$ of the light source. The spectral radiant flux coming from the object
20 corresponds to the colour stimulus $\varphi(\lambda) = S(\lambda) \cdot R(\lambda)$ in trichromy.

Moreover, the output of a colorimeter depends not only on the spectral transmission curves $T_x(\lambda)$, $T_y(\lambda)$, $T_z(\lambda)$ and $T_w(\lambda)$ of the spectral filters 4x, 4y, 4z, 4w that were selected to separate the spectral measurement channels, but also on the spectral
25 detectivity $D(\lambda)$ of the implemented detector or of the infrared detector device 2. An InGaAs detector is often used in a SWIR colorimeter.

Therefore, a colorimetric measurement leads to the following 4-tuple of colour values, which take account of all the aforementioned effects:

30

$$X = k_x \cdot \int_{900}^{1700} \varphi(\lambda) \cdot D(\lambda) \cdot T_x(\lambda) d\lambda;$$

$$\begin{aligned}
 Y &= k_y \cdot \int_{900}^{1700} \varphi(\lambda) \cdot D(\lambda) \cdot T_y(\lambda) d\lambda; \\
 Z &= k_z \cdot \int_{900}^{1700} \varphi(\lambda) \cdot D(\lambda) \cdot T_z(\lambda) d\lambda; \\
 W &= k_w \cdot \int_{900}^{1700} \varphi(\lambda) \cdot D(\lambda) \cdot T_w(\lambda) d\lambda.
 \end{aligned}
 \tag{1}$$

- 5 The integration is implemented over the entire shortwave infrared region. The instrument constants k_i are freely selectable, but may be calculated in such a way that all four colour values are the same for a perfect matte white target. This procedure ensures that the chromaticity coordinates for the colour value components for the colour "white" all equal 0.25.

10

The colour value components are defined below in relation to the colour values according to ratios such that $x + y + z + w = 1$ applies:

$$\begin{aligned}
 x &= X / (W+X+Y+Z); \\
 y &= Y / (W+X+Y+Z); \\
 z &= Z / (W+X+Y+Z); \\
 w &= W / (W+X+Y+Z).
 \end{aligned}
 \tag{2}$$

- 20 Each of the four colour value components defines the relative component of the four above-defined spectral measurement channels that are required in order to correspond with the SWIR colour of a sample 12 (see Figure 8). Since the sum of the four colour value components equals 1, it is only necessary to specify three thereof, x , y and z ; the fourth can then be calculated by subtracting x , y and z from 1.

- 25 As is clear from Figure 4, the SWIR colour of the sample 12 can be specified by a point in a three-dimensional chromaticity diagram, which differs significantly from the two-dimensional CIE chromaticity diagram from trichromy. The SWIR primary colours are denoted by the points (0, 0, 0), (1, 0, 0), (0, 1, 0) and (0, 0, 1). Consequently, the maximum space is delimited by a corner cube. The location of all spectral colours of

the shortwave infrared spectral region (specified in nanometres nm) is plotted in the three-dimensional chromaticity diagram according to Figure 4.

The surface of the SWIR colour diagram or of the chromaticity diagram is defined by the totality of all rays that extend from a white point P (0.25, 0.25, 0.25) to the spectral colour line along the edge. In Figures 4 and 5, the white point P is indicated by a hatched square. Each point in the chromaticity diagram specifies the SWIR chromaticity (hue and saturation), independently of the luminance. This is advantageous in field applications, in which the colour distinction is important and the illuminance is usually not monitored.

A pure spectral colour has maximum possible saturation. The more white radiation is mixed in, the more the saturation reduces and the chromaticity coordinates change in such a way that the point is displaced along a straight line or linearly to the white point P in the chromaticity diagram (see Figure 6). In Figure 5, a full line 9 is plotted for the spectral colour or wavelength of 1150 nm in exemplary fashion. It extends from the point of the spectral colour 1150 nm at the coordinates (0.23, 0.74, 0.01) directly to the white point P (0.25, 0.25, 0.25).

The difference between two colours A and B can be calculated by means of the Euclidean metric, which is applied to the corresponding points in the diagram:

$$\Delta C_{\text{SWIR}} = \{(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2\}^{1/2} \quad (3)$$

Whether two colours A and B can be considered to be different depends on an error range of the colorimeter to be established. Different thresholds are specified in relation to hue and saturation; these also vary with location on the chromaticity diagram. A first estimate for the capability of distinguishing between spectral colours can be derived by calculating the variation of the chromaticity coordinates per unit wavelength $\Delta C_{\text{SWIR}}(\lambda) / \Delta \lambda$ along a chromaticity curve 10 (see Figure 7).

At the tips of the chromaticity curve 10, a small change in wavelength causes a relatively large change in the chromaticity coordinates, and therefore this is detected

more easily than the same wavelength change in one of the troughs of the chromaticity curve 10. In military applications, this has a certain significance for the detection and spectral identification of laser radiation (e.g., a laser target mark).

- 5 Colorimetric measurements using a 4-channel SWIR radiometer are described below.

In the case of a filter colorimeter, a light source 11 alternately illuminates a sample 12 and a white standard or standard target 13 (see Figure 8). The reflected light is spectrally selected by a set of bandpass filters in a filter wheel 7, and then measured by a detector.

In the proposed SWIR colorimetry, the reflected radiation is measured by four spectral filters 4x, 4y, 4z, 4w instead of three filters like the tristimulus colour measurements. Four measurement values (Mx_0 , My_0 , Mz_0 and Mw_0) are produced as output signal for the standard target 13, said measurement signals containing all spectral information items about the light source 11, the spectral filters 4x, 4y, 4z, 4w and the infrared detector device 2 and serving to calibrate the appliance. The second 4-tuple of the values (Mx , My , Mz and Mw) additionally contains the spectral reflectivity of the sample 12. Consequently, the following applies:

$$\begin{aligned}
 Mx_0 &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_x(\lambda) \cdot D(\lambda) d\lambda; & Mx &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_x(\lambda) \cdot D(\lambda) \cdot R(\lambda) d\lambda; \\
 My_0 &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_y(\lambda) \cdot D(\lambda) d\lambda; & My &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_y(\lambda) \cdot D(\lambda) \cdot R(\lambda) d\lambda; \\
 Mz_0 &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_z(\lambda) \cdot D(\lambda) d\lambda; & Mz &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_z(\lambda) \cdot D(\lambda) \cdot R(\lambda) d\lambda; \\
 Mw_0 &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_w(\lambda) \cdot D(\lambda) d\lambda; & Mw &= k \cdot \int_{900}^{1700} S(\lambda) \cdot T_w(\lambda) \cdot D(\lambda) \cdot R(\lambda) d\lambda.
 \end{aligned} \quad (4)$$

Therefore, the colour values of the sample 12 are accordingly derived by the ratios of the values of sample 12 and standard target 13:

$$X = M_x / M_{x0}; Y = M_y / M_{y0}; Z = M_z / M_{z0}; W = M_w / M_{w0}. \quad (5)$$

The colour value components of the sample 12 emerge from the equation $x + y + z + w = 1$.

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$$\begin{aligned} x &= X / (X+Y+Z+W); \\ y &= Y / (X+Y+Z+W); \\ z &= Z / (X+Y+Z+W); \\ w &= W / (X+Y+Z+W). \end{aligned} \quad (6)$$

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The result can be plotted on a SWIR colour scale and can be compared to the colours of other samples or references.

The camera system 1 according to the invention, which is equipped with four different spectral filters 4x, 4y, 4z, 4w that are arranged in a filter wheel 7, in particular, can be used to carry out quantitative colorimetric measurements of objects 14 in the scenery (see Figure 9). Here, solar or sky radiation serves as a light source 11. The output signal of the camera system 1 comprises a 4-tuple of values M_x , M_y , M_z and M_w or of values $M_x(pxI)$, $M_y(pxI)$, $M_z(pxI)$ and $M_w(pxI)$ for each sensor element or detector element pxI (not illustrated in any more detail at the figures), which is measured by means of the spectral filters 4x, 4y, 4z, 4w. Using Equations (5) and (6), the chromaticity coordinates are evaluated in the same way as in the case of SWIR colorimetry, with the difference that data of a factory calibration have to be used as a reference in place of internal reference values.

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The calibration process can be carried out using a suitable radiation source and frosted glass as a diffuser. For a camera system 1 to be applied in the field (e.g., for monitoring or reconnaissance), the use of a radiation source emitting a spectral radiant flux near the standard light type D65 appears advantageous since this simulates the typical radiation of northern sky regions. However, the sky radiation in the SWIR spectral region deviates significantly from the specified D65 black body of 6504 K on account of three strong water vapour absorption bands, the strongest of

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which lies in the wavelength band from approximately 1350 nm to almost 1500 nm. However, this can be simulated by suitable filters.

- Consequently, chromaticity coordinates can be assigned to each picture element or pixel of the scene and the SWIR colour of different objects 14 can be compared quantitatively to decide whether or not two objects are the same. By way of example, it is possible to distinguish between camouflage colours and natural green, or even between camouflage colours with different origins. However, since it is only carried out in one picture, all picture elements clearly have identical light conditions.
- 10 Variations of the sky radiation have a very small effect.

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List of reference signs:

	1	Camera system
	2	Infrared detector device
5	3	Optical unit
	4x, 4y, 4z, 4w	Spectral filter
	5	Control and processing device
	6	Water absorption band
	7	Filter wheel
10	8x, 8y, 8z, 8w	Pictures
	9	Full line
	10	Chromaticity curve
	11	Light source
	12	Sample
15	13	Standard target
	14	Object
	$T_x(\lambda), T_y(\lambda), T_z(\lambda), T_w(\lambda)$	Spectral transmission curves
	$S(\lambda)$	Spectral distribution
	$R(\lambda)$	Spectral reflectance
20	P	White point
	L	Incident electromagnetic radiation

Patent claims:

1. Camera system (1), comprising:

- at least one infrared detector device (2) that is sensitive to electromagnetic radiation
5 in the shortwave infrared range from approximately 900 nm to approximately 1700 nm and that has a plurality of sensor elements arranged next to one another in rows and columns for capturing individual spatial picture elements;
- at least one optical unit (3) that images electromagnetic radiation (L) incident on the camera system (1) onto the at least one infrared detector device (2);
- 10 - at least two different spectral filters (4x, 4y, 4z, 4w) that are disposed or disposable upstream of the at least one infrared detector device (2) and that are each light-transmissive in different shortwave infrared spectral regions;
- a control and processing device (5) that is configured to capture a picture of at least approximately the same scene using the at least one infrared detector device (2) with
15 the at least two different spectral filters (4x, 4y, 4z, 4w) disposed upstream thereof, in such a way that picture signals of the recorded scene are produced in the different shortwave infrared spectral regions of the at least two different spectral filters (4x, 4y, 4z, 4w), wherein each spatial picture element captured by the at least one infrared detector device (2) is provided with spectral information items corresponding to the at
20 least two different upstream spectral filters (4x, 4y, 4z, 4w).

2. Camera system (1) according to Claim 1, wherein the at least two different spectral filters (4x, 4y, 4z, 4w) comprise:

- at least one first spectral filter (4x) that is light-transmissive in a first shortwave
25 infrared spectral region from approximately 900 nm to approximately 1300 nm and preferably is maximally light-transmissive at approximately 1000 nm;
- at least one second spectral filter (4y) that is light-transmissive in a second shortwave infrared spectral region from approximately 1000 nm to approximately 1400 nm and preferably is maximally light-transmissive at approximately 1200 nm;
- 30 - at least one third spectral filter (4z) that is light-transmissive in a third shortwave infrared spectral region from approximately 1200 nm to approximately 1600 nm and preferably is maximally light-transmissive at approximately 1400 nm; and/or

- at least one fourth spectral filter (4w) that is light-transmissive in a fourth shortwave infrared spectral region from approximately 1300 nm to approximately 1700 nm and preferably is maximally light-transmissive at approximately 1600 nm.

5 3. Camera system (1) according to Claim 1 or 2, wherein four different spectral filters (4x, 4y, 4z, 4w) are present.

4. Camera system (1) according to Claim 1, 2 or 3, wherein at least one of the different shortwave infrared spectral regions comprises a water absorption band (6),
10 in particular a dominant water absorption band.

5. Camera system (1) according to any one of Claims 1 to 4, wherein the different shortwave infrared spectral regions of the at least two different spectral filters (4x, 4y, 4z, 4w) partly overlap, in particular by several nanometres, preferably by at least
15 50%, if they are spectrally adjacent.

6. Camera system (1) according to any one of Claims 1 to 5, wherein the at least two different spectral filters (4x, 4y, 4z, 4w) are interchangeable, in particular pivotable or displaceable, and/or arranged in a filter changer with at least two positions, in
20 particular a filter wheel (7).

7. Camera system (1) according to any one of Claims 1 to 6, wherein the at least one infrared detector device (2) is an InGaAs detector or an MCT detector.

25 8. Camera system (1) according to any one of Claims 1 to 7, wherein the control and processing device (5) is configured to produce a multispectral picture of the recorded scene by superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions.

30 9. Camera system (1) according to Claim 8, wherein the picture signals of an infrared spectral region that comprises a water absorption band (6), in particular a dominant water absorption band, is not taken into account when superposing or combining the

picture signals of the recorded scene in the different shortwave infrared spectral regions.

10. Camera system (1) according to any one of Claims 1 to 9, wherein the control
5 and processing device (5) is configured to produce an RGB colour picture of the recorded scene by superposing or combining the picture signals of the recorded scene in the different shortwave infrared spectral regions, wherein one RGB colour channel is assigned in each case to a different shortwave infrared spectral region.

10 11. Camera system (1) according to any one of Claims 1 to 10, wherein the control and processing device (5) is configured to determine colour value components for at least two spatial picture elements from the picture signals of the different shortwave infrared spectral regions, and compare these by forming a difference, in particular a difference based on the Euclidean metric.

15 12. Camera system (1) according to Claim 11, wherein the control and processing device (5) is configured, for the purposes of object identification in the recorded picture, to compare colour value components of objects and/or object surfaces, which were determined in advance and preferably stored, with colour value components
20 determined in the recorded picture by forming a difference, in particular a difference based on the Euclidean metric.

13. Camera system (1) according to any one of Claims 6 to 12, wherein there is a beam deflection by approximately $\pm \frac{1}{2}$ pixel in the horizontal or vertical direction of
25 the electromagnetic radiation (L) incident on the camera system (1) whenever there is a change of the at least two different spectral filters (4x, 4y, 4z, 4w).



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Claims searched: 1-13

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Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-7, 11 & 12	US 2012/0154792 A1 (TREADO ET AL) - See in particular figure 2A and paragraphs [0031] to [0038]
X	1 & 8-10	WO 2018/119209 A1 (UNIV MICHIGAN REGENTS) - See in particular paragraphs [0052], [0075] and [0089]
X	1-5 & 7	US 2016/0077253 A1 (YETZBACHER ET AL) - See in particular figure 1 and paragraphs [0037], [0039] and [0048]
X	1, 3, 6 & 13	CN 105357487 A (MIANYANG SHAOJUN INFORMATION TECHNOLOGY CO LTD) - See in particular figure 2 and associated description
X	1, 4 & 7	EP 2557414 A2 (FIAT RICERCHE) - See in particular figure 1 and paragraphs [0007], [0012] and [0013]
X	1 & 6-8	US 2012/0062740 A1 (TREADO ET AL) - See in particular figure 1B and paragraphs [0031] to [0033], [0042], [0043] & [0064]
X	1 & 6	US 2014/0110585 A1 (JUSTICE JAMES) - See in particular figure 1 and paragraphs [0029] to [0030], [0039]

Categories:

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^N :

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G01J; G01N; G06T; H04N

The following online and other databases have been used in the preparation of this search report



WPI, EPODOC, Patent Fulltext

International Classification:

Subclass	Subgroup	Valid From
H04N	0005/33	01/01/2006
G01N	0021/35	01/01/2014
H04N	0005/335	01/01/2011