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United States Patent Application Publication

20250264693

Kind Code

A1

Publication Date

August 21, 2025

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MINIATURE WIDE-ANGLE IMAGING LENS

Abstract

A miniature wide-angle imaging lens has a miniaturization ratio, of a total track length from the center of a first surface to a focal plane by an image circle diameter, with a value less than 3.0. The imaging lens includes, starting from an object side of the lens, a first group of at least three optical elements, a second group including an aperture stop and an optical element immediately in front of or behind the aperture stop, and a third group of at least two optical elements.

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Family ID: 1000008575010

Appl. No.: 19/197154

Filed: May 02, 2025

Related U.S. Application Data

parent US continuation 17010417 20200902 PENDING child US 19197154

parent US continuation 16432180 20190605 parent-grant-document US 10795120 child US 17010417

parent US continuation 15384900 20161220 parent-grant-document US 10353173 child US 16432180

us-provisional-application US 62298795 20160223

us-provisional-application US 62387409 20151223

Publication Classification

Int. Cl.: G02B13/00 (20060101); **G02B5/00** (20060101); **G02B5/20** (20060101); **G02B9/62** (20060101); **G02B9/64** (20060101); **G02B13/06** (20060101)

U.S. Cl.:

CPC G02B13/001 (20130101); **G02B5/005** (20130101); **G02B5/208** (20130101); **G02B9/62** (20130101); **G02B9/64** (20130101); **G02B13/0045** (20130101); **G02B13/06** (20130101);

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of U.S. patent application Ser. No. 17/010,417, filed Sep. 2, 2020, entitled “Miniature Wide-Angle Imaging Lens,” currently pending, which is a continuation application of U.S. patent application Ser. No. 16/432,180, filed Jun. 5, 2019, entitled “Miniature Wide-Angle Imaging Lens,” now U.S. Pat. No. 10,795,120, which is a continuation application of U.S. patent application Ser. No. 15/384,900, filed Dec. 20, 2016, entitled “Miniature Wide-Angle Imaging Lens,” now U.S. Pat. No. 10,353,173, which claims the benefit of U.S. Provisional Patent Application No. 62/387,409, filed Dec. 23, 2015, entitled “Miniature wide-angle imaging lens,” now expired, and U.S. Provisional Patent Application No. 62/298,795, filed Feb. 23, 2016, entitled “Miniature wide-angle imaging lens,” now expired, the entire contents of all of which are incorporated by reference herein.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to optical lenses and more particularly to miniature lenses having a wide-angle field of view.

[0003] For most applications requiring wide-angle imaging, larger lens constructions having a miniaturization ratio (i.e., a total track length over an image circle diameter) greater than 3.0 are often used. However, for consumer applications, especially with mobile devices, the trend is that the lens thicknesses are becoming thinner while the sensor sizes are becoming larger. Accordingly, a new kind of wide-angle lenses with a miniaturization ratio less than 3.0 are required.

[0004] Previously suggested miniature wide-angle lenses, such as that described in “Consumer electronic optics: how small can a lens be: the case of panomorph lenses” published in “Proc. SPIE 9192, Current Developments in Lens Design and Optical Engineering XV, 91920H,” or as in U.S. Pat. No. 8,248,715 or U.S. Pat. App. Pub. Nos. 2014/0029115, 2013/0308206, 2014/0226222, 2014/0285906, 2015/0253542, 2015/0268446 or 2012/0212839 were designed for previous generations of sensors having smaller sizes and larger pixels. These lenses had lower performance requirements, especially regarding image quality and aperture size. For these existing lens constructions, a total of three to six optical elements were enough to meet the required performances for these sensors. For the existing wide-angle 6-element lenses, a symmetric construction using 3 elements in front of the stop and 3 elements behind the stop has been used. However, with new larger sensors and smaller pixels, more complex wide-angle lens constructions using six elements with asymmetric constructions around the stop or using seven or more elements must be designed to achieve the required performances.

[0005] One of the challenges to achieve good imaging performance over the whole field of view of a miniature wide-angle lens is the change of relative illumination from the center to the edge of the field of view. In wide-angle lenses, the relative illumination is usually maximum in the center and drops continuously toward the edge of the field of view. The consequence of lower illumination toward the edge is a lower image quality at the edge due to increased diffraction effects and additional sensor noise at the edges.

[0006] Another challenge to achieve good imaging performance over the whole field of view of a miniature wide-angle lens is a drop of the modulation transfer function (MTF) from the center to the edge of the field of view. In wide-angle lenses, the image MTF is usually maximum in the center and drops continuously toward the edge of the field of view. The consequence of lower MTF toward the edge is a lower image quality at the edge.

BRIEF SUMMARY OF THE INVENTION

[0007] To overcome all the previously mentioned issues, embodiments of the current invention describe miniature wide-angle imaging lenses having a miniaturization ratio (i.e., total track length from the center of the first surface to the focal plane over the image circle diameter) having a value less than 3.0 while maintaining a good balance between image quality parameters, including MTF, relative illumination, and resolution. The imaging lens construction, in order from the object space to the image space, preferably includes a first group of elements, a second group of elements, and a third group of elements.

[0008] The first group of elements, preferably including all the elements in front of the second group, has a negative optical power in the paraxial region and preferably includes at least three optical lenses. Of these at least three optical lenses, the first lens on the object side is generally a negative meniscus lens with a surface on the object side and accepting light from an opening angle of at least 100° and generally between 120° to 280° .

[0009] The second group of elements preferably includes an aperture stop and a single optical lens immediately in front of or behind the aperture stop. The single optical lens of the second group is preferably a positive lens.

[0010] The third group of elements preferably includes at least two optical lenses after the second group. Of these at least two optical lenses, there is generally at least one positive element and at least one negative element. The last lens element on the image side has a surface on the image side transmitting light to an opening angle of at least 40° .

[0011] In an embodiment of the current invention, the miniature optical lens has six optical elements, split as three, one, and two elements respectively for the first, second, and third groups. In another embodiment of the current invention, the miniature optical lens has seven optical elements in it, split as three, one, and three elements respectively for the first, second, third groups. In another embodiment of the current invention, the miniature optical lens has eight optical elements in it, split as four, one, and three elements respectively for the first, second and third groups.

[0012] In some embodiments of the current invention, the targeted resolution curve of the miniature wide-angle lens is configured to offset, at least in part, the drop of relative illumination from the miniature wide-angle lens by increasing the number of pixels imaged in the zone where the relative illumination is lower.

[0013] In some other embodiments of the current invention, the targeted resolution curve of the miniature wide-angle lens is configured to offset, at least in part, the drop of MTF from the miniature wide-angle lens by increasing the number of pixels imaged in the zone where the MTF is lower.

[0014] In some other embodiments of the current invention, the targeted resolution curve of the miniature wide-angle lens is configured as the optimal curve to produce the highest relative illumination and MTF values combination and hence produce the optimal image quality for the whole lens plus camera system.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0015] The foregoing summary, as well as the following detailed description of a preferred

embodiment of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustration, there is shown in the drawings an embodiment which is presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown.

[0016] In the drawings:

[0017] FIG. **1** is a first preferred embodiment of a miniature wide-angle lens with six total lens elements;

[0018] FIG. **2** is a second preferred embodiment of a miniature wide-angle lens with seven total lens elements;

[0019] FIG. **3** is third preferred embodiment of a miniature wide-angle lens with eight total lens elements;

[0020] FIG. **4** is an example of a typical relative illumination curve of a miniature wide-angle lens;

[0021] FIG. **5** is an example of a typical MTF curve of a miniature wide-angle lens;

[0022] FIG. **6** is an example of a targeted resolution curve used to at least partially compensate the relative illumination or at least partially compensate the MTF according to certain embodiments of the present invention; and

[0023] FIG. **7** is an example of a targeted resolution curve chosen to produce the highest relative illumination in the whole field of view while keeping the highest MTF according to certain embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Certain terminology is used in the following description for convenience only and is not limiting. The words “right”, “left”, “lower”, and “upper” designate directions in the drawings to which reference is made. The words “inwardly” and “outwardly” refer to directions toward and away from, respectively, the geometric center of the device and designated parts thereof. The terminology includes the above-listed words, derivatives thereof, and words of similar import. Additionally, the words “a” and “an”, as used in the claims and in the corresponding portions of the specification, mean “at least one.”

[0025] FIG. **1** shows a first embodiment of the present invention with an optical layout for a design having six optical elements in an asymmetric configuration around the stop, having four optical elements before the stop and two optical elements after the stop. The lens **100** is comprised of the three groups **110**, **112** and **114**. In this embodiment of the miniature wide-angle lens **100**, the first group **110** from the object space is made of lenses **120**, **121** and **122**. The first group has a negative total optical power. The second group **112** includes an aperture stop **124** and a single positive lens **123**. The second group **112** has positive optical power. In this embodiment of the miniature wide-angle lens **100**, the third group **114** has two optical elements **125**, **126** and has a negative total optical power.

[0026] Light entering the miniature lens **100** hits a first surface of element **120** from all directions between an upper angle **130** and a lower angle **134**. In this example embodiment of FIG. **1**, a total field of view around the central field **132** of the lens **100** is 180°, but any total field of view over 100° can be considered as a wide-angle lens according to the present invention.

[0027] The light then passes through all the elements **120**, **121**, **122**, of the first group **110**, the single lens **123** and the aperture stop **124** of the second group **112**, and the elements **125** and **126** of the third group **114** to reach an IR filter and image sensor **127**. More specifically, the light beam from direction **130** reaches the sensor **127** at position **144**, the light from direction **132** reaches the sensor **127** at position **142**, and the light from direction **134** reaches the sensor **127** at position **140**. For all beams of light **130**, **132** and **134**, the chief-ray is defined as the middle ray of the three rays drawn because it passes through the center of the aperture stop **124**. In this example embodiment, the angle of the cone of light formed by the chief-rays reaching the sensor plane at positions **140** and **144** is over 40° to minimize the dimensions of the lens **100**. When measured with respect to the chief-ray reaching the sensor **127** at position **142**, which represents the optical axis of the lens **100**,

the chief-ray angle of the extreme rays reaching the sensor at position **140** or **144** are over 20° .
[0028] The lens **100** has a total track length **150**, which is a measure from the first surface on the object side of lens **120** to the image sensor **127**, and forms an image having a diameter **160**, which is a distance on the sensor **127** between the position **140** and the position **144** where the light beams from the lower and the upper fields **130**, **134** reach the sensor **127**. The miniaturization ratio is calculated by dividing the total track length **150** over the footprint diameter **160** and is less than 3.0 for any miniature lens according to the present invention and could even be less than 2.0 for an extreme miniature lens.

[0029] FIG. **2** shows an embodiment of the present invention with an optical layout for a design having seven optical elements. The lens **200** is comprised of the three groups **210**, **212** and **214**. In this embodiment of the miniature wide-angle lens **200**, the first group **210** from the object space is made of lenses **220**, **221**, and **222**. The first group **210** has a negative total optical power. The second group **212** includes the aperture stop **223** and a single positive lens **224**. The second group **212** has positive optical power. In this embodiment of the miniature wide-angle lens **200**, the third group **214** has three optical elements **225**, **226**, **227** and has a negative total optical power.

[0030] Light entering the miniature lens **200** hits the first surface of element **220** from all directions between the upper angle **230** and the lower angle **234**. In this example embodiment of FIG. **2**, the total field of view around the central field **232** is 180° , but any total field of view over 100° can be considered as a wide-angle lens according to the present invention.

[0031] The light then passes through all the elements **220**, **221**, **222** of the first group **210**, the aperture stop **223** and positive lens **224** of the second group **212**, and the elements **225**, **226** and **227** of the third group **214** to reach the IR filter and image sensor **228**. More specifically, the light beam from direction **230** reaches the sensor at position **244**, the light from direction **232** reaches the sensor at position **242**, and the light from direction **234** reaches the sensor at position **240**. In this example, an angle of the cone of light formed by the chief-rays reaching the sensor plane at positions **240** and **244** is over 40° to minimize the dimensions of the lens **200**. When measured with respect to the chief ray reaching the sensor **228** at position **242**, which represents the optical axis of the lens **200**, the chief-ray angle of the extreme rays is over 20° .

[0032] The lens **200** has a total track length **250**, which is a measure from the first surface on the object side of lens **220** to the image sensor **228** and forms an image having a diameter **260**, which is the distance on the sensor between the position **240** and the position **244** where the light beams from the upper and the lower fields **230**, **234** reach the sensor. The miniaturization ratio is calculated by dividing the total track length **250** over the footprint diameter **260** and is less than 3.0 for any miniature lens according to the present invention, and could even be less than 2.0 for an extreme miniature lens.

[0033] FIG. **3** shows an embodiment of the present invention with an optical layout for a design having eight optical elements. The lens is comprised of the three groups **310**, **312** and **314**. In this embodiment of the miniature wide-angle lens, the first group **310** from the object space is made of lenses **320**, **321**, **322** and **323**. The first group has a negative total optical power. The second group **312** includes the aperture stop **324** and a single positive lens **325**. The second group **312** has positive optical power. In this embodiment of the miniature wide-angle lens **300**, the third group **314** has three optical elements **326**, **327**, **328** and has a negative total optical power.

[0034] Light entering the miniature lens **300** hit the first surface of element **320** from all directions between the upper angle **330** and the lower angle **334**. In this example embodiment of FIG. **3**, the total field of view around the central field **332** is 180° , but any total field of view over 100° can be considered as a wide-angle lens according to the present invention.

[0035] The light then passes through all the elements **320**, **321**, **322**, **323** of the first group **310**, the aperture stop **324** and lens **325** of the second group **312**, and the elements **326**, **327** and **328** of the third group **314** to reach the IR filter and image sensor **329**. More specifically, the light beam from direction **330** reaches the sensor **329** at position **344**, the light from direction **332** reaches the sensor

329 at position **342**, and the light from direction **334** reaches the sensor **329** at position **340**. In this example, the angle of the cone of light formed by the chief-rays reaching the sensor plane at positions **340** and **344** is over 40° to minimize the dimensions of the lens. When measured with respect to the chief ray reaching the sensor at position **342**, which represents the optical axis of the lens, the chief-ray angle of the extreme rays is over 20° .

[0036] The lens has a total track length **350**, which is a measure from the first surface on the object side of lens **320** to the image sensor **329**, and forms an image having a diameter **360** which is a distance on the sensor **329** between the position **340** and the position **344** where the light beams from the upper and the lower fields **330**, **334** reach the sensor. The miniaturization ratio is calculated by dividing the total track length **250** over the footprint diameter **260** and is less than 3.0 for any miniature lens according to the present invention and could even be less than 2.0 for an extreme miniature lens.

[0037] In some embodiments of the present invention, all of the elements inside the miniature wide-angle lenses are made of plastic materials in part to ease the mass-production or lower the costs. In some other embodiments of the present invention, the miniature wide-angle lens consist of at least one glass element to improve the optical performances of the miniature wide-angle lens or to increase the rigidity of when the glass element is the first element.

[0038] FIG. **4** shows a typical relative illumination curve **400** for a miniature wide-angle lens according to embodiments of the present invention. The exact values of the relative illumination with respect to the field of view vary between each embodiment of the present invention, but the overall shape having a value around 100% at 0° shown at center **410** and under 80% at the maximum field angle shown at position **420** is present in all families of miniature wide-angle lenses according to the present invention.

[0039] FIG. **5** shows a typical sagittal MTF curve **500** and tangential MTF curve **505** for a miniature wide-angle lens according to embodiments of the present invention. The exact values of the MTF with respect to the field of view vary between each embodiment of the present invention and also vary according to the spatial frequency at which the MTF is calculated, but the overall shape having a higher value at 0° shown at center **510** than at the edge shown at position **520** is present in all families of miniature wide-angle lenses according to the present invention.

[0040] FIG. **6** shows an example targeted resolution curve **600** for a miniature wide-angle lens according to embodiments of the present invention where the targeted resolution is non-linear and a higher number of pixels per degree is intentionally present in a part of the image. In some embodiments of the miniature wide-angle, the shape of the targeted resolution curve is intentionally designed to compensate for the drop of relative illumination seen in FIG. **4**. In some other embodiments of the miniature wide-angle lens, the shape of the targeted resolution is intentionally designed to compensate for the drop of MTF seen in FIG. **5**. In the zone where the resolution is higher, there are more pixels of the sensors used to image a given angle of the object space. By having more imaging pixels in this zone, this compensates for the lower image quality in this zone either due to the lower relative illumination or the lower MTF. The final resulting image can then be processed to create a resulting image with constant image quality across the whole field of view.

[0041] FIG. **7** shows another example embodiment of a non-linear targeted resolution curve **700** for a miniature wide-angle lens according to the present invention. The targeted resolution curve is chosen to have an upward curve between the center resolution value **710** and a maximum **712** (number of pixels/degree), followed by a downward curve between the maximum **712** and a region near the edge of the field of view around position **714**. This downward curve between maximum value **712** and position **714** allows the lens system to have a higher relative illumination value toward the edge of the field of view by having a lower object to image magnification ratio in that region and hence redirecting the same quantity of light from an object to a smaller region in the image with more illumination.

[0042] In some embodiments of a miniature wide-angle lens according to the present invention, the

resolution curve has a change of direction at the edge of the field of view **716**. This change of direction is an upward trend if it is preceded by a downward trend and it is a downward trend if it is preceded by an upward trend. This change of direction allows for a closer value of resolution in pixels/degree in the center **710** and at the edge **716**, creating the best balance of MTF between the center **710** and the edge **716**.

[0043] Combined together, the downward curve between maximum value **712** and position **714** allowing higher relative illumination and the change of direction in the curve between position **714** and edge provides **716** the best image quality on the lens and camera system. The more balanced relative illumination creates less sensor noise in the images due to illumination differences and less difference of diffraction effects on the image quality due to the variable f/# across the field of view. For the more balanced MTF, thanks to the change of direction between position **614** and edge **616**, it is directly related to the image quality of the lens.

[0044] All of the above are figures and examples of miniatures wide-angle lenses. They are examples of families of constructions having three groups and at least six optical elements. Furthermore, the miniature wide-angle lenses can be optimized according to a function which at least includes the relative illumination, the resolution and the MTF. Similar constructions are possible and the three examples presented should not limit the scope and spirit of the present invention. It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the appended claims.

Claims

1. A miniature wide-angle imager comprising: an image sensor; a plurality of optical elements arranged along an optical axis and configured to form an image on the image sensor, a maximum dimension of the image formed on the image sensor being defined by a first position on the image sensor and a second position on the image sensor, light beams reaching the image sensor at the first and second positions defining a field of view of between 100° and 120°, an angle of chief rays reaching the image sensor at the first and second positions being over 20° from the optical axis; a non-linear targeted resolution creating a magnified zone in the image with a higher object to image magnification compared to a linear targeted resolution, the first and second positions on the image sensor being within the magnified zone, a center of the field of view having a lower object to image magnification compared to the linear targeted resolution; and a modulation transfer function (MTF), a value of the MTF at any field angle in the magnified zone being lower than a value of the MTF at any field angle outside of the magnified zone.
 2. The miniature wide-angle imager of claim 1, wherein the plurality of optical elements is between six and eight.
 3. The miniature wide-angle imager of claim 2, wherein the plurality of optical elements is six.
 4. The miniature wide-angle imager of claim 1, wherein a first of the optical elements on an object side is made of glass.
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