

(43) International Publication Date
12 October 2017 (12.10.2017)

(51) International Patent Classification:

G02B 13/06 (2006.01) G03B 37/06 (2006.01)
G02B 13/08 (2006.01) H04N 5/232 (2006.01)
G02B 3/06 (2006.01)

(21) International Application Number:

PCT/FI2017/050203

(22) International Filing Date:

23 March 2017 (23.03.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

20165296 6 April 2016 (06.04.2016) FI

(71) Applicant: TEKNOLOGIAN TUTKIMUSKESKUS
VTT OY [FI/FI]; Vuorimiehentie 3, 02150 Espoo (FI).(72) Inventor: AIKIO, Mika; c/o VTT, P.O.Box 1000, 02044
VTT (FI).(74) Agent: BERGGREN OY; Visiokatu 1, 33720 Tampere
(FI).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: WIDE ANGLE LENS FOR CAPTURING A PANORAMA IMAGE

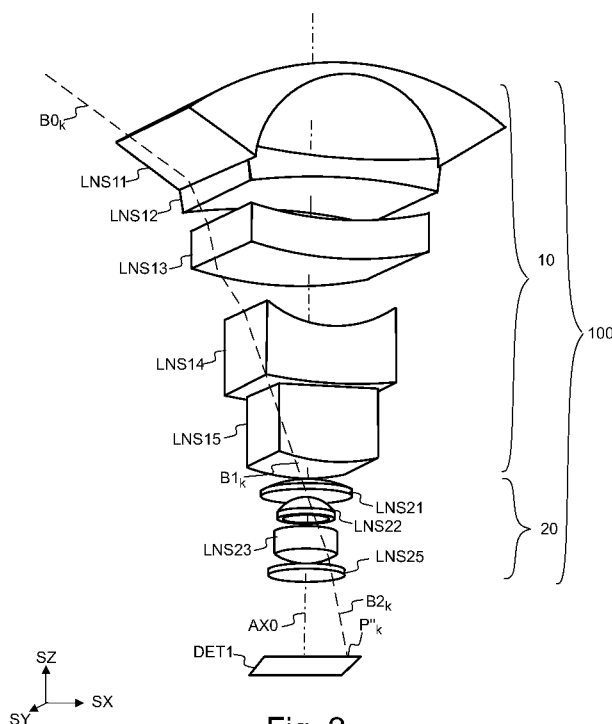


Fig. 2

(57) Abstract: An imaging device (100,500) comprises: - an anamorphic unit (10) to form a virtual image (VMG1) of a cylindrical viewing region (SRF1), and - a focusing unit (20) to form a real image (IMG1) of the auxiliary virtual image (VMG1), wherein the anamorphic unit (10) comprises two or more refractive lenses (LNS11, LNS12) which have been selected such that the horizontal refractive power ($P_{x,c}$) of the imaging device (100) is greater than 1.5 times the vertical refractive power ($P_{y,c}$) of the imaging device (100), and the anamorphic unit (10) is arranged to form the virtual image (VMG1) by refracting light ($B0_k$) received from the cylindrical viewing region (SRF1) such that the aspect ratio ($\Delta\phi/\Delta\Phi$) of the virtual image (VMG1) is lower than the aspect ratio ($\Delta\phi'/\Delta\Phi'$) of the viewing region (SRF1).

**Declarations under Rule 4.17:**

- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

— of inventorship (Rule 4.17(iv))

Published:

— with international search report (Art. 21(3))

WIDE ANGLE LENS FOR CAPTURING A PANORAMA IMAGE

FIELD

5

The present invention relates to an imaging device suitable for capturing a panorama image.

10 BACKGROUND

It is known that a panorama image may be captured by using a fish eye lens and an image sensor. The aspect ratio of the image sensor may be e.g. equal to 4:3, whereas the aspect ratio of the panorama image may be e.g. greater than 3:1. The panorama image may cover e.g. less than 40 % of the active area of the image sensor when capturing the panorama image with the fish eye lens and with the image sensor.

Referring to the comparative example shown in Fig. 8, a wide angle lens of Prior Art may provide a circular optical image, and a rectangular portion of an image sensor may be arranged to capture a rectangular portion of said circular image. The circular optical image may correspond e.g. to a field of view of 170°. The rectangular portion of the circular image may correspond e.g. to a horizontal field of view having an angular width of 165°, and to a vertical field of view having an angular height of 40°. The ratio of the height H_R of the rectangular portion to the height H_S of the active area of the image sensor may be e.g. less than 0.40.

30 SUMMARY

Some variations may relate to a wide angle lens. Some variations may relate to an imaging device, which comprises a wide angle lens. Some variations may relate to a method for imaging.

35

According to an aspect, there is provided an imaging device (100,500), comprising:

- an anamorphic unit (10) to form a virtual image (VMG1) of a cylindrical viewing region (SRF1), and
- 5 - a focusing unit (20) to form a real image (IMG1) of the auxiliary virtual image (VMG1),

wherein the anamorphic unit (10) comprises two or more refractive lenses (LNS11, LNS12) which have been selected such that the horizontal refractive power ($P_{x,C}$) of the imaging device (100) is greater than 1.5 times the vertical refractive power ($P_{y,C}$) of the imaging device (100), and the anamorphic unit (10) is arranged to form the virtual image (VMG1) by refracting light ($B0_k$) received from the cylindrical viewing region (SRF1) such that the aspect ratio ($\Delta\phi'/\Delta\theta'$) of the virtual image (VMG1) is lower than the aspect ratio ($\Delta\phi/\Delta\theta$) of the viewing region (SRF1).

15

According to an aspect, there is provided a method for forming a real image (IMG1) of a viewing region (SRF1), the method comprising:

- forming a virtual image (VMG1) of the viewing region (SRF1) by using an anamorphic unit (10), and
- 20 - forming a real image (IMG1) of the auxiliary virtual image (VMG1) by using a focusing unit (20),

wherein the anamorphic unit (10) comprises two or more refractive lenses (LNS11, LNS12) which have been selected such that the horizontal refractive power ($P_{x,C}$) of the imaging device (100) is greater than 1.5. times the vertical refractive power ($P_{y,C}$) of the imaging device (100), and the anamorphic unit (10) is arranged to form the virtual image (VMG1) by refracting light ($B0_k$) received from the cylindrical viewing region (SRF1) such that the aspect ratio ($\Delta\phi'/\Delta\theta'$) of the virtual image (VMG1) is lower than the aspect ratio ($\Delta\phi/\Delta\theta$) of the viewing region (SRF1).

30

Further aspects are defined in the claims.

An imaging apparatus may comprise the imaging device and an image sensor. The imaging apparatus may be arranged to capture a panorama image of the viewing region by forming an optical image on the image sensor

35

such that the optical image may cover e.g. more than 95% of the active area of the image sensor, wherein the aspect ratio of the viewing region may be e.g. at least 50% higher than the aspect ratio of the image sensor. Thus, the pixels of the image sensor may be used in a more effective manner, so as to improve the spatial resolution of the captured image. In particular, the optical image may cover an increased number of detector pixels of the image sensor in the vertical direction.

The imaging device may provide a high anamorphic compression ratio. By using the imaging device, the fill factor of the image sensor may be high. The optical image may cover e.g. more than 95% of the active area of the image sensor when capturing a panorama image, wherein the aspect ratio of the panorama image may be e.g. in the range of 3:1 to 7:1, and the aspect ratio of the image sensor may be e.g. in the range of 1:1 to 2:1. By using the imaging device, the distortion aberration of the optical image in the vertical direction may be low, when compared with the object surface.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following examples, several variations will be described in more detail with reference to the appended drawings, in which

Fig. 1a shows, by way of example, in a cross-sectional top view, an imaging device, which comprises an anamorphic unit,

Fig. 1b shows, by way of example, in a cross-sectional top view, propagation of a light ray through the elements of the imaging device,

Fig. 1c shows, by way of example, in a cross-sectional side view, propagation of a light ray through the elements of the imaging device,

- Fig. 2 shows, by way of example, in a three-dimensional view, the imaging device,
- 5 Fig. 3a shows, by way of example, in a three-dimensional view, capturing an image of a viewing region by using the imaging device,
- 10 Fig. 3b shows, by way of example, in a three-dimensional view, capturing an image of a cylindrical object surface by using the imaging device,
- Fig. 4 shows, by way of example, forming an optical image of the object surface,
- 15 Fig. 5a shows, by way of example, mapping functions for conversion of a vertical input angle into a vertical image coordinate,
- Fig. 5b shows, by way of example, curves which indicate the geometric distortion at different positions of the optical image,
- 20 Fig. 5c shows, by way of example, image points located on a horizontal line, on a vertical line, and on a diagonal line,
- Fig. 6 shows, by way of example, forming a panorama image from a digital image,
- 25 Fig. 7 shows, by way of example, an imaging apparatus, which comprises the imaging device, and
- 30 Fig. 8 shows a comparative example where an image sensor overlaps a circular image formed by a fish eye objective.

DETAILED DESCRIPTION

Referring to Fig. 1a, the imaging device 100 may comprise an anamorphic unit 10 and a focusing unit 20. The anamorphic unit 10 may receive input light B0 from a viewing region VREG1. The input light B0 may comprise a plurality of input beams B0₀, B0₁, B0_k. The anamorphic unit 10 may receive
5 input light beams B0₀, B0₁, B0_k. e.g. from one or more objects O1, O2, O3 (Fig. 3a). The anamorphic unit 10 may provide an auxiliary virtual image VMG1 (Fig. 4) by providing intermediate light beams B1₀, B1₁, B1_k. The anamorphic unit 10 may provide the intermediate light beams B1₀, B1₁, B1_k by refracting light of the input beams B0₁, B0_k. The anamorphic unit 10 may
10 provide deflected intermediate beams B1₁, B1_k by refracting light of the input beams B0₁, B0_k, and the anamorphic unit 10 may provide an axial intermediate beam B0₁, by refracting light of an axial input beam B0₀. The anamorphic unit 10 may cause mainly a horizontal change in the direction of the deflected beams B1₁, B1_k. The direction of a light beam may be defined
15 by an azimuth angle and by an elevation angle. The anamorphic unit 10 may refract light such that the azimuth angle of the deflected beams B1₁, B1_k is substantially smaller than the azimuth angle of the input beams B0₁, B0_k. The azimuth angle of a light beam means the angle between the direction of the light beam and the vertical plane defined by the optical axis AX0 of the
20 imaging device 100. The elevation angle of the light beam means the angle between the direction of the light beam and the horizontal plane defined by the optical axis AX0.

The imaging device 100 may be arranged to form an optical image IMG1 on
25 an image sensor DET1. An imaging apparatus 500 may comprise the imaging device 100 and the image sensor DET1. The imaging device 100 may form an image IMG1 of a viewing region VREG1 on the image sensor DET1. The viewing region VREG1 may comprise an object O1. The viewing region VREG1 may be represented by a cylindrical object surface SRF1 (Fig.
30 3b). A part of the object surface SRF1 may represent the object O1.

The anamorphic unit 10 may provide an auxiliary image VMG1, which is shrunk in one dimension (1D) when compared with the original scene SRF1. The anamorphic unit 10 may provide anisotropic image compression. The
35 anamorphic unit 10 may provide an intermediate light beam B1 as the optical

output of the anamorphic unit 10. The anamorphic unit 10 may provide intermediate light B1, which comprises the intermediate beams B1₀, B1₁, B1_k. The intermediate light beams B1₀, B1₁, B1_k may together represent an auxiliary image VMG1.

5

For example, an observer could view the auxiliary image VMG1 in a situation where the anamorphic unit 10 would operate without the focusing unit 20 so that the intermediate light beam may impinge on the eye of the observer.

10 Light refracted by the anamorphic unit 10 may be coupled to the focusing unit 20. The optical output of the anamorphic unit 10 may be coupled into the focusing unit 20. The focusing unit 20 may receive an intermediate light beam B1 provided by the anamorphic unit 10.

15 The focusing unit 20 may form an image IMG1 of the auxiliary virtual image VMG1 on the image sensor DET1 by focusing light of the intermediate beams B1₀, B1₁, B1_k. The focusing unit 20 may provide isotropic scaling. The focusing unit 20 may provide the image IMG1 by compressing (i.e. scaling) the auxiliary image VMG1 by a scale factor that is the same in the direction
20 SX and in the direction SY. The lenses of the focusing unit 20 may have circular symmetry (i.e. axial symmetry) with respect to the optical axis AX0. The focusing unit 20 may be e.g. a camera objective.

The focusing unit 20 may provide the optical real image IMG1 from the
25 auxiliary virtual image VMG1 by radially compressing (i.e. scaling) the auxiliary image VMG1. The anamorphic unit 10 may comprise two or more refractive optical elements LNS11, LNS12, ... The optical elements LNS11, LNS12 of the anamorphic unit 10 may be selected such that the horizontal refractive power of the imaging device 100 is greater than e.g. 150% of the
30 vertical refractive power of the imaging device 100.

The refractive power P of an optical unit is equal to the inverse of the focal length f of said optical unit, i.e. $P=1/f$.

The anamorphic unit 10 may provide a deflected light beam $B1_k$ by refracting light of an input beam $B0_k$. The anamorphic unit 10 may provide the deflected light beam $B1_k$ such that the azimuth angle of the light beam $B1_k$ is substantially smaller than the azimuth angle of the light beam $B0_k$. The

5 anamorphic unit 10 may provide the deflected light beam $B1_k$ such that the elevation angle of the light beam $B1_k$ is substantially equal to the elevation angle of the light beam $B0_k$. The ratio of the elevation angle of the deflected beam $B1_k$ to the elevation angle of the input beam $B0_k$ may be substantially greater than the ratio of the azimuth angle of the deflected beam $B1_k$ to the

10 azimuth angle of the input beam $B0_k$. The azimuth angle means the angle between the direction of the light beam and the vertical plane. The elevation angle means the angle between the direction and the horizontal plane. The vertical plane is defined by the directions SX and SZ. The horizontal plane is defined by the directions SY and SZ. The direction SZ is shown e.g. in Fig. 2.

15

The anamorphic unit 10 may have a first focal length $f_{x,A}$ for refraction in the horizontal plane defined by the directions SX and SZ. The anamorphic unit 10 may have a second focal length $f_{y,A}$ for refraction in the vertical plane defined by the directions SY and SZ. The anamorphic unit 10 may have a

20 horizontal refractive power $P_{x,A}$, which may be defined by the equation $P_{x,A}=1/f_{x,A}$. The anamorphic unit 10 may have a vertical refractive power $P_{y,A}$, which may be defined by the equation $P_{y,A}=1/f_{y,A}$. For example, the focal length $f_{y,A}$ may be infinite, and the vertical refractive power $P_{y,A}$ may be substantially equal to zero, respectively.

25

The horizontal refractive power $P_{x,A}$ may be substantially equal to the vertical refractive power $P_{y,A}$. In particular, the anamorphic unit 10 may be substantially afocal, wherein the focal length $f_{y,A}$ may be substantially infinite and also the focal length $f_{x,A}$ may be substantially infinite. The use of an

30 afocal anamorphic unit 10 may provide efficient coupling of light into the focusing unit 20 and/or may reduce aberrations e.g. in a situation where the focusing unit 20 is arranged to provide a sharp image of an object located at infinity (i.e. when the focus of the focusing unit 20 is set at infinity).

Alternatively, the horizontal refractive power $P_{x,A}$ may be different from the vertical refractive power $P_{y,A}$. For example, the vertical refractive power $P_{y,A}$ may be substantially equal to zero, wherein the horizontal refractive power $P_{x,A}$ may be different from the vertical refractive power $P_{y,A}$.

5

The focusing unit 20 may have a focal length f_B . The focusing unit may have a focal length $f_{X,B}$ for refraction in the horizontal plane defined by the directions SX and SZ. The focusing unit may have a focal length $f_{Y,B}$ for refraction in the vertical plane defined by the directions SY and SZ. The focal length $f_{X,B}$ of the focusing unit 20 may be equal to the focal length $f_{Y,B}$. The focal lengths $f_{X,B}$ and $f_{Y,B}$ may be equal to the focal length f_B . The focusing unit 10 may have a horizontal refractive power $P_{x,B}$, which may be defined by the equation $P_{x,B}=1/f_{X,B}$. The focusing unit 10 may have a vertical refractive power $P_{y,B}$, which may be defined by the equation $P_{y,B}=1/f_{Y,B}$. The vertical refractive power $P_{y,B}$ of the unit 20 may be equal to the horizontal refractive power $P_{x,B}$ of the unit 20. The horizontal refractive power ($P_{x,B}$) of the focusing unit (20) may be equal to the vertical refractive power ($P_{y,B}$) of the focusing unit (20) in a situation where the focusing unit (20) is operated without the anamorphic unit (10).

20

The imaging device 100 may have a first focal length $f_{X,C}$ for refraction in the horizontal plane, and a second focal length $f_{Y,C}$ for refraction in the vertical plane. The imaging unit 100 may have a horizontal refractive power $P_{x,C}$, which may be defined by the equation $P_{x,C}=1/f_{X,C}$, and a vertical refractive power $P_{y,C}$ which may be defined by the equation $P_{y,C}=1/f_{Y,C}$. The focal length $f_{X,C}$ may be different from the focal length $f_{Y,C}$, and the horizontal refractive power $P_{x,C}$ may be different from the vertical refractive power $P_{y,C}$.

Figs. 1b and 1c show, by way of example, propagation of a light ray RAY1 through the optical elements of the device 100. The marginal light ray RAY1 impinging on an optical element may intersect the input surface of said optical element at an intersection point IC. For example, the marginal ray RAY1 may intersect the first six elements LNS11, LNS12, LNS13, LNS14, LNS15, LNS21 at intersections points IC₁, IC₂, IC₃, IC₄, IC₅, IC₆. $h_{x,q}$ may denote the horizontal distance (in the direction SX) between the optical axis

35

AX0 and the intersection point on the input surface of a q^{th} element. $h_{y,q}$ may denote the vertical distance (in the direction SY) between the optical axis AX0 and the intersection point on the input surface of the q^{th} element. $h_{x,1}$, $h_{x,2}$, $h_{x,3}$, $h_{x,4}$, $h_{x,5}$, $h_{x,6}$ may denote the horizontal distances $h_{x,q}$ for the intersection points of the first six elements LNS11, LNS12, LNS13, LNS14, LNS15, LNS21. $h_{y,1}$, $h_{y,2}$, $h_{y,3}$, $h_{y,4}$, $h_{y,5}$, $h_{y,6}$ may denote the vertical distances $h_{y,q}$ for the intersection points of the first six elements LNS11, LNS12, LNS13, LNS14, LNS15, LNS21. The light ray RAY1 may be parallel with the optical axis AX0. The position and the direction of the ray RAY1 may be selected such that the horizontal distance $h_{x,1}$ is different from zero and/or such that the vertical distance $h_{y,1}$ is different from zero. The path of the ray RAY1 and the positions $h_{x,k}$, $h_{y,k}$ of the intersection points may be determined e.g. by ray tracing.

Weighting coefficients $w_{x,q}$ and $w_{y,q}$ for the q^{th} element be defined by using the horizontal distances $h_{x,1}$, $h_{x,q}$ and the vertical distances $h_{y,1}$, $h_{y,q}$ e.g. as follows:

$$w_{x,q} = \frac{h_{x,q}}{h_{x,1}} \quad (1a)$$

$$w_{y,q} = \frac{h_{y,q}}{h_{y,1}} \quad (1b)$$

Thus, the weighting coefficient $w_{x,q}$ for the refractive power of an element associated with the index q may be proportional to the horizontal distance between the ray RAY1 and the axis AX0 at the location of said element. The weighting coefficient $w_{y,q}$ for the refractive power of an element associated with the index q may be proportional to the vertical distance between the ray RAY1 and the axis AX0 at the location of said element.

The weighting coefficients $w_{x,1}$ and $w_{y,1}$ for the first element of the anamorphic unit 10 (i.e. the lens LNS11) may be equal to one (i.e. $w_{x,1}=h_{x,1}/h_{x,1}=1$, $w_{y,1}=h_{y,1}/h_{y,1}=1$).

The horizontal refractive power $P_{x,C}$ of the imaging device 100 may be equal to the weighted sum of the horizontal refractive powers $P_{x,q}$ of the anamorphic unit 10 and the horizontal refractive powers $P_{x,q}$ of the focusing unit 20:

$$P_{x,C} = \left(\sum_{q=1}^N w_{x,q} \cdot P_{x,q} \right) + \left(\sum_{q=N+1}^{N+M} w_{x,q} \cdot P_{x,q} \right) \quad (1c)$$

The symbol N may denote the number of the optical elements of the anamorphic unit 10. The symbol M may denote the number of the optical elements of the focusing unit 20. The first summation (from $q=1$ to $q=N$) in equation 1c may take into account the contribution of the elements of the anamorphic unit 10. The second summation (from $q=N+1$ to $q=N+M$) may take into account the contribution of the elements of the focusing unit 20.

The vertical refractive power $P_{y,C}$ of the imaging device 100 may be equal to the weighted sum of the vertical refractive powers $P_{y,q}$ of the anamorphic unit 10 and the horizontal refractive powers $P_{y,q}$ of the focusing unit 20:

$$P_{y,C} = \left(\sum_{q=1}^N w_{y,q} \cdot P_{y,q} \right) + \left(\sum_{q=N+1}^{N+M} w_{y,q} \cdot P_{y,q} \right) \quad (1d)$$

The horizontal refractive power $P_{x,C}$ of the imaging device 100 may be equal to the weighted sum of the horizontal refractive power $P_{x,A}$ of the anamorphic unit 10 and the horizontal refractive power $P_{x,B}$ of the focusing unit 20:

$$P_{x,C} = P_{x,A} + (w_{x,B} \cdot P_{x,B}) \quad (1e)$$

The vertical refractive power $P_{y,C}$ of the imaging device 100 may be equal to the weighted sum of the vertical refractive power $P_{y,A}$ of the anamorphic unit 10 and the vertical refractive power $P_{y,B}$ of the focusing unit 20:

$$P_{y,C} = P_{y,A} + (w_{y,B} \cdot P_{y,B}) \quad (1f)$$

The weighting coefficient $w_{x,B}$ of the focusing unit 20 may be equal to the weighting coefficient $w_{x,q}$ of the first lens LNS21 of the focusing unit 20. The
 5 weighting coefficient $w_{y,B}$ of the focusing unit 20 may be equal to the weighting coefficient $w_{y,q}$ of the first lens LNS21 of the focusing unit 20. In particular, the weighting coefficient $w_{x,B}$ may be e.g. equal to $h_{x,6}/h_{x,1}$, and the weighting coefficient $w_{y,B}$ may be e.g. equal to $h_{y,6}/h_{y,1}$.

10 The anamorphic unit 10 may steer the light transmitted through the anamorphic unit 10 such that ratio $(h_{x,N+1}/h_{x,1})$ of the horizontal weighting coefficients may be substantially different from the ratio $(h_{y,N+1}/h_{y,1})$ of the vertical weighting coefficients. Consequently, the horizontal refractive power $P_{x,C}$ of the imaging device 100 may be substantially different from the vertical
 15 refractive power $P_{y,C}$ of the device 100 in a situation where the horizontal refractive power $P_{x,B}$ of the focusing unit 20 coupled to the anamorphic unit 10 is equal to the vertical refractive power $P_{y,B}$ of the focusing unit 20.

The lenses may be selected e.g. such that the ratio $h_{x,6}/h_{x,1}$ is e.g. greater
 20 than 1.5 times the ratio $h_{y,6}/h_{y,1}$. The lenses may be selected e.g. such that the ratio $h_{x,N+1}/h_{x,1}$ is e.g. greater than 1.5 times the ratio $h_{y,N+1}/h_{y,1}$. The weighting coefficient $w_{x,B}$ may be e.g. greater than 1.5 times the weighting coefficient $w_{y,B}$.

25 The vertical refractive power $P_{y,A}$ of the anamorphic unit 10 may be substantially equal to zero, and the vertical refractive power $P_{y,C}$ of the imaging device 100 may be substantially equal to the vertical refractive power $P_{y,B}$ of the focusing unit 20.

30 The anamorphic unit 10 may comprise two or more refractive optical elements LNS11, LNS12. The horizontal refractive power $P_{x,A}$ of the anamorphic unit 10 may be equal to the weighted sum of the horizontal refractive powers $P_{x,1}, P_{x,2}, \dots, P_{x,q}, \dots, P_{x,N}$ of the individual optical elements LNS11, LNS12, LNS13, ... of the anamorphic unit 10:

$$P_{x,A} = \sum_{q=1}^N w_{x,q} \cdot P_{x,q} \quad (2a)$$

- The vertical refractive power $P_{y,A}$ of the anamorphic unit 10 may be equal to the weighted sum of the vertical refractive powers $P_{y,1}, P_{y,2}, \dots, P_{y,q}, \dots, P_{y,N}$ of the individual optical elements LNS11, LNS12, LNS13,... of the anamorphic unit 10:

$$P_{y,A} = \sum_{q=1}^N w_{y,q} \cdot P_{y,q} \quad (2b)$$

- 10 The anamorphic unit 10 may comprise e.g. 5 elements LNS11, LNS12, LNS13, LNS14, LNS15 shown in Fig. 1a, and the horizontal refractive power $P_{x,A}$ of the anamorphic unit 10 may be calculated according to the following equation:

$$\begin{aligned}
 & \sum_{q=1}^N w_{x,q} \cdot P_{x,q} \\
 15 \quad & = \frac{1}{f_{x,LNS11}} + \frac{h_{x,2}/h_{x,1}}{f_{x,LNS12}} + \frac{h_{x,3}/h_{x,1}}{f_{x,LNS13}} + \frac{h_{x,4}/h_{x,1}}{f_{x,LNS14}} + \frac{h_{x,5}/h_{x,1}}{f_{x,LNS15}} \\
 & \quad (2c)
 \end{aligned}$$

- 20 The optical elements of the anamorphic unit 10 may be selected such that the horizontal refractive power $P_{x,C}$ of the imaging device 100 is greater than e.g. 1.5 times the vertical refractive power $P_{y,C}$ of the imaging device 100:

$$P_{x,C} > 1.5 \cdot P_{y,C} \quad (3a)$$

- 25 The light ray RAY1 may be coupled from the anamorphic unit 10 into the focusing unit 20 such that the anamorphic unit 10 defines the horizontal distance $h_{x,6}$ and the vertical distance $h_{y,6}$ between the between the light ray

RAY1 and the axis AX0 at the location of the first element (LNS21) of the focusing unit 20. The anamorphic unit 10 may define the position ($h_{x,6}$, $h_{y,6}$) of the intersection point (IC₆) where the light ray RAY1 meets the input surface of the focusing unit 20. The weighting coefficients $w_{x,B}$, $w_{y,B}$ may be
 5 calculated e.g. based on the distances $h_{x,6}$, $h_{y,6}$.

The optical elements of the anamorphic unit 10 may be selected e.g. according to the following equation (3b):

$$10 \quad \sum_{q=1}^N w_{x,q} \cdot P_{x,q} + w_{x,B} \cdot P_{x,B} > 1.5 \cdot \left(\sum_{q=1}^N w_{y,q} \cdot P_{y,q} + w_{y,B} \cdot P_{y,B} \right) \quad (3b)$$

Equation (3b) may be obtained from equation (3a) e.g. by using the equations (1e), (1f), (2a) and (2b). The weighting coefficient $w_{x,B}$ may be
 15 different from the weighting coefficient $w_{y,B}$ so that the imaging device 100 may provide anamorphic compression also in a situation where the anamorphic unit 10 is afocal and the focusing unit 20 is axially symmetric.

The vertical refractive power $P_{y,A}$ of the anamorphic unit 10 may also be e.g.
 20 smaller than 10% of the vertical refractive power $P_{y,C}$ of the imaging device 100:

$$|P_{y,A}| < 0.10 \cdot P_{y,C} \quad (3c)$$

25 The anamorphic unit 10 may comprise at least one negative refractive lens LNS11 and at least one positive refractive lens (e.g. LNS 15). The refractive powers of the lenses of the anamorphic unit 10 may be selected such that equations (3b) and (3c) are fulfilled.

30 The first refractive lens of the anamorphic unit 10 may be e.g. a negative cylindrical meniscus lens LNS11. The negative cylindrical meniscus lens LNS11 may have a first cylindrical convex surface and a second cylindrical

concave surface, wherein the radius of curvature of the second cylindrical surface may be smaller than the radius of curvature of the first cylindrical surface. The convex surface of the first lens LNS11 may receive the light beams $B0_k$ from the viewing region VREG1. All other lenses of the anamorphic unit 10 may be located between the lens LNS11 and the real image IMG1. All other lenses of the imaging device 100 may be located between the lens LNS11 and the real image IMG1.

The anamorphic unit 10 may comprise e.g. a combination of a cylindrical negative meniscus lens LNS11, and a bi-concave cylindrical lens LNS12. The lenses LNS11, LNS12 may provide anamorphic compression by causing mainly a horizontal change in the direction of light. The lenses LNS11, LNS12 may provide a refracted beam by refracting light of an input beam $B0_k$ such that the azimuth angle of the refracted beam is substantially smaller than the azimuth angle of the input beam $B0_k$, wherein the elevation angle of the refracted beam may be substantially equal to the elevation angle of the input beam $B0_k$. The azimuth angle means the angle between the direction of a light beam and the vertical plane. The elevation angle means the angle between the direction and the horizontal plane. The ratio of the elevation angle of the refracted beam to the elevation angle of the input beam $B0_k$ may be substantially greater than the ratio of the azimuth angle of the refracted beam to the azimuth angle of the input beam $B0_k$.

The anamorphic unit 10 may further comprise a lens LNS13 to correct aberrations. The lens LNS13 may be e.g. a cylindrical positive meniscus lens LNS13. The lens LNS13 may have a first cylindrical concave surface and a second cylindrical convex surface, wherein the radius of curvature of the second surface may be smaller than the radius of curvature of the first surface.

The anamorphic unit 10 may optionally comprise one or more lenses LNS14, LNS15 to match the optical output of the anamorphic unit 10 with the viewing region of the focusing unit 20. Without using the lens LNS14 and/or LNS15, some peripheral light beams provided by the lens LNS13 could be outside the angular viewing region of the focusing unit 20.

The lens LNS13 and the lens LNS15 may at least partly compensate the effect of the negative refractive power of the lenses LNS11, LNS12, LNS14. The lens LNS14 may at least partly compensate chromatic aberration caused by the lens LNS15. The lens LNS14 may at least partly compensate geometric distortion.

The anamorphic unit 10 may comprise lenses LNS11, LNS12, LNS13, LNS14, LNS15. The lenses LNS11, LNS1, and LNS14 may be negative lenses. The lenses LNS13, LNS15 may be positive lenses. Also the lenses LNS13, LNS14, LNS15 may be cylindrical lenses. The lenses LNS11, LNS1, and LNS14 may be negative cylindrical lenses, and the lenses LNS13, LNS15 may be positive cylindrical lenses.

Light refracted by the lens LNS11 may be coupled to the lens LNS12. Light refracted by the lens LNS12 may be coupled to the lens LNS13. Light refracted by the lens LNS13 may be coupled to the lens LNS14. Light refracted by the lens LNS14 may be coupled to the lens LNS15. Light refracted by the lens LNS15 may be coupled to the focusing unit 20.

The focusing unit 20 may comprise e.g. two or more axially symmetric lenses LNS21, LNS22, LNS23, LNS24, LNS25. The lens LNS21, LNS22, LNS23, LNS24, and/or LNS25 may be axially symmetric. The axially symmetric surfaces of the lenses LNS21, LNS22, LNS23, LNS24, LNS25 may be spherical, aspherical or planar. The focusing unit 20 may provide focused light B2 by focusing the intermediate light B1. The focusing unit 20 may provide focused light beams B_{20} , B_{21} , B_{2k} by focusing light of the intermediate beams B_{10} , B_{11} , B_{1k} . The focusing unit 20 may provide the real image IMG1 by providing the focused light beams B_{20} , B_{2k} .

SX, SY and SZ denote orthogonal directions. The direction SX may be called e.g. as the horizontal direction, and the direction SY may be called e.g. as the vertical direction. The direction SZ may be called e.g. as the axial direction or as the longitudinal direction. The directions SX, SY, SZ may be defined by the device 100. The direction SY does not need to be parallel to

the direction of gravity, and the direction SX does not need to be perpendicular to the direction of gravity. The imaging device 100 may have an optical axis AX0. The optical axis AX0 may be parallel to the direction SZ. The anamorphic unit 10 may exhibit symmetry with respect to a plane defined by the directions SY and SZ. The anamorphic unit 10 may also exhibit symmetry with respect to a plane defined by the directions SX and SZ.

The direction of an axial input beam $B0_0$ may remain substantially unaltered.

Figs. 1a and 1b shows, in a top view, the imaging device 100. The viewing direction of Figs. 1a and 1b is perpendicular to the horizontal plane defined by the directions SX and SZ. Fig. 2 shows a three dimensional view of the imaging device 100.

Table 1 shows, by way of example, suitable dimensions for the surfaces of the imaging device 100. Table 2 shows, by way of example, suitable optical materials for the optical elements of the imaging device 100. The materials listed in Table 2 may be used in the device of Table 1.

Table 1. Suitable dimensions of the surfaces of the imaging device 100.

Element	Surface number #	Surface type	Radius of curvature in direction SY (mm)	Thickness (mm)	Radius of curvature in direction SX (mm)
SRF1	0	CYLINDRICAL	INF	5000	5000
LNS11	1	CYLINDRICAL	INF	2	55.63
LNS11	2	CYLINDRICAL	INF	15.85	18.57
LNS12	3	CYLINDRICAL	INF	3.79	-124.76
LNS12	4	CYLINDRICAL	INF	8.00	101.00
LNS13	5	CYLINDRICAL	INF	7.82	-67.46
LNS13	6	CYLINDRICAL	INF	11.74	-55.22
LNS14	7	CYLINDRICAL	INF	11.17	-22.20

LNS14	8	CYLINDRICAL	INF	0.20	-98.76
LNS15	9	CYLINDRICAL	INF	14.54	5372.56
LNS15	10	CYLINDRICAL	INF	2.00	-40.65
LNS21	11	SPHERICAL	18.36	2.97	18.36
LNS21	12	SPHERICAL	111	0.44	111
LNS22	13	SPHERICAL	6.62	1.97	6.62
LNS22	14	SPHERICAL	4.55	3.89	4.55
AS1	15	STOP	INF	1.69	INF
LNS23	16	SPHERICAL	-8.64	1.00	-8.64
LNS23	17	SPHERICAL	13.74	4.66	13.74
LNS24	17	SPHERICAL	13.74	4.66	13.74
LNS24	18	SPHERICAL	-9.41	0.50	-9.41
LNS25	19	SPHERICAL	64.55	2.61	64.55
LNS25	20	SPHERICAL	-25.22	1.00	-25.22
Window A	21	PLANE	INF	1.00	INF
Window A	22	PLANE	INF	13.28	INF
Window B	23	PLANE	INF	1.00	INF
Window B	24	PLANE	INF	0.55	INF
DET1	25	PLANE	INF		INF

- 5 The lenses LNS23 and LNS24 may together form a doublet lens (i.e. they may have the common surface #17). Window A and window B may refer to protective windows, which may be optionally positioned e.g. between the lens LNS25 and the detector DET1. SRF1 denotes the object surface. DET1 means the image sensor. INF means infinite radius. The glass types may refer to the glass type designations specified by the company Schott AG on the date of filing of this application.

10

Table 2. Suitable optical materials of the elements of the imaging device 100.

Element	Glass type
---------	------------

LNS11	N-LAK34
LNS12	N-SK4
LNS13	N-LASF41
LNS14	N-BAF10
LNS15	N-LASF46A
LNS21	N-BAF52
LNS22	N-SK16
LNS23	N-SF56
LNS24	N-LAF36
LNS25	N-LAK14
Window A	N-BK7
Window B	B270

In case of the device specified in Tables 1 and 2, the horizontal field of view may be substantially equal to 179°, and the vertical field of view may be substantially equal to 29.8°. The operating wavelength range may be e.g. in the range of 486 nm to 656 nm. The F-number may be substantially equal to 2.8. The effective focal length $f_{x,c}$ may be substantially equal to 4.85 mm, and the effective focal length $f_{y,c}$ may be substantially equal to 18.5 mm. The full width of the image formed on the detector may be substantially equal to 12.8 mm, and the full height of the image formed on the detector may be substantially equal to 9.6 mm.

Referring to Fig. 3a, the imaging device 100 may form an image IMG1 of a viewing region VREG1 on the image sensor DET1. The viewing region VREG1 may comprise one or more objects O1, O2, O3. An object O1 may comprise an object point P_k , which may emit or reflect light $B0_k$ towards the

input aperture of the lens element LNS11. The light sent from the object point P_k to the lens element LNS11 may be understood to constitute an input light beam $B0_k$. The direction of the input light beam $B0_k$ may be specified by angles (ϕ_k, θ_k) . The azimuth angle ϕ_k may denote an angle between the
 5 direction of the input light beam $B0_k$ and a vertical reference plane defined by the directions SY and SZ. The elevation angle θ_k may denote an angle between the direction of the input light beam $B0_k$ and a horizontal reference plane defined by the directions SX and SZ.

- 10 The entrance pupil of the device 100 may be defined by an aperture stop AS1 of the focusing unit 20. The aspheric unit 10 does not need to comprise an aperture stop. The entrance pupil may also be called e.g. as the input pupil. The aperture stop AS1 of the focusing unit 20 may be e.g. substantially circular, and entrance pupil of the device 100 may be substantially elliptical.
- 15 The shape of the perimeter of the input aperture of the lens element LNS11 may substantially correspond to the shape of a projection of an ellipse on the curved input surface of the element LNS11.

The image IMG1 of the viewing region VREG1 may comprise sub-images
 20 SUB1, SUB2, SUB3. The sub-image SUB1 may be an image of the object O1. The sub-images SUB2, SUB3 may be images of the objects O2, O3.

The viewing region VREG1 may have an angular width $\Delta\phi$ and an angular height $\Delta\theta$. The active light-detecting surface of the image sensor DET1 may
 25 be in a plane defined by directions SU and SV. The direction SU may be parallel to the direction SX, and the direction SV may be parallel to the direction SY.

Referring to Fig. 3b, the viewing region VREG1 may comprise a cylindrical
 30 object surface SRF1. The object surface SRF1 may represent the viewing region VREG1. The angular width of the object surface SRF1 may be equal to the angular width of the viewing region VREG1, and the angular height of the object surface SRF1 may be equal to the angular height of the viewing region VREG1, when viewed by the imaging device 100.

The imaging device 100 may be arranged to form a sharp image IMG1 of the cylindrical surface SRF1. The imaging device may form a real optical image of a cylindrical object surface on a planar image sensor. The cylindrical object surface may have a predetermined radius of curvature. The imaging
 5 device may form a sharply focused real image of the cylindrical object surface on the planar image sensor.

The object surface SRF1 may comprise an object O1. The object surface SRF1 may comprise a portion O1, which represents an object. The image
 10 IMG1 may comprise a sub-image SUB1 of an object O1. The object O1 may have an object point P_k . The image IMG1 may comprise an image P''_k of the object point P_k . The image The position of the image point P''_k may be specified e.g. by coordinates (u_k, v_k) .

15 The cylindrical surface SRF1 may have a radius L_0 of curvature. The distance between the cylindrical surface SRF1 and the first lens LNS11 may be equal to L_0 . The cylindrical surface SRF1 may have a circumferential length Δs and a height Δy . The cylindrical surface SRF1 may have an aspect ratio $\Delta s/\Delta y$. The position of the object point P_k may be specified e.g. by
 20 coordinates (s_k, y_k) or by the angular coordinates (ϕ_k, θ_k) .

The optical real image IMG1 of the cylindrical surface SRF1 may cover a large part of the active area of the image sensor DET1. For example, the image IMG1 may cover more than 95% of the active area of the image
 25 sensor DET1. The fill factor of the image sensor DET1 may be e.g. higher than 95%. The fill factor of the image sensor DET1 may mean the ratio of the area covered by the image IMG1 to the area of the active area.

The imaging device 100 may have a first focal length $f_{x,c}$ for refraction in the
 30 horizontal plane defined by the directions SX and SZ. The imaging device 100 may have a second focal length $f_{y,c}$ for refraction in the vertical plane defined by the directions SY and SZ. The second focal length $f_{y,c}$ may be greater than the first focal length $f_{x,c}$. The ratio $(f_{y,c}/f_{x,c})$ of the focal lengths may be e.g. in the range of 3.0 to 6.0. The ratio $(f_{y,c}/f_{x,c})$ may also be called
 35 e.g. as the anamorphic compression ratio of the imaging device 100. The

anamorphic compression ratio ($f_{Y,C}/f_{X,C}$) may be e.g. in the range of 3.0 to 6.0.

- 5 The dimensions w_{DET1} , h_{DET1} of the active area of the image sensor DET1 defines the maximum dimensions of the optical image IMG1, which can be captured by the image sensor DET1. The relationship between the angular dimensions of the object surface SRF1 and the dimensions of the optical image IMG1 may be approximated e.g. by the following equations:

$$10 \quad \frac{w_{DET1}}{2} = f_{X,C} \cdot \frac{\Delta\phi}{2} \quad (4a)$$

$$\frac{h_{DET1}}{2} = f_{Y,C} \cdot \tan\left(\frac{\Delta\theta}{2}\right) \quad (4b)$$

- 15 The image IMG1 formed by the imaging device 100 may match with the image sensor DET1 when the focal lengths f_x and f_y fulfill the equations (4a) and (4b). The focal lengths f_x and f_y may be given e.g. by the following equations:

$$20 \quad f_{X,C} = \frac{w_{DET1}}{\Delta\phi} \quad (5a)$$

$$f_{Y,C} = \frac{h_{DET1}}{2 \cdot \tan\left(\frac{\Delta\theta}{2}\right)} \quad (5b)$$

- 25 The lenses of the imaging device 100 may be selected such that the imaging device 100 provides the focal lengths $f_{X,C}$ and $f_{Y,C}$ determined by the equations (5a) and (5b).

For example, the object surface SRF1 may have angular dimensions $\Delta\phi=180^\circ$, and $\Delta\theta=30^\circ$, and the active area of the image sensor DET1 may

have dimensions $w_{DET1}=12.8$ mm and $h_{DET1}=9.6$ mm. The corresponding focal lengths $f_{X,C} = 4.07$ mm, and $f_{Y,C} = 17.91$ mm may be calculated from the equations (5a) and (5b). The imaging device 100 may be arranged to operate such that the focal length $f_{X,C} = 4.07$ mm, and $f_{Y,C} = 17.91$ mm. In this example, the aspect ratio of the active area is 4:3, and the angular height $\Delta\theta$ of the viewing region is 16.67% of the angular width $\Delta\phi$ of the viewing region.

Fig. 4 illustrates how the image IMG1 may be formed from light received from the cylindrical surface SRF1. The cylindrical surface SRF1 may have an angular width $\Delta\phi$ and an angular height $\Delta\theta$. The optical axis AX0 of the imaging device 100 may intersect the cylindrical surface SRF1 at the point P_0 . The upper edge of the surface SRF1 may have an angular coordinate θ_{MAX} . The right side of the surface SRF1 may have an angular coordinate ϕ_{MAX} . The angular width $\Delta\phi$ may be equal to $2 \cdot \phi_{MAX}$. The height $\Delta\theta$ may be equal to $2 \cdot \theta_{MAX}$. The length Δs may be equal to $L_0 \cdot \phi_{MAX}$. The height Δy may be equal to $L_0 \cdot \tan(\theta_{MAX})$. The surface SRF1 may have an aspect ratio $\Delta\phi/\Delta\theta$.

The aspect ratio of the surface SRF1 may be e.g. greater than 3:1, greater than 4:1, greater than 5:1, or even greater than 6:1. The aspect ratio of the surface SRF1 may be e.g. in the range of 3 to 5. The aspect ratio of the surface SRF1 may be e.g. in the range of 3 to 7 (i.e. in the range of 3:1 to 7:1).

The horizontal field of view $\Delta\phi$ may be e.g. in the range of 120° to 180° . The horizontal field of view $\Delta\phi$ may even be greater than 180° . The vertical field of view $\Delta\theta$ may be e.g. in the range of 40° to 60° . The vertical field of view may be e.g. in the range of 15% to 34% of the horizontal field of view. The value 15% may substantially correspond to the aspect ratio 7 ($1/0.15=6.7$), and the value 34% may substantially correspond to the aspect ratio 3 ($1/0.34=2.9$).

The angular width $\Delta\phi$ of the viewing region may be e.g. in the range of 120° to 160° , and the angular height $\Delta\theta$ of the viewing region may be e.g. in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

The angular width $\Delta\phi$ of the viewing region may be e.g. in the range of 160° to 220° , and the angular height $\Delta\theta$ of the viewing region may be e.g. in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

- 5 The angular width $\Delta\phi$ of the viewing region may be e.g. in the range of 220° to 270° , and the angular height $\Delta\theta$ of the viewing region may be e.g. in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

- 10 The angular width $\Delta\phi$ of the viewing region may be e.g. in the range of 120° to 270° , and the angular height $\Delta\theta$ of the viewing region may be e.g. in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

- 15 The fill factor of the image sensor may be e.g. higher than 95%, corresponding to the horizontal and vertical field of view. The aspect ratio of the image sensor may be e.g. in the range of 1:1 to 2:1.

- The aspect ratio of the image sensor may be e.g. 4:3 or 16:9. The aspect ratio of the view region may be e.g. substantially equal to 7:1, 6:1, 5:1, 4:1, or 3:1.

- 20 The anamorphic unit 10 may be arranged to form a virtual image VMG1 of the cylindrical surface SRF1 by refracting light received from the surface SRF1. The virtual image VMG1 may be a sharp image. The anamorphic unit 10 may be arranged to form a substantially sharp virtual image VMG1 of the cylindrical surface SRF1 by refracting light received from the surface SRF1.

- 25 The virtual image VMG1 may have an angular width $\Delta\phi'$ and an angular height $\Delta\theta'$. The virtual image VMG1 may have an image point P'_0 , which corresponds to the central object point P_0 . The virtual image VMG1 may have an image point P'_k , which corresponds to the object point P_k . The virtual image VMG1 may comprise a sub-image SUB1' of the object O1. The virtual image VMG1 may have an aspect ratio $\Delta\phi'/\Delta\theta'$. The aspect ratio $\Delta\phi'/\Delta\theta'$ may be e.g. smaller than 2.

The anamorphic unit 10 may be interpreted to provide the virtual image VMG1 by straightening the curved surface SRF1, and by compressing the straightened surface SRF1 in the direction SX. The focusing optics 20 may "see" the virtual image VMG1 through the anamorphic unit 10. The

5 anamorphic unit 10 may provide the virtual image VMG1 such that the vertical scaling factor $\Delta\theta'/\Delta\theta$ is substantially equal to one. The anamorphic unit 10 may provide the virtual image VMG1 such that the horizontal scaling factor $\Delta\phi'/\Delta\phi$ is substantially smaller than one. The anamorphic unit 10 may provide the virtual image VMG1 such that the horizontal scaling factor $\Delta\phi'/\Delta\phi$

10 is substantially smaller than the vertical scaling factor $\Delta\theta'/\Delta\theta$.

The focusing unit 20 may form the real image IMG1 of the virtual image VMG1 by focusing light refracted by the anamorphic unit 10. The focusing unit 20 may be understood to provide the real image IMG1 by radially

15 compressing the virtual image VMG1 towards the axis AX0. Depending on the properties of the focusing optics 20, the virtual image IMG1 may be planar or slightly curved so that the real image IMG1 may be substantially planar.

20 The image IMG1 may have a width Δu and a height Δv . The position of the image point P''_k may be specified by coordinates u_k, v_k . The coordinates u_k, v_k may specify the position of the image point P''_k with respect to a reference point. In particular, the coordinates u_k, v_k may specify the position of the image point P''_k with respect to the central point P''_0 . The optical axis AX0

25 may intersect the image sensor DET1 at the central point P''_0 .

The image sensor DET1 may have a width w_{DET1} and a height h_{DET1} . The image sensor DET1 may have an aspect ratio w_{DET1}/h_{DET1} . The aspect ratio w_{DET1}/h_{DET1} may be e.g. smaller than 2. For example, the aspect ratio w_{DET1}/h_{DET1}

30 h_{DET1} may be e.g. 4:3 or 16:9.

The image IMG1 of the surface SRF1 may cover e.g. more than 80% of the active area of the image sensor DET1. The image IMG1 may cover 100% of the active area of the image sensor DET1. The width Δu of the image IMG1

35 may be greater than 80% of the width w_{DET1} of the image sensor DET1, and

the height Δv of the image IMG1 may be greater than 80% of the height h_{DET1} of the image sensor DET1. The image IMG1 of the surface SRF1 may cover e.g. more than 80% of the active area of the image sensor DET1 such that the width Δu of the image IMG1 is equal to the width w_{DET1} of the image sensor DET1, or the height Δv of the image IMG1 is equal to the height h_{DET1} of the image sensor DET1. The image IMG1 of the surface SRF1 may cover e.g. more than 95% of the active area of the image sensor DET1 such that the width Δu of the image IMG1 is equal to the width w_{DET1} of the image sensor DET1, and the height Δv of the image IMG1 is equal to the height h_{DET1} of the image sensor DET1.

The image sensor DET1 may convert the real optical image IMG1 into a digital image DIMG1. The image sensor DET1 may capture the image IMG1.

The object surface SRF1 may have an (angular) aspect ratio $\Delta\phi/\Delta\theta$, and the optical image IMG1 may have an aspect ratio $\Delta u/\Delta v$. The ratio $(\Delta\phi/\Delta\theta)/(\Delta u/\Delta v)$ of these aspect ratios may be called e.g. as the anamorphic compression coefficient of the imaging device 100. The anamorphic compression coefficient may be e.g. in the range of 3.0 to 5.0.

The dimensions of the optical elements of the anamorphic unit 10 and the focusing unit 20 may be selected e.g. such that the anamorphic compression coefficient is in the range of 3.0 to 5.0 in a situation where the angular width $\Delta\phi$ of the viewing region is in the range of 120° to 180° , and the angular height $\Delta\theta$ of the viewing region is in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

The dimensions of the optical elements of the anamorphic unit 10 and the focusing unit 20 may be selected e.g. such that the anamorphic compression coefficient is in the range of 3.0 to 5.0 in a situation where the angular width $\Delta\phi$ of the viewing region is in the range of 160° to 270° , and the angular height $\Delta\theta$ of the viewing region is in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

The dimensions of the optical elements of the anamorphic unit 10 and the focusing unit 20 may be selected e.g. such that the anamorphic compression coefficient is in the range of 3.0 to 5.0 in a situation where the angular width $\Delta\phi$ of the viewing region is in the range of 120° to 270° , and the angular height $\Delta\theta$ of the viewing region is in the range of 15% to 34% of the angular width $\Delta\phi$ of the viewing region.

The modulation transfer function of the imaging apparatus may depend on the modulation transfer function of the imaging device 100 and on the modulation transfer function of the image sensor DET1. The modulation transfer function of the image sensor DET1 may depend on the height and width of the detector pixels of the image sensor DET1.

Fig. 5a shows, by way of example, mapping from the tangent $\tan(\theta_k)$ of the vertical angular position θ_k of an object point P_k to the vertical position v_k of the corresponding image point P''_k . The image point P''_k may be the image of the object point P_k . The vertical position v_k of the image point P''_k may depend on the vertical angular position θ_k , and also (to a lesser extent) on the horizontal angular position ϕ_k of the object point P_k . The vertical position v_k of the image point P''_k may be expressed by a mapping function $v_k(\phi_k, \tan(\theta_k))$, where the vertical position v_k depends on the angle ϕ_k and on the tangent $\tan(\theta_k)$ of the angle θ_k .

The dashed curve of Fig. 5a shows the vertical position $v_k(\phi_k=\phi_{MAX}, \tan(\theta_k))$ of the image point P''_k as the function of the tangent $\tan(\theta_k)$ of the vertical angular position θ_k when the object point P_k is at the right edge ($\phi_k=\phi_{MAX}$) of the object surface SRF1. The solid curve of Fig. 5a shows the vertical position $v_k(\phi_k=0^\circ, \tan(\theta_k))$ of the image point P''_k as the function of the tangent $\tan(\theta_k)$ of the vertical angular position θ_k when the object point P_k is on a vertical line at the center ($\phi_k=0$) of the object surface SRF1.

The relationship between the tangent $\tan(\theta_k)$ of the vertical angular position θ_k and the vertical position v_k may be nearly linear at each object point of the object surface SRF1 within the viewing region VREG1, i.e. when $-\phi_{MAX} \leq \phi_k \leq +\phi_{MAX}$, and when $-\theta_{MAX} \leq \theta_k \leq +\theta_{MAX}$.

The curves of Figs. 5a and 5b may illustrate image distortion e.g. in an embodiment, where the width Δs of the cylindrical object surface SRF1 may be e.g. 15.0 m, the height Δy of the object surface SRF1 may be e.g. 2.6 m, and the radius L_0 of curvature may be e.g. 5.0 m. The corresponding angular width $\Delta\phi$ of the object surface SRF1 may be e.g. $360^\circ \cdot \Delta s / (2\pi \cdot L_0) = 170^\circ$. The width w_{DET1} of the light-detecting area of the image sensor DET1 may be e.g. equal to 12.8 mm, and the height h_{DET1} of the light-detecting area may be e.g. equal to 9.6 mm. The aspect ratio of the image sensor DET1 may be e.g. 4:3.

10

Fig. 5b shows, by way of example, the relative vertical distortion $(v_k - v_{k,\text{REF}})/v_{k,\text{REF}}$ caused by the mapping from an object point P_k to the corresponding image point P''_k . $v_{k,\text{REF}}$ denotes an ideal vertical position of an image point of the object point P_k without distortion. The ideal vertical position $v_{k,\text{REF}}$ may be calculated e.g. according to the following equation:

15

$$v_{k,\text{REF}} = f_{Y,C} \cdot \tan(\theta_k) \quad (6)$$

θ_k may denote the input elevation angle of the input beam received from the object point P_k . The curves of Fig. 5b may be interpreted to illustrate how much the curves of Fig. 5a deviate from a straight line.

20

The relative difference between vertical magnification $(d\theta''/d\theta)$ at a corner of the real image (IMG1) and vertical magnification $(d\theta''/d\theta)$ at the center of the real image (IMG1) may be e.g. smaller than 5%.

25

The imaging device 100 may provide substantially constant vertical magnification for several different object points (P_k) which are located on the cylindrical object surface SRF1. The imaging device 100 may provide substantially sharp image points (P''_k) for the different object points (P_k) which are located on the cylindrical object surface SRF1.

30

Input azimuth angle means the azimuth angle of an input beam, and input elevation angle means the elevation angle of the input beam. The parameters of the surfaces of the lenses of the anamorphic unit 10 may be

35

selected e.g. such that the modulation transfer function (MTF) of the imaging device 100 at a predetermined spatial frequency is higher than 50% for each input azimuth angle (ϕ_k) which is in the range of 0° to $\Delta\phi/2$ when the input elevation angle $\theta_k = 0^\circ$, and such that the modulation transfer function (MTF) of the imaging device (500) at the predetermined spatial frequency (ν_1) is higher than 50% for each input azimuth angle (ϕ_k) which is in the range of 0° to $\Delta\phi/2$ when the input elevation angle θ_k is equal to the maximum value $\Delta\theta/2$. $\Delta\phi$ denotes the angular width and $\Delta\theta$ denotes the angular height of the viewing region VREG1. The modulation transfer function (MTF) at the predetermined spatial frequency may have a first value MTF1 when $\phi_k=0^\circ$, $\theta_k = 0^\circ$. The modulation transfer function (MTF) at the predetermined spatial frequency may have a second value MTF2 when $\phi_k=\Delta\phi/2$, $\theta_k = \Delta\theta/2$. The parameters of the surfaces of the lenses of the anamorphic unit 10 may be selected e.g. such that the sum MTF1+MTF2 is maximized.

Fig. 5c shows a horizontal line LIN1, a vertical line LIN2, and a diagonal line LIN3 positioned on the optical image IMG1. The lines LIN1, LIN2, and LIN3 may intersect the center P''_0 of the image IMG1. The lines LIN1, LIN2, and LIN3 may intersect the optical axis AX0 of the imaging device 100, and the lines LIN1, LIN2, and LIN3 may be perpendicular to the axis AX0. The dimensions and materials of the optical elements of the imaging device 100 may be selected such that optical performance of the imaging device 100 is optimized for image points P''_k which are on the diagonal line LIN3. The optical performance may be optimized for image points P''_k which are on the diagonal line LIN3 outside the center P''_0 . The optical performance may be optimized for image points P''_k which are on the diagonal line LIN3 close to the corner point $(\Delta u/2, \Delta v/2)$ of the image IMG1. The optical performance may be optimized for image points which are on the line LIN1 outside the center P''_0 , for image points which are on the line LIN2 outside the center, and also for image points which are on the line LIN3 outside the center.

The parameters of the surfaces of the lenses of the anamorphic unit 10 may be selected e.g. such that the minimum value of the modulation transfer function (MTF) at the predetermined spatial frequency is maximized for image points, which are located on the diagonal LIN3 of the image IMG1.

- Referring to Fig. 6, the apparatus 500 may comprise a data processor CNT1, which may be configured to form a panorama image PAN1 from the digital image DIMG1 captured by the image sensor DET1. The data processor
- 5 CNT1 may be configured to form the panorama image PAN1 e.g. by scaling the digital image DIMG1 by a first scaling coefficient in the horizontal direction and by scaling the digital image DIMG1 by a second different scaling coefficient in the horizontal direction. The optical image IMG1 may be slightly distorted when compared with the cylindrical object surface SRF1.
- 10 Consequently, also the digital image DIMG1 captured by the image sensor DET1 may be slightly distorted when compared with the cylindrical object surface SRF1. The data processor CNT1 may be configured to correct the distortion of the digital image DIMG1.
- 15 Referring to Fig. 7, the imaging apparatus 500 may comprise the imaging device 100 and the image sensor DET1. The imaging apparatus 500 may optionally comprise a memory MEM1 for storing the digital image DIMG1 captured by the image sensor DET1. The imaging apparatus 500 may optionally comprise a data processor CNT1 for processing the digital image
- 20 DIMG1. The data processor CNT1 may be configured to form an image PAN1 from the digital image DIMG1. The image PAN1 may be a panorama image. The aspect ratio of the image PAN1 may be e.g. greater than or equal to 3:1. The imaging apparatus 500 may optionally comprise a memory MEM2 for storing the image PAN1. The imaging apparatus 500 may optionally
- 25 comprise a memory MEM3 for storing computer program code PROG1. The imaging apparatus 500 may optionally comprise a user interface UIF1 for receiving input from a human user. The user interface UIF1 may comprise e.g. a touch screen and/or keys for selecting operating parameters of the imaging apparatus 500. The user interface UIF1 may comprise e.g. a display
- 30 for displaying the digital image DIMG1 and/or the image PAN1. The imaging apparatus 500 may optionally comprise a communication unit RXTX1 for sending image data DIMG1 and/or PAN1. The communication unit RXTX1 may communicate data e.g. by wireless communication, via an electric cable, and/or via an optical cable. The communication unit RXTX1 may
- 35 communicate data e.g. with a mobile phone network. The communication unit

RXTX1 may communicate data e.g. with the Internet. COM1 denotes a data transmission signal.

The apparatus 500 may comprise at least one processor CNT1, a memory
5 MEM3 including computer program code PROG1 stored in the memory
MEM3. The computer program code PROG1 may be configured to, with the
at least one processor CNT1, cause the apparatus 500 to perform at least
one of the following:

- capturing a digital image DIMG1,
- 10 - forming a panorama image PAN1 from the digital image DIMG1,
- storing the digital image DIMG1 and/or the panorama image PAN1 in a
memory, and/or
- transmitting the digital image DIMG1 and/or the panorama image PAN1.

15 The imaging device 100 may provide a wide viewing region. The imaging
device 100 may be e.g. positioned at a corner of a building or vehicle. A first
wall may meet a second wall at the corner such that the angle between the
walls is substantially equal to 270° . The horizontal angular width $\Delta\phi$ of the
viewing region of the imaging device 100 may cover the full 270° angle
20 between said walls.

The imaging device 100 or apparatus 500 may be used e.g. as a part of a
surveillance system, as part of a navigation system, or as a part of a machine
vision system. A surveillance system may comprise the imaging device 100
25 or the apparatus 500 for capturing a panorama image of an environment. A
navigation system may comprise the imaging device 100 or the apparatus
500 for capturing a panorama image of an environment. The imaging device
100 or the apparatus 500 may be attached e.g. to a vehicle. The captured
image may be compared with image data e.g. in order to determine the
30 position of the imaging device 100 with respect to the environment. The
captured image may be compared with image data e.g. in order to determine
the position of the vehicle with respect to the environment. A machine vision
system may comprise the imaging device 100 or the apparatus 500 for
capturing a panorama image of a product. The panorama image may be
35 analyzed in order to control the manufacturing process of the product.

An imaging apparatus 500 may be attached to a vehicle, in particular to a car. The imaging apparatus 500 may capture a digital image DIMG1 of the environment of the vehicle, and the digital image DIMG1 and/or the
5 panorama image PAN1 may be displayed to the driver of the vehicle by using the user interface UIF1.

The imaging device 100 may be used as a part of a laser distance measuring device.

10

The image sensor DET1 may be e.g. a CMOS sensor or a CCD sensor. The imaging device 100 or apparatus 500 may be arranged to capture a video of the viewing region. The video may comprise one or more digital images DIMG1 captured by the image sensor DET1.

15

An imaging apparatus 500 may be arranged to operate as an image projector. The image sensor DET1 may be replaced with a two-dimensional light modulator, and the surface SRF1 may operate as a projection screen. The light modulator may be e.g. a digital micro mirror device, a liquid crystal
20 modulator, or an array of light emitting diodes. The imaging apparatus 500 may comprise the imaging device 100 and the light modulator. The light modulator may be arranged to form an image, and the imaging device 100 may be arranged to project the image on the surface SRF1.

25 In an embodiment, the anamorphic unit 10 may be manufactured, stored, and/or transported separately from the focusing unit 20. A digital camera CAM1 may comprise the focusing unit 20 and the image sensor DET1. The anamorphic unit 10 may be provided as a separate unit, which may be attached to the digital camera. The anamorphic unit 10 may be attached e.g.
30 to the digital camera by an end user of the apparatus 500.

In an embodiment, the digital image DIMG1 may be stored in a memory and/or displayed to a viewer without digitally correcting the distortion. Thanks to the anamorphic unit, the relative vertical distortion of the digital image
35 DIMG1 may be so small that a human viewer may recognize the images of

the objects also without digitally correcting the distortion. The digital image DIMG1 may comprise an image of a linear object such that the image of the linear object may be substantially linear without digitally correcting the distortion. The aspheric unit 10 may be attached to a digital camera, and the
5 digital images DIMG1 provided by the digital camera may be stored and/or used without a need to install new software to the camera.

Fig. 8 shows a prior art solution for capturing a panorama image.

10 For the person skilled in the art, it will be clear that modifications and variations of the devices and the methods according to the present invention are perceivable. The figures are schematic. The particular embodiments described above with reference to the accompanying drawings are illustrative only and not meant to limit the scope of the invention, which is defined by the
15 appended claims.

CLAIMS

1. An imaging device (100,500), comprising:
 - an anamorphic unit (10) to form a virtual image (VMG1) of a cylindrical viewing region (SRF1), and
 - a focusing unit (20) to form a real image (IMG1) of the auxiliary virtual image (VMG1),wherein the anamorphic unit (10) comprises two or more refractive lenses (LNS11, LNS12) which have been selected such that the horizontal refractive power ($P_{x,C}$) of the imaging device (100) is greater than 1.5 times the vertical refractive power ($P_{y,C}$) of the imaging device (100), and the anamorphic unit (10) is arranged to form the virtual image (VMG1) by refracting light ($B0_k$) received from the cylindrical viewing region (SRF1) such that the aspect ratio ($\Delta\phi'/\Delta\theta'$) of the virtual image (VMG1) is lower than the aspect ratio ($\Delta\phi/\Delta\theta$) of the viewing region (SRF1).
2. The device (100,500) of claim 1 wherein the anamorphic unit (10) is afocal.
3. The device (100,500) of claim 1 or 2 wherein the first refractive lens (LNS11) of the device (100,500) on the object side of the device (100,500) is a negative cylindrical meniscus lens.
4. The device (100,500) according to any of the claims 1 to 3 wherein the horizontal refractive power ($P_{x,B}$) of the focusing unit (20) is equal to the vertical refractive power ($P_{y,B}$) of the focusing unit (20) in a situation where the focusing unit (20) is operated without the anamorphic unit (10).
5. The device (100,500) according to any of the claims 1 to 4 wherein the anamorphic unit (10) comprises a first negative cylindrical meniscus lens (LNS11), and a second bi-concave negative cylindrical lens LNS12.
6. The device (100,500) according to any of the claims 1 to 5 wherein the anamorphic unit (10) comprises one or more lenses (LNS14, LNS15) arranged to match the optical output of the anamorphic unit 10 with the viewing region of the focusing unit 20.

7. The device (100,500) according to any of the claims 1 to 6, wherein the angular width ($\Delta\phi$) of the viewing region (SRF1) is in the range of 120° to 270°, and the angular height ($\Delta\theta$) of the viewing region (SRF1) is in the range of 15% to 34% of the angular width ($\Delta\phi$) of the viewing region (SRF1).

8. The device (100,500) according to any of the claims 1 to 7, wherein the aspect ratio ($\Delta\phi/\Delta\theta$) of the viewing region (SRF1) is in the range of 3:1 to 7:1.

9. The device (500) according to any of the claims 1 to 8 comprising an image sensor (DET1), wherein the imaging device (100) is arranged to form the real image (IMG1) on the image sensor (DET1), and the aspect ratio (w_{DET1}/h_{DET1}) of the active area of the image sensor (DET1) is lower than or equal to 2:1.

10. The device (500) of claim 9, wherein the real image (IMG1) covers more than 95% of the active area of the image sensor (DET1)

11. The device (500) of claim 9 or 10, wherein the image sensor (DET1) is arranged to provide a digital image (DIMG1), and the device (500) comprises a data processor (CNT1), which is configured to provide a panorama image (PAN1) by correcting distortion of the digital image (DIMG1).

12. The device (500) according to any of the claims 1 to 11, wherein the relative difference between vertical magnification ($d\theta''/d\theta$) at a corner of the real image (IMG1) and vertical magnification ($d\theta''/d\theta$) at the center of the real image (IMG1) is smaller than 5%.

13. A method for forming a real image (IMG1) of a viewing region (SRF1), the method comprising:

- forming a virtual image (VMG1) of the viewing region (SRF1) by using an anamorphic unit (10), and
- forming a real image (IMG1) of the auxiliary virtual image (VMG1) by using a focusing unit (20),

- wherein the anamorphic unit (10) comprises two or more refractive lenses (LNS11, LNS12) which have been selected such that the horizontal refractive power ($P_{x,C}$) of the imaging device (100) is greater than 1.5 times the vertical refractive power ($P_{y,C}$) of the imaging device (100), and the anamorphic unit
- 5 (10) is arranged to form the virtual image (VMG1) by refracting light ($B0_k$) received from the cylindrical viewing region (SRF1) such that the aspect ratio ($\Delta\phi'/\Delta\theta'$) of the virtual image (VMG1) is lower than the aspect ratio ($\Delta\phi/\Delta\theta$) of the viewing region (SRF1).
- 10 14. The method of claim 13, wherein the anamorphic unit (10) is afocal, and the first refractive lens (LNS11) of the anamorphic unit (10) is a negative cylindrical meniscus lens.

1/9

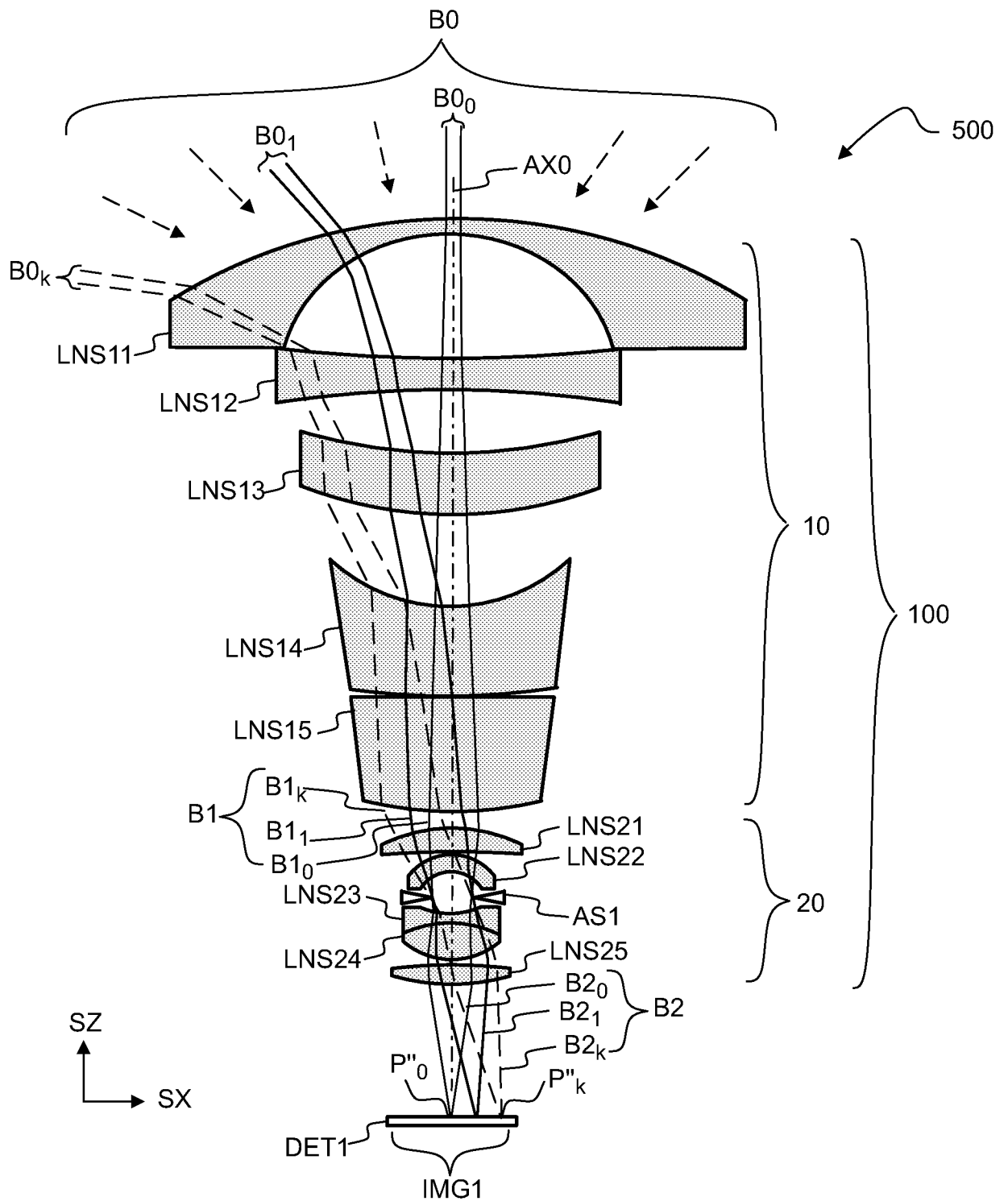


Fig. 1a

2/9

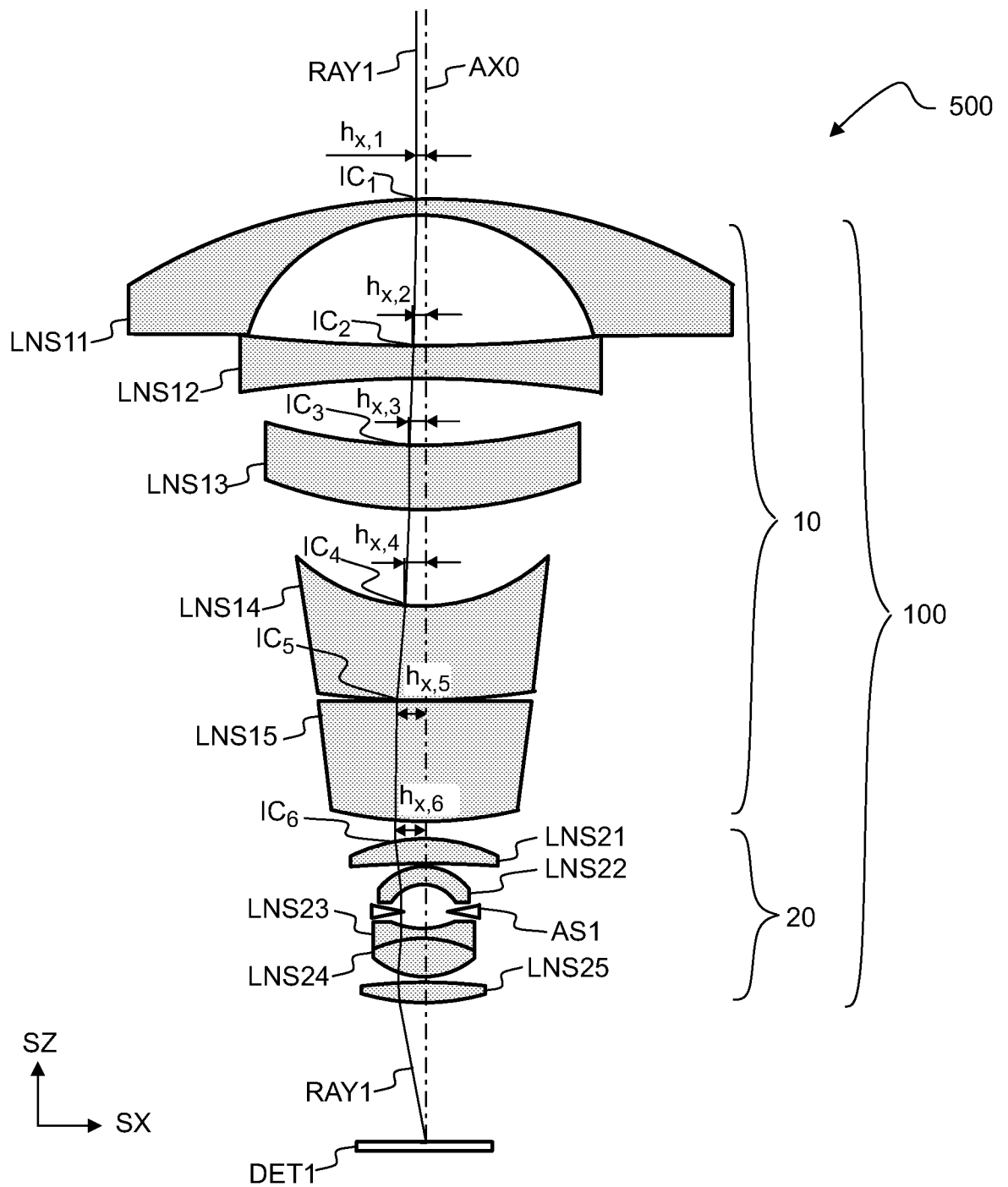


Fig. 1b

3/9

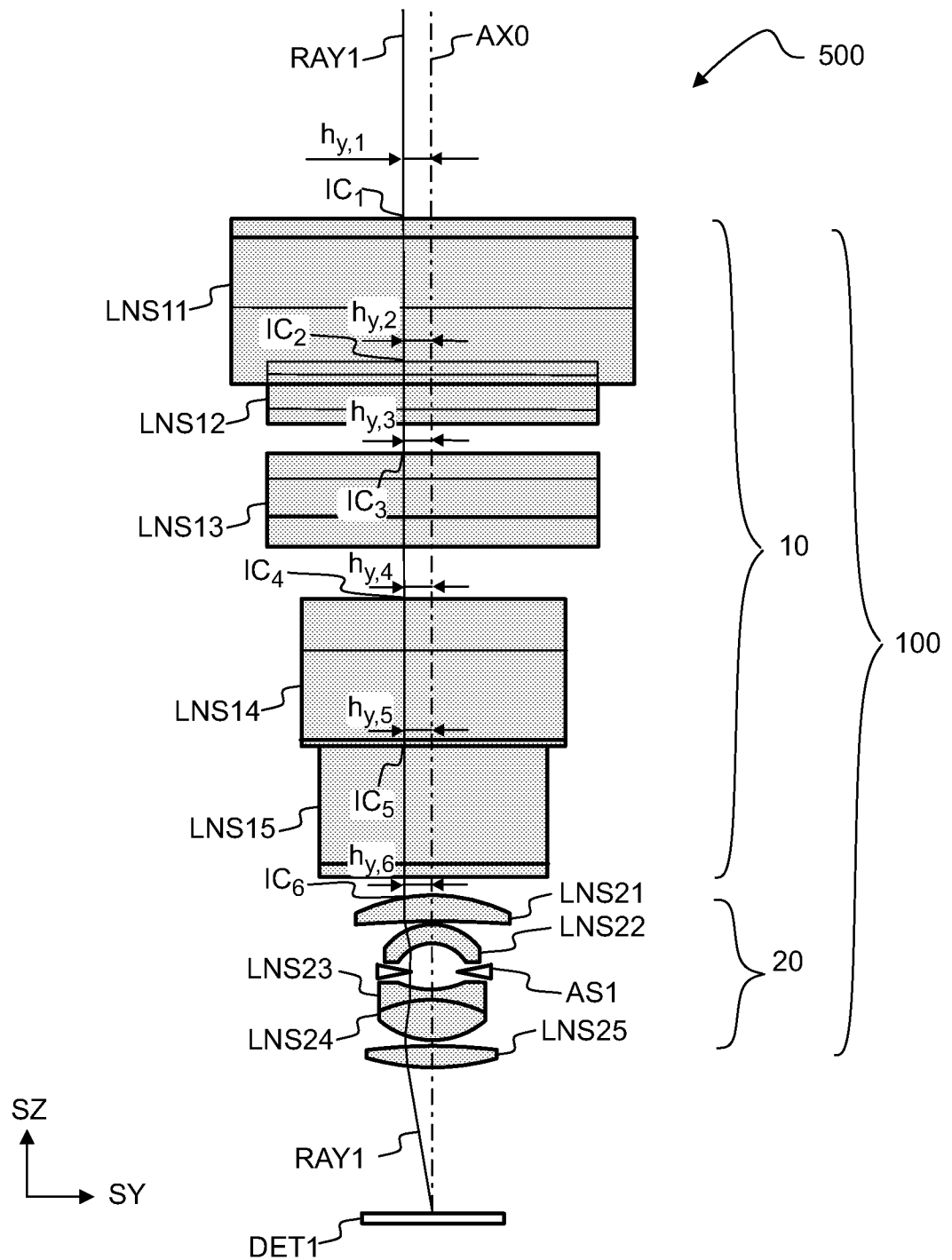
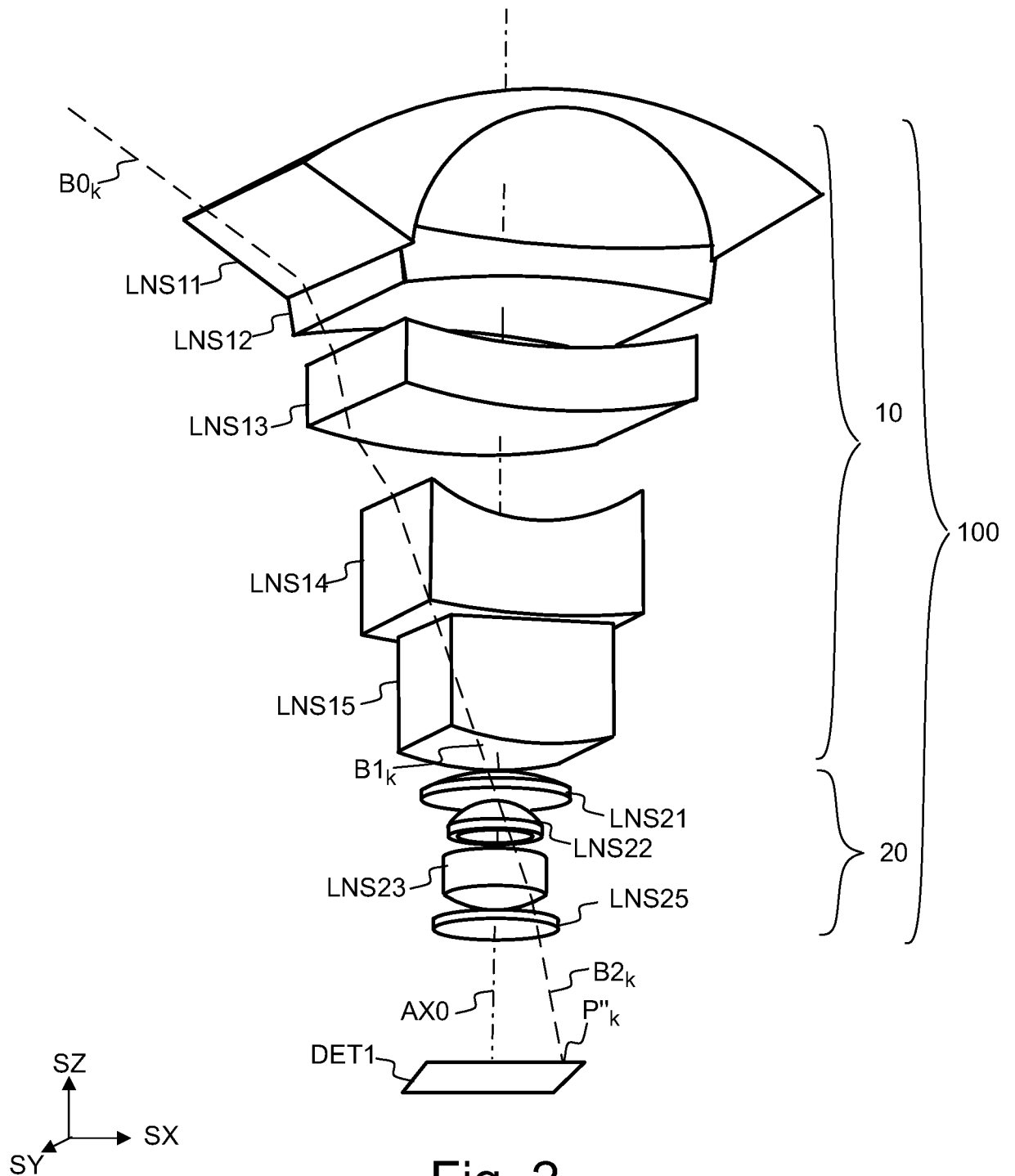


Fig. 1c

4/9



5/9

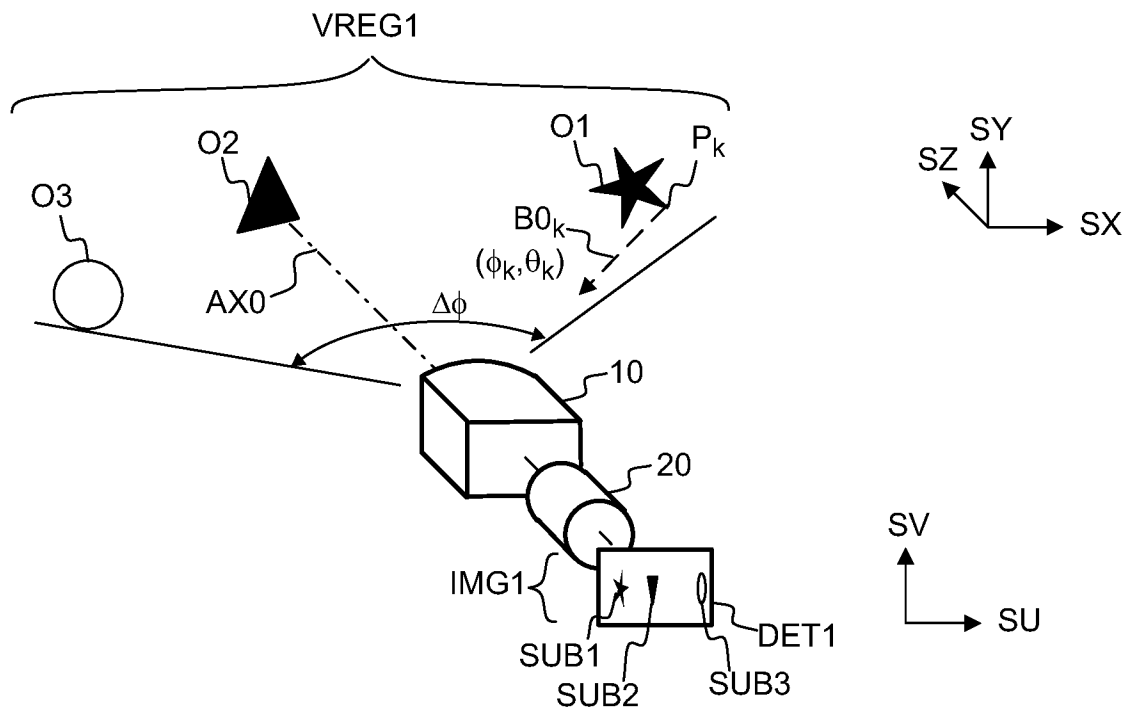


Fig. 3a

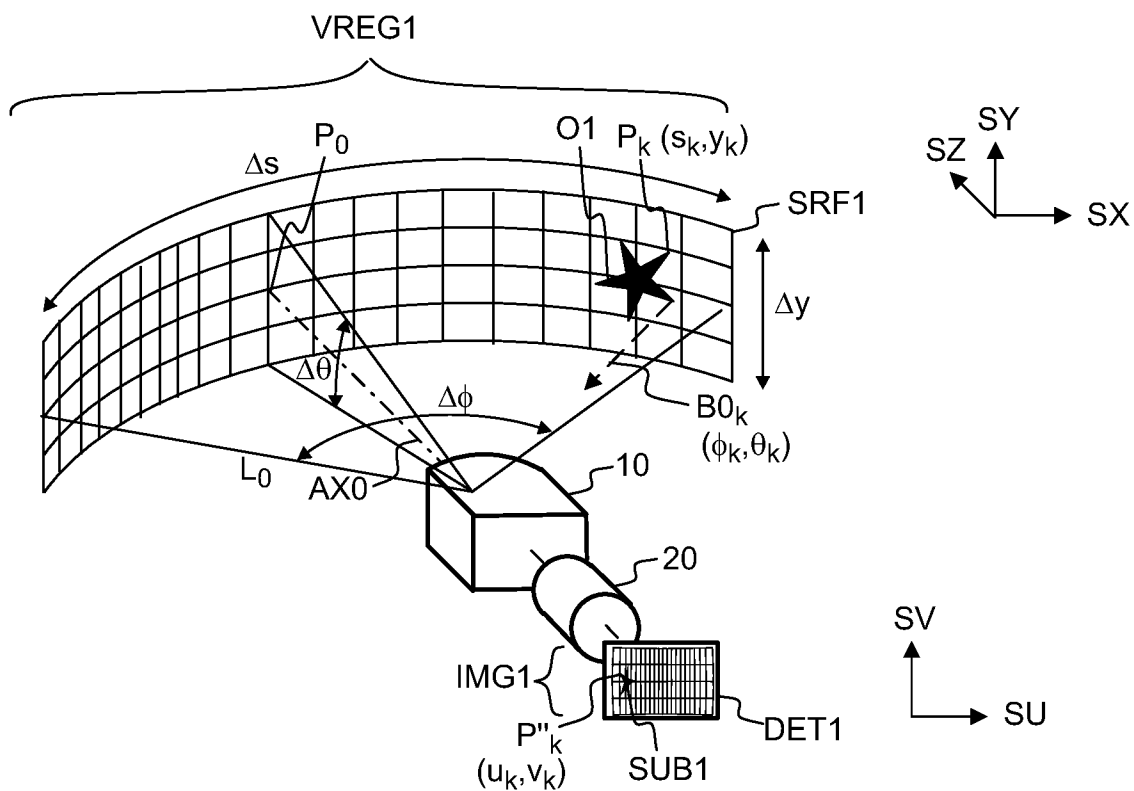


Fig. 3b

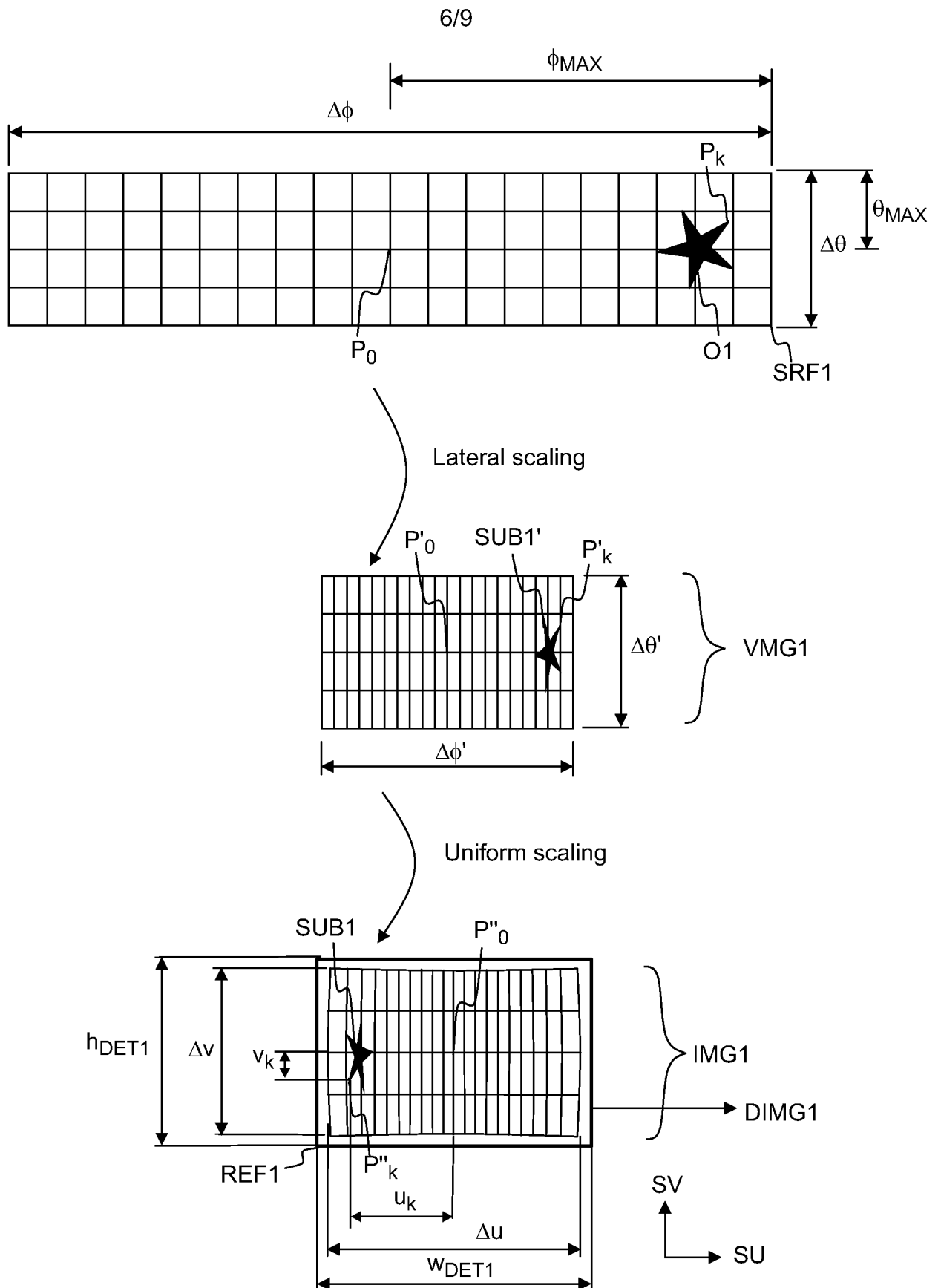


Fig. 4

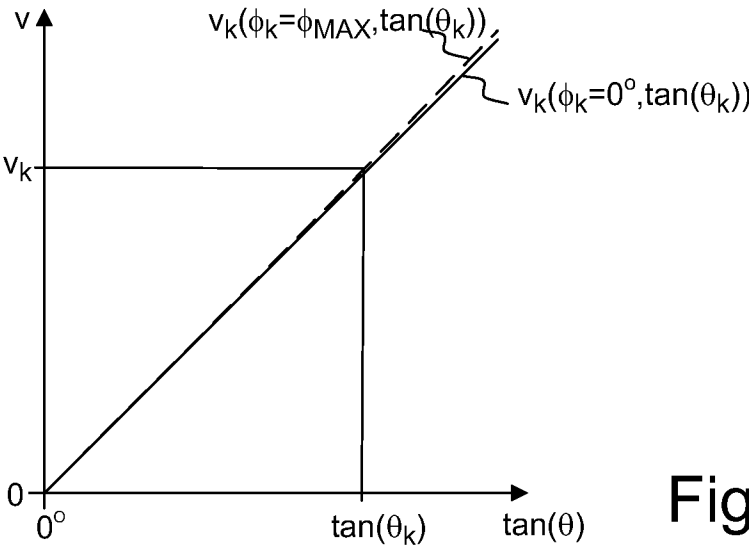


Fig. 5a

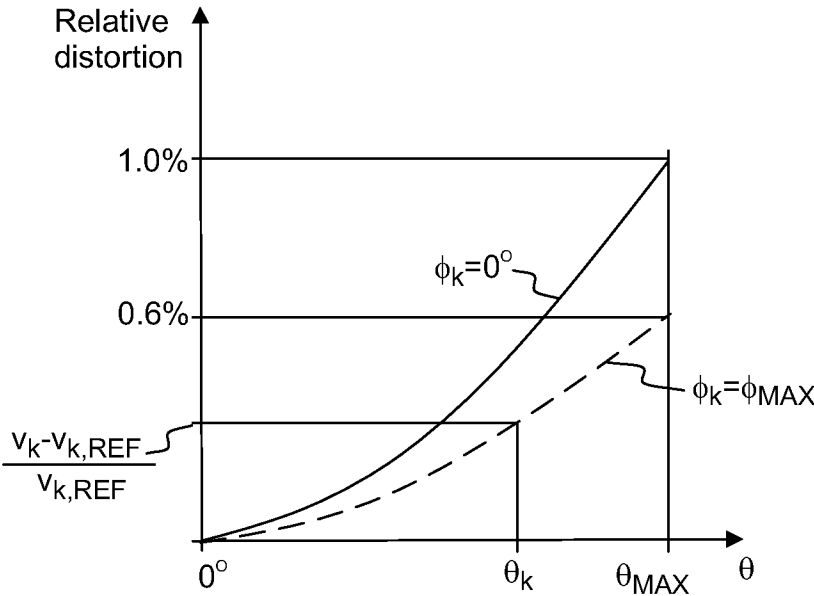


Fig. 5b

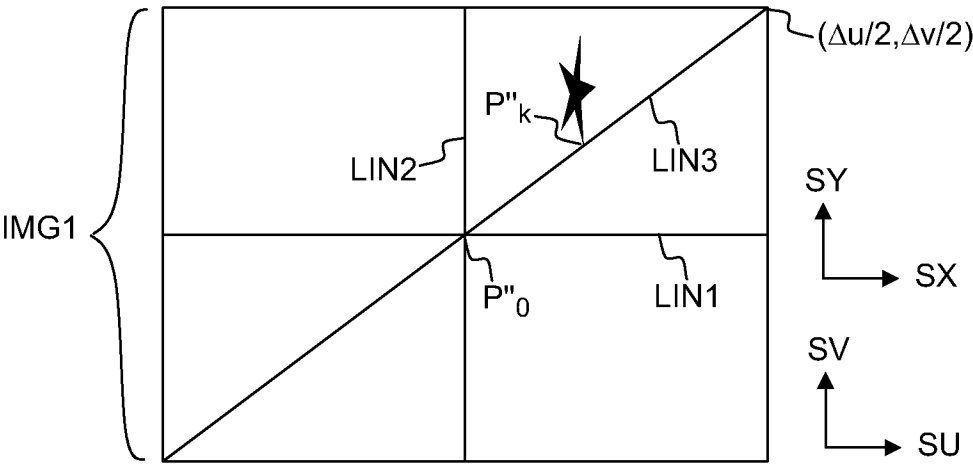


Fig. 5c

8/9

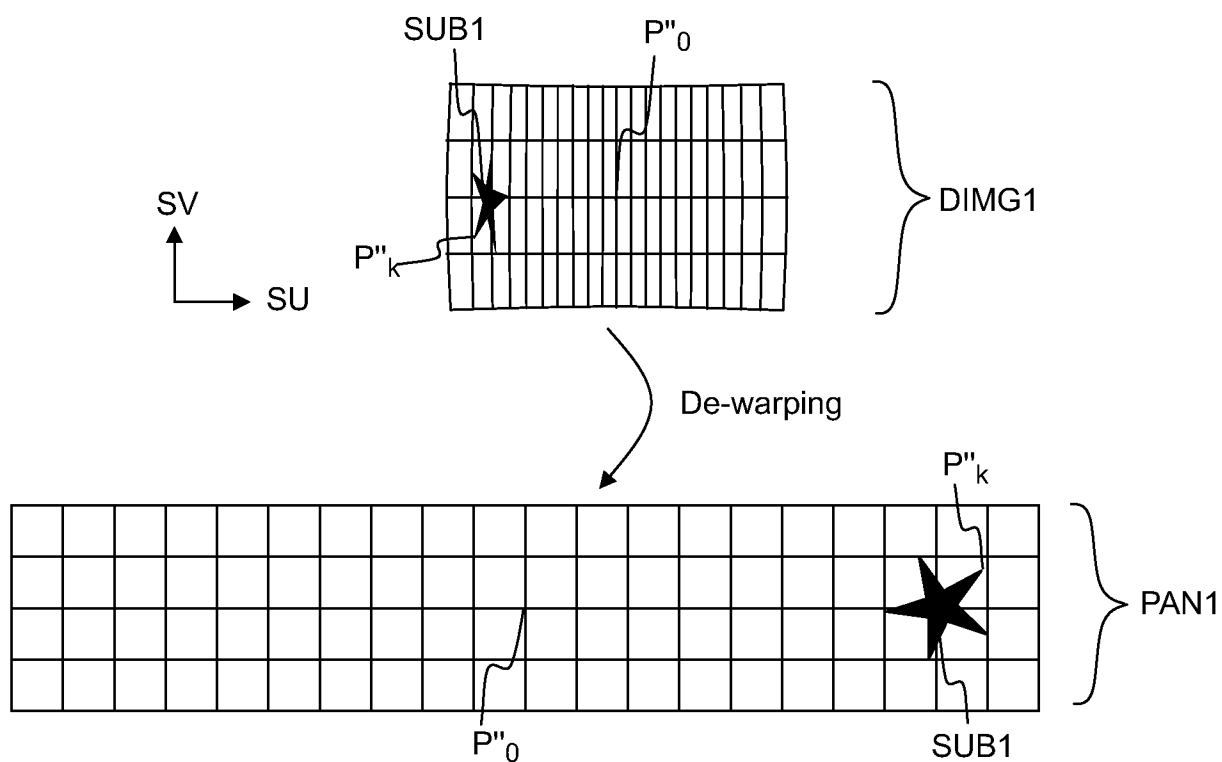


Fig. 6

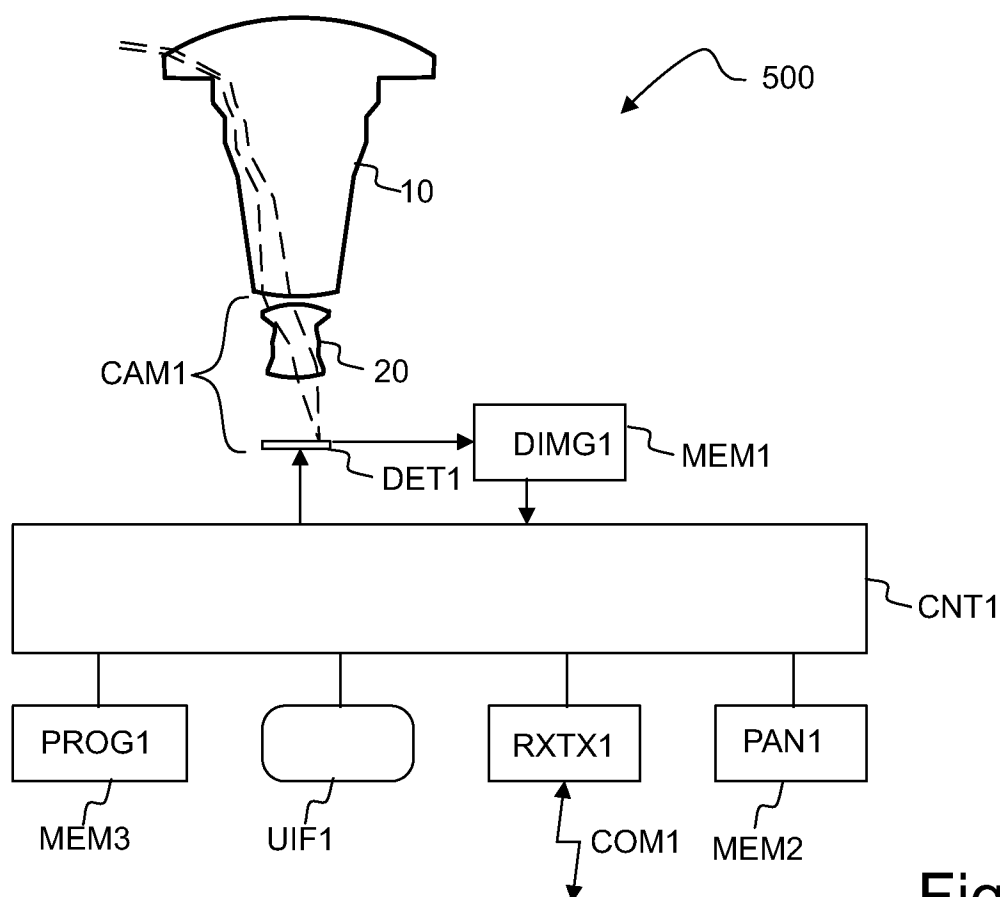


Fig. 7

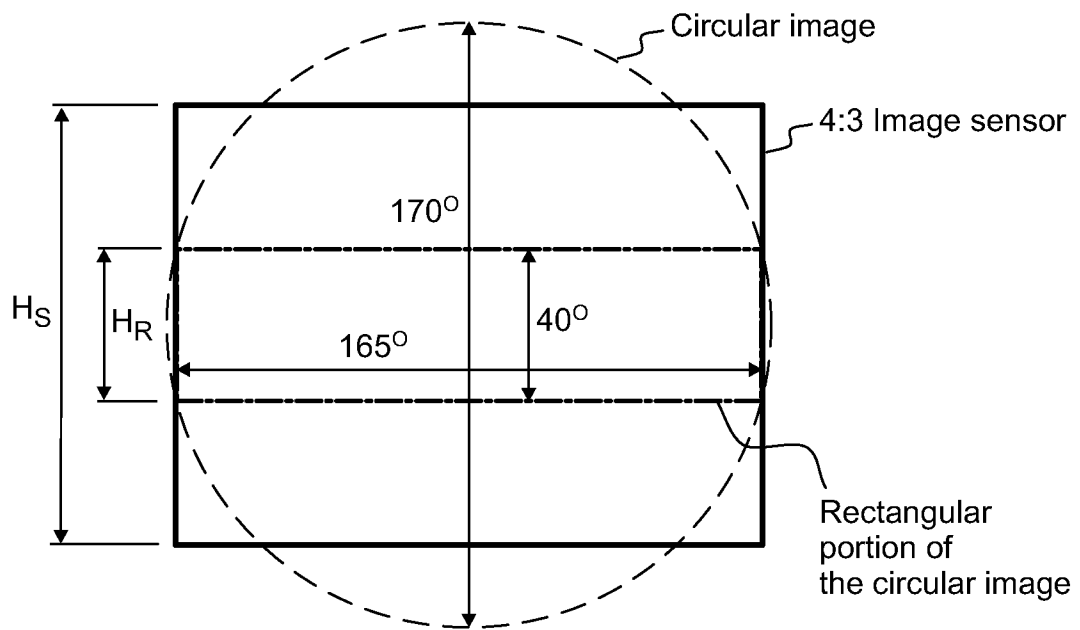


Fig. 8
Comparative example

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2017/050203

A. CLASSIFICATION OF SUBJECT MATTER INV. G02B13/06 G02B13/08 G02B3/06 G03B37/06 H04N5/232 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G02B G03B H04N		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/300973 A1 (NEIL IAIN A [CH]) 9 October 2014 (2014-10-09) paragraphs [0049] - [0059]; figures 1,2; tables 1,2	1-14
X	----- US 2009/268305 A1 (PRETORIUS MARCO [DE]) 29 October 2009 (2009-10-29) paragraphs [0093] - [0098]	1
X	----- US 2013/022345 A1 (DODOC AURELIAN [DE] ET AL) 24 January 2013 (2013-01-24) paragraphs [0066] - [0089]	1
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 31 May 2017		Date of mailing of the international search report 12/06/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Stemmer, Michael

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/FI2017/050203

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2014300973	A1	09-10-2014	NONE	

US 2009268305	A1	29-10-2009	DE 102008021341 A1	05-11-2009
			US 2009268305 A1	29-10-2009

US 2013022345	A1	24-01-2013	DE 102011077509 A1	20-12-2012
			EP 2535752 A1	19-12-2012
			US 2013022345 A1	24-01-2013
