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(54) Title: OPTICAL SYSTEMS FOR MULTI-SENSOR ENDOSCOPES

(57) Abstract: There is provided herein an optical system for a tip section of a multi-sensor endoscope, the system comprising: a front-pointing camera sensor; a front objective lens system; a side-pointing camera sensor; and a side objective lens system, wherein at least one of said front and side objective lens systems comprises a front and a rear sub-systems separated by a stop diaphragm, said front sub-system comprises, in order from the object side, a first front negative lens and a second front positive lens, said rear sub-system comprises, in order from the object side, a first rear positive lens, an achromatic sub-assembly comprising a second rear positive lens and a third rear negative lens, wherein the following condition is satisfied: f (first rear positive lens) $\leq 1.8f$, where f is the composite focal length of the total lens system and f (first rear positive lens) is the focal length of said first rear positive lens.

OPTICAL SYSTEMS FOR MULTI-SENSOR ENDOSCOPES**FIELD OF THE INVENTION**

This invention relates to a wide FOV objective lens system for an endoscope.

BACKGROUND

5 Endoscopes have attained great acceptance within the medical community, since they provide a means for performing procedures with minimal patient trauma, while enabling the physician to view the internal anatomy of the patient. Over the years, numerous endoscopes have been developed and categorized according to specific applications, such as cystoscopy, colonoscopy, laparoscopy, upper GI endoscopy and others. Endoscopes may be inserted into the
10 body's natural orifices or through an incision in the skin.

An endoscope is usually an elongated tubular shaft, rigid or flexible, having a video camera or a fiber optic lens assembly at its distal end. The shaft is connected to a handle, which sometimes includes an ocular for direct viewing. Viewing is also usually possible via an external screen. Various surgical tools may be inserted through a working channel in the
15 endoscope for performing different surgical procedures.

There are known various endoscopes employing in their front insertion part, optical heads for viewing the interior of a body cavity or lumen such as the lower digestive track. Such optical head normally includes at least an illumination means for illuminating the object, an objective lens system and a sensor array.

20 US 6,956,703 discloses an objective lens for endoscopes comprises a front lens unit component and a rear lens unit component, between which a aperture stop is located, wherein the front lens unit component comprises, in order from the object side, a first lens having a negative refractive power, and a second lens having a positive refractive power which directs a surface of the small radius of curvature toward the object side; wherein the rear lens unit
25 component comprises a third lens having a positive refractive power which directs a surface of the small radius of curvature toward the image side, a fourth lens having a positive refractive power, and a fifth lens having a negative refractive power; and wherein the fourth lens and the fifth lens are cemented. The following condition is satisfied: $2.0 < |f_3/f| < 3.0$ where f is the composite focal length of the total system and f_3 is the focal length of the third lens. Still, the

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asymmetric colon environment), requires high quality images capturing a wide Field of View (FOV), which cannot be accomplished using only one detector.

More efforts have been undertaken to improve the optical design of these systems and
5 to create a wide FOV, as seen for example, in US patent number 5,870,234 entitled "Compact wide angle lens", as well as US patent number 6,476,851 entitled "Electronic endoscope". Although these patents bring the advantage of a wide FOV they mainly provide a front view. Another disadvantage is a significant distortion in the periphery looking at the borders of the wide view image.

10

These disadvantages may be partially solved by using a multi image lens for example as shown in US patent application number 2005/0168616 entitled "Methods and apparatus for capturing images with a multi-image lens" or by using other Omni-directional optical solutions, as disclosed, for example, in US patent number 7,362,516 entitled "Optical lens
15 providing Omni-directional coverage and illumination". These technologies may support a wide FOV with relatively low distortion in the periphery of the image however they suffer from a major disadvantage of low optical resolution on side views. Another disadvantage of these technologies is the complexity and space consuming design which typically eliminates the possibility to combine other crucial features like jet, working channels and illuminating
20 sources to the endoscope.

There is still a need in the art for endoscopes, such as colonoscopies, that provide a wide FOV, a wide range of Depth of Field/ Depth of Focus (DOF) and acceptable resolution within the required dimensions of the device used of a medical application.

SUMMARY

25 The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods which are meant to be exemplary and illustrative, not limiting in scope.

It is an object of the current invention to provide optical system(s) for front looking and side looking cameras to be housed in the same head (tip) of an endoscope. The cameras
30 together with their respective optic systems are adapted to provide a high quality image capturing a wide FOV of the complex environment examined by the use of the endoscope. According to some embodiments, there is provided an endoscope comprising at least a front

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looking camera and a side looking camera being essentially perpendicular to one another. According to some embodiments any of the cameras may include a small-sized image sensors such as CCD or CMOS sensors (hereinafter referred to as CCD but can also mean CMOS or any other sensor). In order to keep the outer diameter of the front part of the endoscope as small as possible, the optical systems used in the plurality of cameras need to be compact. Specifically, optical track of the side looking camera needs to be short. In the case where two side looking cameras are positioned along the same axis, preferably essentially, perpendicular to the long axis of the endoscope, the minimal diameter of the endoscope's head is limited to at least twice the total length of the cameras (which typically includes the optical track of the camera, the sensor, and any electronic circuitry and wiring which may be located behind the sensor). Shortening the total length should not affect the FOV or cause distortion. Both optical characteristics should be maintained together with minimal total length.

Additionally, working channel(s) and fluid channel(s) need to traverse the endoscope's head. Thus, the diameter of the cameras and its optical systems needs to be small to allow for space occupied by the channels. Since different sensors may be used per field of view it opens the opportunity for additional working channels space giving big advantage to this application.

In order to effectively work within the confined space in a body cavity, the cameras may be equipped with wide-angle lens, capable of imaging close objects and a wide range of working distances with preservation of image quality.

Optionally, several optical modules (cameras) in one endoscope head, with similar or different designs may be used, optionally each tuned to its desired Depth of Field (DOF).

According to some embodiments, there is provided herein an optical system for a tip section of a multi-sensor endoscope, the system comprising: a front-pointing camera sensor; a front objective lens system; a side-pointing camera sensor; and a side objective lens system, wherein at least one of the front and side objective lens systems comprises a front and a rear sub-systems separated by a stop diaphragm, the front sub-system comprises, in order from the object side, a first front negative lens and a second front positive lens, the rear sub-system comprises, in order from the object side, a first rear positive lens, an achromatic sub-assembly (optionally, a compound achromatic sub-assembly) comprising a second rear positive lens and a third rear negative lens, wherein the following condition is satisfied:

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$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of the first rear positive lens.

The front sub-system may further include an additional front positive lens (such as a meniscus lens) disposed between the first front negative lens and the second front positive lens (as seen, for example, in Fig. 4c).

The rear sub-system may further include a rear protective glass situated between the third rear negative lens and the front-pointing and/or side-pointing camera sensor, wherein the rear protective glass is adapted to protect a detector array of the front-pointing and/or side-pointing camera sensor.

10 According to some embodiments, $f_{(\text{first rear positive lens})} = 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of the first rear positive lens.

According to some embodiments, the front-pointing camera sensor and the front objective lens system may be adapted to provide a Depth of Focus (DOF) of between 4 and 15 110 mm. Optical system having a Depth of Focus (DOF) of between 4 and 110 mm may mean that the optical system is adapted to image objects at an object distance of 4-110mm. The front-pointing camera sensor and the front objective lens system may be adapted to provide a Depth of Focus (DOF) of between 3.5 and 50 mm. The front-pointing camera sensor and the front objective lens system may be adapted to provide an effective spatial 20 resolution of at least 60 lines per mm at Depth of Focus (DOF) of between 5 and 50 mm. The front-pointing camera sensor and the front objective lens system may be adapted to provide an effective angular resolution of about 2' per degree or less at Depth of Focus (DOF) of between 5 and 50 mm. The front-pointing camera sensor and the front objective lens system may be adapted to provide a Field of View (FOV) of about 150 degrees or more. The front- 25 pointing camera sensor and the front objective lens system may be adapted to provide a Field of View (FOV) of about 170 degrees or more.

According to some embodiments, the front-pointing camera sensor and the front objective lens system have a total optical length of about 5 mm or less.

According to some embodiments, the side-pointing camera sensor and the side 30 objective lens system may be adapted to provide a Depth of Focus (DOF) of between 3.5 and

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50 mm. The side-pointing camera sensor and the side objective lens system may be adapted to provide an effective spatial resolution of at least 60 lines per mm at Depth of Focus (DOF) of between 5 and 50 mm. The side-pointing camera sensor and the side objective lens system may be adapted to provide a Depth of Focus (DOF) of between 3 and 30 mm. The side-pointing camera sensor and the side objective lens system may be adapted to provide an effective angular resolution of about 2' per degree or less at Depth of Focus (DOF) of between 4.5 and 25 mm. The side-pointing camera sensor and the side objective lens system may be adapted to provide a Field of View (FOV) of about 150 degrees or more. The side-pointing camera sensor and the side objective lens system may be adapted to provide a Field of View (FOV) of about 170 degrees or more.

According to some embodiments, the side-pointing camera sensor and the side objective lens system may have a total optical length of about 5 mm or less (for example, 4 mm or less, 3 mm or less).

According to some embodiments, the diameter of the first front negative lens may be 2.5 mm or less (without the barrel or lens holder).

According to some embodiments, there is provided an objective lens system for at least one of a front-pointing and side-pointing camera sensors of a multi-sensor endoscope, the objective lens system comprising: a front and a rear sub-systems separated by a stop diaphragm, wherein the front sub-system comprises a first front negative lens and a second front positive lens, and the rear sub-system comprises a first rear positive lens, an achromatic sub-assembly (optionally, a compound achromatic sub-assembly) comprising a second rear positive lens and a third rear negative lens, wherein the following condition is satisfied:

$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of the first rear positive lens.

According to some embodiments, there is provided a tip section of a multi-sensor endoscope comprising an optical system comprising: a front-pointing camera sensor; a front objective lens system; a side-pointing camera sensor; and a side objective lens system, wherein at least one of the front and side objective lens systems comprises a front and a rear sub-systems separated by a stop diaphragm, the front sub-system comprises a first front negative lens and a second front positive lens, the rear sub-system comprises a first rear positive lens, an achromatic sub-assembly (optionally, a compound achromatic sub-assembly)

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comprising a second rear positive lens and a third rear negative lens, wherein the following conditions are satisfied:

$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of the first rear positive lens.

5 More details and features of the current invention and its embodiments may be found in the description and the attached drawings.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can
10 be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Some embodiments of the invention are herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily
20 understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

25 In order to understand the invention and to see how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figure 1a schematically depicts an external isometric view of an endoscope having multiple fields of view according to an exemplary embodiment of the current invention.

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Figure 1b schematically depicts a front view of an endoscope having multiple fields of view according to an exemplary embodiment of the current invention.

Figure 1c schematically depicts a side view of endoscope having multiple fields of view according to an exemplary embodiment of the current invention.

5 Figure 2a schematically depicts a cross section of an endoscope having multiple fields of view, for use within bodily cavity according to an exemplary embodiment of the current invention.

Figure 2b schematically depicts a cross section of an endoscope front head having multiple fields of view showing some details of the head according to an exemplary
10 embodiment of the current invention.

Figure 2c schematically depicts a cutout isometric view of an endoscope having multiple fields of view according to another exemplary embodiment of the current invention.

Figure 2d schematically depicts another cutout isometric view of an endoscope having multiple fields of view according to an exemplary embodiment of the current invention.

15 Figure 3 schematically depicts a cross section of a lens assembly of a camera head, according to an exemplary embodiment of the current invention.

Figure 4a schematically illustrates example of light propagation within an objective lens systems according to an exemplary embodiment of the current invention.

Figure 4b schematically illustrates another example of light propagation within an
20 objective lens system according to an exemplary embodiment of the current invention.

Figure 4c schematically illustrates another example of light propagation within an objective lens system according to an exemplary embodiment of the current invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Before explaining at least one embodiment of the invention in detail, it is to be
25 understood that the invention is not necessarily limited in its application to the details set forth in the following description or exemplified by the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

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The terms "comprises", "comprising", "includes", "including", and "having" together with their conjugates mean "including but not limited to".

The term "consisting of" has the same meaning as "including and limited to".

The term "consisting essentially of" means that the composition, method or structure
5 may include additional ingredients, steps and/or parts, but only if the additional ingredients, steps and/or parts do not materially alter the basic and novel characteristics of the claimed composition, method or structure.

As used herein, the singular form "a", "an" and "the" include plural references unless the context clearly dictates otherwise. For example, the term "a compound" or "at least one
10 compound" may include a plurality of compounds, including mixtures thereof.

Throughout this application, various embodiments of this invention may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have
15 specifically disclosed all the possible sub-ranges as well as individual numerical values within that range.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described
20 in the context of a single embodiment, may also be provided separately or in any suitable sub-combination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

In discussion of the various figures described herein below, like numbers refer to like
25 parts. In some cases, pluralities of similar or identical elements are marked with same numbers followed by letters, in some cases; same number without the letter refers to any of these elements. The drawings are generally not to scale. For clarity, non-essential elements were omitted from some of the drawing.

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The optical setup for endoscopes typically used in the prior art requires a relatively large overall optical length (total optical track) of the entire optical system, which is disadvantageous for endoscopes, in particular those used as colonoscopes and gastroscopes, particularly if used in endoscopes having side-viewing camera or cameras, such as
5 endoscopes according to embodiments of the present invention.

In addition, in sensors (such as CCD sensors) used in endoscopes of the prior art, the pixels are partially covered by a photo-shielding film, so that the light energy is concentrated in the center of the pixel, where there is a "window" in the photo-shielding film. This improves the signal-to-noise ratio and increases the light utilization efficiency. However, this
10 also causes the sensor to be sensitive to incident angles between the light rays which have passed the micro-lenses of the sensor and the optical axis of the system. Thus, light rays having relatively small incident angles may reach the pixel, while light rays having relatively large incident angles (between the light rays which have passed the micro-lenses of the sensor and the optical axis of the system) may not reach the "window" and thus the pixel, leading to
15 significant energy losses. The losses are maximized at the edges of the field of view, i.e. for light rays having incident angles close to that of the chief ray.

There is thus provided herein, according to some embodiments, a lens system (assembly) configured for use in an endoscope, such as colonoscope, particularly for use in a multi-sensor endoscope/colonoscope. The lens system, (optionally together with the sensor)
20 according to some embodiments of the invention, has a short total optical length (track), for example, 5 mm or less. The lens system, according to some embodiments of the invention, is configured to provide a large incident angle, for example, a chief incident angle (for example the incident angles forming by rays R_6 in Figs. 4a-4c) larger than 20° , larger than 25° , larger than 30° or between about $20-40^\circ$. The lens system, according to some embodiments of the
25 invention provides minimal distortion (for example, less than 80%).

According to some embodiments, the sensor which is used together with the lens system, is configured to have a window in the photo-shielding film configured to allow rays having large incident angle (for example, a chief incident angle larger than 20° , larger than 25° , larger than 30° or between about $20-40^\circ$) to reach the pixel and thus improve the
30 distortion. According to some embodiments, the width of the window (or any other dimensional parameter) may be about 30-60% of the width of the corresponding pixel. According to some embodiments, the micro-lenses of the sensor may be configured to

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provide substantially aplanatic conditions. In other words, the sensor may be configured to provide an image substantially free of aberrations.

Figure 1a schematically depicts an external isometric view of an endoscope (for example, a colonoscope) 200 having multiple fields of view according to an exemplary 5 embodiment of the current invention.

According to an exemplary embodiment of the current invention, head 230 of endoscope 200 comprises at least a forwards looking camera (such as a TV camera) and at least one side looking camera (such as a TV camera).

Figure 1a shows front camera element 236 of forwards looking camera 116 (seen in 10 figure 2c) on the front face 320 of head 230. The term "camera element" may generally refer to a camera and the optical system/assembly related to the camera. Optical axis of forwards looking camera 116 (seen for example in figure 2a) is substantially directed along the long dimension of the endoscope. However, since forwards looking camera 116 is typically a wide angle camera, its Field of View (FOV) may include viewing directions at large angles to its 15 optical axis. Additionally, optical windows 242a and 242b of discrete light sources such as Light Emitting Diodes (LEDs) 240a and 240b are also seen on front face 320 of head 230. It should be noted that number of LEDs used for illumination of the FOV may vary. Distal opening 340 of working channel 262 (seen for example in figure 2d) may preferably be located on front face 320 of head 230, such that a surgical tool inserted through working 20 channel 262 and deployed beyond front face 320 may be viewed by forwards looking camera 116.

Distal opening 344 of a fluid channel may preferably also be located on front face 320 of head 230. The fluid channel leading to distal opening 344 may be used as a jet channel for cleaning the colon.

25 Liquid injector 346 having a nozzle 348 aimed at front camera element 236 is used for injecting fluid to wash contaminants such as blood, feces and other debris from front camera element 236 of forwards looking camera. Optionally the same injector is used for cleaning both front camera element 236 and one or both optical windows 242a and 242b. Injector 346 may receive fluid (for example, water and/or gas) from the fluid channel or may be fed by a 30 dedicated cleaning fluid channel.

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Visible on the side wall 362 of head 230 is the front camera element 256 of side looking camera 220 (two such cameras are seen in figure 2a) and optical window 252 of a discrete light sources such as LED 250. It is noted that the number of the discrete light sources may vary. Optical axis of side looking camera 220 may be substantially directed 5 perpendicular to the long dimension of the endoscope. However, since side looking camera 220 is typically a wide angle camera, its field of view may include viewing directions at large angles to its optical axis.

Liquid injector 366 having a nozzle 368 aimed at front looking camera element 256 is used for injecting fluid to wash contaminants such as blood, feces and other debris from front 10 camera element 256 of side looking camera. Optionally the same injector is used for cleaning both front camera element 256 and optical windows 252. Preferably, injectors 346 and 366 are fed from same channel. An optional groove 370 helps directing the cleaning fluid from nozzle 368 towards front camera element 256. Groove 370 may be beneficial when side wall 362 is near or pressed against the rectal wall. Optionally, injector 366 may be at least partially 15 recessed in groove 370, thus reducing the maximum diameter of head 230 and reduce the risk of injury to the rectal wall due to friction with injector 366.

In the depicted embodiment, flexible shaft 260 is constructed of a plurality of links 382 connected to each other by pivots 384. Links 382 allows pushing, pulling and rotating the endoscope while pivots 384 provide limited flexibility. The shaft is preferably covered with 20 an elastic sheath (removed for clarity in this figure). The lumen in links 382 holds the working channel 262. Not seen in this figure are the fluid channel connected to opening 344, optional cleaning fluid channel and electrical cables supplying power to the LEDs and cameras and transmitting video signals from the camera. Generally, the shaft may also comprise mechanical actuators (not seen), for example cables attached to the links for 25 directing and aiming the head during use.

It should be noted that while only one side looking camera is seen in figure 1a, optionally, according to some embodiments, two or more side looking cameras may be located within head 230. When two side looking cameras are used, the side looking cameras are preferably installed such that their field of views are substantially opposing. According to 30 some embodiments, Different configurations and number of side looking cameras are possible and covered within the general scope of the current invention.

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Figure 1b schematically depicts a front view of head 230 of endoscope 200 having multiple fields of view according to an exemplary embodiment of the current invention.

According to an exemplary embodiment of the current invention, head 230 of endoscope 200 comprises at least a forwards looking camera and at least one side looking camera. Figure 2b shows a front camera element 236 of forwards looking camera 116 on the front face 320 of head 230. Additionally, optical windows 242a and 242b of LEDs 240a and 240b are also seen on front face 320 of head 230. Distal opening 340 of working channel and distal opening 344 of a fluid channel are preferably also located on front face 320 of head 230. Liquid injector 346 having a nozzle 348 is also visible in this view.

10 Additionally, Liquid injectors 366a and 366b aimed at side looking camera element 256a and 256b respectively are used for injecting fluid to wash contaminants such as blood, feces and other debris from front camera element 256 of side looking cameras.

Figure 1c schematically depicts a side view of endoscope 200 having multiple fields of view according to an exemplary embodiment of the current invention.

15 Figure 1c shows front camera element 256 of side looking camera 220, groove 370 and optical window 252 on the side wall 362 of head 230. Liquid injectors 346 and 366 are also visible in this view.

Figure 2a schematically depicts a cutout isometric view of an endoscope 400 having multiple fields of view according to another exemplary embodiment of the current invention.

20 According to an exemplary embodiment of the current invention, head 230 of endoscope 200 comprises at least a forwards looking camera 116 and two side looking cameras 220a and 220b.

Optical windows 242a and 242b of LEDs used for forward illumination are also seen on front face of head 230.

25 Distal opening 340 of working channel is preferably located on front face of head 230 such that a surgical tool inserted through the working channel 262 and deployed beyond front face may be viewed by forwards looking camera 116.

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Distal opening 344 of a fluid channel is preferably also located on front face of head 230. The fluid channel leading to distal opening 344 may be used as a jet channel for cleaning the colon.

Liquid injector 346 having a nozzle aimed at front camera element of camera 116 is used for injecting fluid to wash contaminants such as blood, feces and other debris from front camera element of forwards looking camera 116. Optionally the same injector is used for cleaning the front camera element and one or both optical windows 242a and 242b. Injector 346 may receive fluid from the fluid channel or may be fed by a dedicated cleaning fluid channel.

Visible on right hand side of head 230 is the front camera element 256b of side looking camera 220b and optical window 252b of side illuminating LED.

Liquid injector 366b having a nozzle aimed at front camera element 256b is used for injecting fluid to wash contaminants such as blood, feces and other debris from front camera element 256b of side looking camera 220b. Optionally the same injector is used for cleaning both front camera element 256b and optical windows 252b. An optional groove 370b helps directing the cleaning jet from injector 366b towards front camera element 256b.

Although not seen in this figure, it is understood that equivalent elements 366a, 370a, 256a and 252a are present on the left hand side of head 230.

Preferably, all the injectors 346 and 366 are fed from same channel.

In the depicted embodiment, flexible shaft 260 is constructed of a plurality of links 382 (only one is marked for clarity). Electrical cable 396 within shaft 260 is seen connected to cameras 116, 220a and 220b. The same or separate electrical cable is used to power the LEDs.

Figure 2b schematically depicts a cross section of an endoscope 200 having multiple fields of view showing some details of the head 230 according to an exemplary embodiment of the current invention.

According to the current invention, head 230 of endoscope 200 comprises at least a forwards looking camera 116 and two side looking cameras 220a and 220b. Each of cameras 116 and 220 is provided with an optical imaging system such as lens assemblies (systems)

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132 and 232 respectively and solid state detector arrays 134 and 234 respectively. Front camera elements 236 and 256 of cameras 116 and 220 respectively may be a flat protective window, but optionally an optical element used as part of the imaging systems such as solid state detector arrays 134 and 234 respectively. Optionally, cameras 116 and 220 are similar or
5 identical, however different camera designs may be used, for example, field of views 118 and 218 may be different. Additionally or alternatively, other camera parameters such as: resolution, light sensitivity, pixel size and pixel number, focal length, focal distance and depth of field may be selected to be same or different.

Light is provided by Light Emitting Diodes (LED) that illuminates the field of views.
10 According to some embodiments, white light LEDs may be used. According to other embodiments, other colors of LEDs or any combination of LEDs may be used (for example, red, green, blue, infrared, ultraviolet).

In the depicted embodiment, field of view 118 of forwards looking camera 116 is illuminated by two LEDs 240a and 240b located within the endoscope head 230 and
15 protected by optical window 242a and 242b respectively.

Similarly, in the depicted embodiment, field of views of side looking camera 220 is illuminated by a single LED 250 located within the endoscope head 230 and protected by optical window 252. It should be noted that number of LED light sources and their position in respect to the cameras may vary within the scope of the current invention. For example few
20 LEDs may be positioned behind the same protective window, a camera and an LED or plurality of LED may be located behind the same protective window, etc.

Head 230 of endoscope 200 is located at the distal end of a flexible shaft 260. Similarly to shafts of the art, shaft 260 comprises a working channel 262 for insertion of surgical tools. Additionally, shaft 260 may comprises channels for irrigation, insufflation,
25 suction and supplying liquid for washing the colon wall.

Figure 2c schematically depicts a cross section cutout of an endoscope 200 showing some details of the head 230 according to an exemplary embodiment of the current invention. For simplicity, details of one of the two side looking cameras are marked in the figure.

According to the current invention, head 230 of endoscope 200 comprises at least one
30 side looking camera 220. Each of cameras 220 is provided with an optical imaging system

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such as lens assemblies 232 and solid state detector arrays 234. Front camera element 256 of camera 220 may be a flat protective window or an optical element used as part of the imaging system 232.

Figure 2d schematically depicts a cross section of an endoscope 200 having multiple 5 fields of view showing some details of the head 230 according to an exemplary embodiment of the current invention.

According to some embodiments of the current invention, the interior of the head 230 comprises forward looking and side looking cameras 116 and 220, respectively. Cameras 116 and/or 220 comprise lens assemblies 132 and 232 (not shown), respectively, having a 10 plurality of lenses 430 to 434 and protective glass 436 (not shown) and a solid state detector arrays 134 and 234 (not shown) connected to a printed circuit board 135 and 235 (not shown) respectively. It is noted that cameras 116 and 220 or any element related to them (such as lens assemblies 132 and 232, lenses 430 to 434 and protective glass 436, solid state detector arrays 134 and 234 and/or printed circuit board 135 and 235) may be the same or different. In other 15 words the front looking camera and the side looking camera(s) may be the same or different in any one or any combinations of their components or other element related to them (such as optical elements).

Figure 3 schematically depicts a cross section of cameras 116 or 220, showing some details of lens assemblies 132 and 232 according to an exemplary embodiment of the current 20 invention. It should be noted that according to some embodiments of the invention, cameras 116 and 220 may be similar or different. Optionally, the focusing distance of camera 116 is slightly different than that of camera 220. Differences in focusing distances may be achieved, for example, by (slightly) changing the distance between the lenses that comprise the lens assemblies 132 and/or 232, or between the lens assembly and the detector array.

25 Air gap "S" between lenses 431 and 432 acts as a stop. Air gap S may affect the focal range (the distance between the closest object and farther objects that can be imaged without excessive blurring caused by being out of optimal focusing of the lens system).

According to an exemplary embodiment of the current invention, cameras 116 and 220 comprise lens assemblies 132 and 232 respectively. The lens assemblies comprise a set 30 of lenses 430 to 434 and protective glass 436.

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Lenses 430 to 434 are situated within a (optionally metallic) barrel 410 and connector thereto (for example, glued in barrel 410). Any one of lens assemblies 132 and/or 232 may also include an adapter 411, optionally, as shown in Fig. 3, positioned within barrel 410. Adapter 411 is configured to adjust the location of one or more of the lenses and adjust the distance between lenses. Adapter 411 may also be configured to function as a stop (in this case, between lenses 432 and 433). Protective glass 436 is situated in proximity to the solid state detector arrays 134 or 234 and is optionally attached thereto.

Focal distance (the distance to the object to be optimally focused by the lens system) may be changed by changing the distance between lenses 434 and protective glass 436. As lens 434 is fixed to the barrel, and protective glass 436 is fixed to lens holder 136 (236), this distance may be varied by changing the relative positioning of lens holder 136 (236) with respect to barrel 410. The space between the lenses 434 and protective glass 436 may be an empty space or may be filled with glass or other transparent material, or a tubular spacer may be inserted to guarantee the correct distance between these lenses. Optionally, optical filters may be placed within the space. Cameras 116 and 220 further comprise solid state detector arrays 134 and 234 respectively. Solid state detector arrays 134 and 234 may each be connected to printed circuit boards. An electrical cabling may connect the printed boards to a central control system unit of the endoscope.

Solid state detector arrays 134 and 234 are attached to lens holders 136 and 236 respectively. Lens holder 136 or 236 are attached to lens assemblies 132 or 232 respectively by attaching detector array cover to barrel 410.

In some applications, protective glass 436 may be a flat-flat optical element, acting primarily as a protection of the detector array (such as detector arrays 134 and 234), and may optionally be supplied with the array. However, optical properties of protective glass 436 need to be accounted for in the optical design.

In order to assemble lens assemblies 132 or 232, lens 430 may first be inserted from left, then 431, and 432 from right. Lenses 433 and 434 which may be glued together (or separated for example by air) are then inserted from right. The complete set is now assembled in a barrel. The assembled detector (such as detector arrays 134 and 234), protective glass 436 and cover 136(236) are then added.

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Figures 4a, 4b and 4c illustrate three examples for the lens assemblies such as lens assemblies 132 and 232 according to the present invention, having objective lens systems 510, 520 and 530 respectively. The sensor used in the lens assemblies 132 and 232, according to this exemplary embodiment, may be a Charge Coupled Device sensor (CCD) having an array of micro-lenses but other sensors, such as CMOS, may also be used.

In an exemplary embodiment of the invention, a color CCD camera having resolution of approximately 800x600 pixels were used with total active area of approximately 3.3 x 2.95 mm. The optical resolution of the lens, according to exemplary embodiments of the current invention, was designed to match the resolution of the sensor. The objective lens system 510 (520/530) are preferably corrected for chromatic; spherical and astigmatism aberrations. In an exemplary embodiment of the invention, objective lens system 510 (520/530) is approximately 4.60 mm (4.62) total length, measured from front face of front lens to the front surface of the sensor. In an exemplary embodiment of the invention, objective lens systems 510 and 520 are wide angle objectives having approximately 170 degrees acceptance angle. In an exemplary embodiment of the invention, objective lens system 510 (520/530) has a short focal distance of measured from the front surface of the front lens to the imaged object. In an exemplary embodiment of the invention objective lens system 510 (520/530) has Depth of Focus (DOF) allowing to effectively image objects between 4-110 mm (or between, 3.5-50 mm). In an exemplary embodiment of the invention, objective lens system 510, 520 and 530 has maximum diameter of about 2.5 mm, defined by the diameter of the front lens, and is housed in a barrel having maximum outer diameter of approximately 3.6 mm. It should be noted that other design parameters may be selected within the general scope of the current invention.

The objective lens system 510 (520/530) has an optical axis "O" depicted by the dashed line. The lens system comprises a front sub-system 510a (520a/530a) and a rear sub-system 510b (520b/530b).

Front sub-system 510a (520a) (Figs. 4a (4b)) comprises a front lens 430 (430') located closest to the object to be viewed, having a negative power and lens 431(431') having a positive power.

Front lens 430 (430') is oriented with its concave surface facing the object to be viewed and optionally having a diameter substantially greater than the largest dimension of the rear sub-

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system 510b in the direction perpendicular to the optical axis. Lens 431(431') has a positive power.

Rear sub-system 510b (520b) comprises lenses 432, 433; 434; and protective glass 436 (lenses 432'; 433'; 434'; and 436'), wherein 432 (432'), has a negative power, 433 (433') has a positive power, 434 (434') has a negative power, and 436 (436') has essentially no optic power. It is noted that protective glass 436 (436') may be a part of the sensor or a part of the rear sub-system 510b (520b). Lenses 433 and 434 (433' and 434') of the rear sub-system 510b (520b) compose an achromatic sub-assembly (a compound achromatic sub-assembly as seen in Fig. 4a, where lenses 433 and 434 are cemented or non-compound achromatic sub-assembly as seen in Fig. 4b, where lens 433' and lens 434' are separated). Lens 433 (433') may be biconvex with radius of curvature of its front surface being smaller than radius of curvature of its rear surface, as indicated in Tables T₁, T₂ below.

Lens 432 of the objective lens systems 510 may have a focal length f_{432} satisfying the following condition: $f_{432} \leq 1.8f$, where f is the composite focal length of the total system. Particularly, for the data indicated in Table T₁ $f_{432}=2.05$ and $f = 1.234\text{mm}$, the condition: $f_{432} \leq 1.8f$ is satisfied.

Lens 432' of the objective lens systems 520 may have a focal length $f_{432'}$ satisfying the following condition: $f_{432'} \leq 1.8f$.

Particularly, for the data indicated in Table T₂ $f_{432'}=2.05$ and $f = 1.15\text{mm}$, the condition: $f_{432'} \leq 1.8f$ is satisfied.

The lenses may be coated with an anti-reflection coating (AR coating) for further improving the efficiency of the lens assemblies 132 (232).

An effective aperture stop S₁ (S₂) is formed between lenses 431 and 432 (431' and 432'). Effective aperture stop S₁ (S₂) may separate between front sub-system 510a (520a) and rear sub-system 510b (520b).

Front sub-system 530a (Figs. 4c) comprises a front lens 430'' located closest to the object to be viewed, having a negative power and lens 431'', having a positive power. Front sub-system 530a (Figs. 4c) further comprises an additional front positive lens (such as the meniscus lens 429) disposed between the first front negative lens 430'' and the second front positive lens 431''.

Front lens 430'' is oriented with its concave surface facing the object to be viewed and optionally having a diameter substantially greater than the largest dimension of the rear sub-system 530b in the direction perpendicular to the optical axis.

Rear sub-system 530b comprises lenses 432'', 433'', 434''; and protective glass 436'', wherein 432'', has a negative power, 433'' has a positive power, 434'' has a negative power, and 436'' has essentially no optic power. It is noted that protective glass 436'' may be a part of the sensor or a part of the rear sub-system 530b. Lenses 433'' and 434'' compose an achromatic sub-assembly of the rear sub-system 530b and may or may not be cemented to each other. Lens 433'' may be biconvex with radius of curvature of its front surface being smaller than radius of curvature of its rear surface, as indicated in Table T₃ below.

Lens 432'' of the objective lens systems 530 may have a focal length f_{432} satisfying the following condition: $f_{432} \leq 1.8f$, where f is the composite focal length of the total system. Particularly, for the data indicated in Table T₃ $f_{432}=2.26$ and $f = 1.06$ mm, the condition: $f_{432} \leq 1.8f$ is satisfied.

The lenses may be coated with an anti-reflection coating (AR coating) for further improving the efficiency of the lens assemblies 132 (232).

An effective aperture stop S_3 is formed between lenses 431'' and 432''. Effective aperture stop S_3 may separate between front sub-system 530a and rear sub-system 530b.

Tables T₁ T₂ and T₃ summarize the parameters of lenses in the objective lens systems 510, 520 and 530, respectively, according to some embodiments of the current invention:

Table T₁ (FOV=164°, DOF=3-110mm. $f = 1.234$ mm, total optical track 4.09mm)

Lens	Type	R ₁	R ₂	Th	D	Glass	Semi-Diameter d ₁ /2	Semi-Diameter d ₂ /2	f _{mm}
430	Negative	15	0.7	0.2	0.18	N-LASF31	1.2	0.64	-0.837
431	Plan-convex	0.9	Infinity	0.56	0.27	N-LASF31	0.8	0.8	1.02
S ₁	Stop				0.05		0.104		
432	Plan-convex	Infinity	-1.0	0.75	0.09	FK5	0.8	0.8	2.05
433	Biconvex	1.93	-4.2	0.75	0.005	N-LAK22	1.1	1.1	2.13
434	Biconcave	-4.2	4.44	0.3	0.65	N-SF66	1.1	1.2	-2.3
436	Protection Glass	Infinity	Infinity	0.3	0	N-BK7	1.5	1.5	Infinity

Table T₂ (FOV=164°, DOF=3-110mm, f = 1.15mm, total optical track 4.09mm)

Lens	Type	R ₁	R ₂	Th	D	Glass	Semi-Diameter d ₁ /2	Semi-Diameter d ₂ /2	f _{mm}
430	Negative	6	0.7	0.2	0.3	N-LASF31	1.2	0.66	-0.913
431	Plan-convex	1.26	Infinity	0.50	0.27	N-LASF31	0.8	0.8	1.43
S ₁	Stop				0.05		0.105		
432	Plan-convex	Infinity	-1.0	0.60	0.15	FK5	0.8	0.8	2.05
433	Biconvex	1.67	-1.65	0.70	0.30	FK5	0.95	0.95	1.83
434	Meniscus	-1.33	-12.0	0.35	0.40	N-SF66	1.0	1.2	-1.65
436	Protection Glass	Infinity	Infinity	0.3	0	N-BK7	1.5	1.5	Infinity

Table 3, shows an example of a six-component system also comprising an additional positive lens 429 (for example, as indicated in Table 3, a meniscus lens).

5

Table T₃ (FOV=164°, DOF=3-110mm, f = 1.06mm, total optical track 4.69mm)

Lens	Type	R ₁	R ₂	Th	D	Glass	Semi-Diameter d ₁ /2	Semi-Diameter d ₂ /2	f _{mm}
430''	Negative	4.3	0.75	0.2	0.22	N-LASF31	1.3	0.72	-1.06
429	Meniscus	0.95	0.9	0.44	0.18	N-SF66	0.8	0.65	5.75
431''	Plan-convex	2.0	Infinity	0.75	0.02	N-LASF31	0.8	0.8	2.26
S ₃	Stop				0.02		0.116		
432''	Plan-convex	Infinity	-1.0	0.78	0	N-PSK57	0.8	0.8	1.69
433''	Biconvex	2.52	-2.0	0.50	0.154	YGH52	0.8	0.8	1.49
434''	Biconcav	-1.44	11.0	0.25	0.91	PBH56	0.8	0.9	-1.50
436''	Protection Glass	Infinity	Infinity	0.3	0	N-BK7	1.5	1.5	Infinity

R₁ – radius of curvature of the lens front surface (front surface is the surface facing the direction of the object);

10 R₂ – radius of curvature of the lens rear surface (facing away from the object);

Th – thickness of the lens – from center of front surface to center of rear surface;

Glass – lens glass type;

d₁ – radius of the front optical surface of the lens;

d₂ – radius of the rear optical surface of the lens;

15 D – distance between components such as lenses, measured front center of rear surface of the component, such as lens to the front surface of the next optical element (in the case of a stop,

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S, the distance is measured front center of rear surface of a component on the front side of the stop, to the front surface of the next component),

As commonly used, radius of curvature equal to infinity is interpreted as planar. All lenses are optionally spherical.

5

Figs. 4a, 4b and 4c also show the propagation of five incident rays of light R_1 to R_6 through the objective lens system 510, 520 and 530 respectively, from the front lens 430 (Fig. 4a), 430' (Fig. 4b) or 430'' (Fig. 4c) till the creating of an image of the object at an image plane.

10 Rays R_1 to R_6 , enter the lens assembly at angles α_1 (alpha 1) to α_6 (alpha 6), respectively, for example, essentially equal to the following angles: $\alpha_1=0^\circ$, $\alpha_2=45^\circ$, $\alpha_3=60^\circ$, $\alpha_4=75^\circ$ and $\alpha_5=84^\circ$. The corresponding incident angles (the angles between the light rays which have passed the micro-lenses of the sensor and the optical axis of the system) are β_1 (beta 1) – β_6 (beta 6). According to some embodiments, the chief incident angle (for example
15 the incident angles forming by rays R_6 in Figs. 4a-4c) is larger than 20° , larger than 25° , larger than 30° or between about $20-40^\circ$. The lens system, according to some embodiments of the invention provides minimal distortion (for example, less than 80%).

The optical system assembly 132 (232) may be assembled by a method comprising the step of:

20 Optionally, cementing the rear doublet of lenses 433-434 (433'-434');

and:

Assembling in the barrel the front lenses 430 (430');

Assembling lens 431 (431') in the barrel;

Assembling lens 432 (432') in the barrel;

25 Assembling in the barrel, the rear doublet 433-434 (433'-434'); and

Note that front lens 430 (430') may be assembled last.

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Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended
5 claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is
10 available as prior art to the present invention.

CLAIMS:**What we claim is:**

1. An optical system for a tip section of a multi-sensor endoscope, the system
5 comprising:

a front-pointing camera sensor;

a front objective lens system;

a side-pointing camera sensor; and

a side objective lens system,

10 wherein at least one of said front and side objective lens systems comprises a front
and a rear sub-systems separated by a stop diaphragm,

said front sub-system comprises, in order from the object side, a first front negative
lens and a second front positive lens,

said rear sub-system comprises, in order from the object side, a first rear positive lens,
15 an achromatic sub-assembly (optionally, a compound achromatic sub-assembly) comprising a
second rear positive lens and a third rear negative lens, wherein the following condition is
satisfied:

$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens
system and $f_{(\text{first rear positive lens})}$ is the focal length of said first rear positive lens.

20 2. The optical system according to claim 1, wherein said front sub-system further
comprises an additional front meniscus lens disposed between said first front negative lens
and said second front positive lens.

3. The optical system according to claim 1, wherein said rear sub-system further
comprises a rear protective glass situated between said third rear negative lens and said front-
25 pointing and/or side-pointing camera sensor, wherein said rear protective glass is adapted to
protect a detector array of said front-pointing and/or side-pointing camera sensor.

4. The optical system according to claim 1, wherein:

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$f_{(\text{first rear positive lens})} = 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of said first rear positive lens.

5 5. The optical system according to claim 1, wherein said front-pointing camera sensor and said front objective lens system are adapted to provide a Depth of Focus (DOF) of between 4 and 110 mm.

6. The optical system according to claim 5, wherein said front-pointing camera sensor and said front objective lens system are adapted to provide a Depth of Focus (DOF) of between 3.5 and 50 mm.

7. The optical system according to claim 1, wherein said front-pointing camera
10 sensor and said front objective lens system are adapted to provide an effective spatial resolution of at least 60 lines per mm at Depth of Focus (DOF) of between 5 and 50 mm.

8. The optical system according to claim 1, wherein said front-pointing camera sensor and said front objective lens system are adapted to provide an effective angular resolution of about 2' per degree or less at Depth of Focus (DOF) of between 5 and 50 mm.

15 9. The optical system according to claim 1, wherein said front-pointing camera sensor and said front objective lens system are adapted to provide a Field of View (FOV) of about 150 degrees or more.

10. The optical system according to claim 9, wherein said front-pointing camera sensor and said front objective lens system are adapted to provide a Field of View (FOV) of
20 about 170 degrees or more.

11. The optical system according to claim 1, wherein said front-pointing camera sensor and said front objective lens system have a total optical length of about 5 mm or less.

12. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system are adapted to provide a Depth of Focus (DOF) of
25 between 3.5 and 50 mm.

13. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system are adapted to provide a Depth of Focus (DOF) of between 3 and 30 mm.

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14. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system are adapted to provide an effective spatial resolution of at least 60 lines per mm at Depth of Focus (DOF) of between 5 and 50 mm.

15. The optical system according to claim 1 wherein said side-pointing camera sensor and said side objective lens system are adapted to provide an effective angular resolution of about 2' per degree or less at Depth of Focus (DOF) of between 5 and 50 mm.

16. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system are adapted to provide a Field of View (FOV) of about 150 degrees or more.

17. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system are adapted to provide a Field of View (FOV) of about 170 degrees or more.

18. The optical system according to claim 1, wherein said side-pointing camera sensor and said side objective lens system have a total optical length of about 5 mm or less.

19. The optical system according to claim 1, wherein the diameter of said first front negative lens is 2.5 mm or less.

20. An objective lens system for at least one of a front-pointing and side-pointing camera sensors of a multi-sensor endoscope, the objective lens system comprising:

a front and a rear sub-systems separated by a stop diaphragm, wherein

said front sub-system comprises a first front negative lens and a second front positive lens, and

said rear sub-system comprises a first rear positive lens, an achromatic sub-assembly (optionally, a compound achromatic sub-assembly) comprising a second rear positive lens and a third rear negative lens,

wherein the following condition is satisfied:

$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens system and $f_{(\text{first rear positive lens})}$ is the focal length of said first rear positive lens.

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21. A tip section of a multi-sensor endoscope comprising an optical system comprising:

- a front-pointing camera sensor;
- a front objective lens system;
- 5 a side-pointing camera sensor; and
- a side objective lens system,

wherein at least one of said front and side objective lens systems comprises a front and a rear sub-systems separated by a stop diaphragm,

said front sub-system comprises a first front negative lens and a second front positive
10 lens,

said rear sub-system comprises a first rear positive lens, an achromatic sub-assembly (optionally, a compound achromatic sub-assembly) comprising a second rear positive lens and a third rear negative lens, wherein the following conditions are satisfied:

$f_{(\text{first rear positive lens})} \leq 1.8f$, where f is the composite focal length of the total lens system
15 and $f_{(\text{first rear positive lens})}$ is the focal length of said first rear positive lens.

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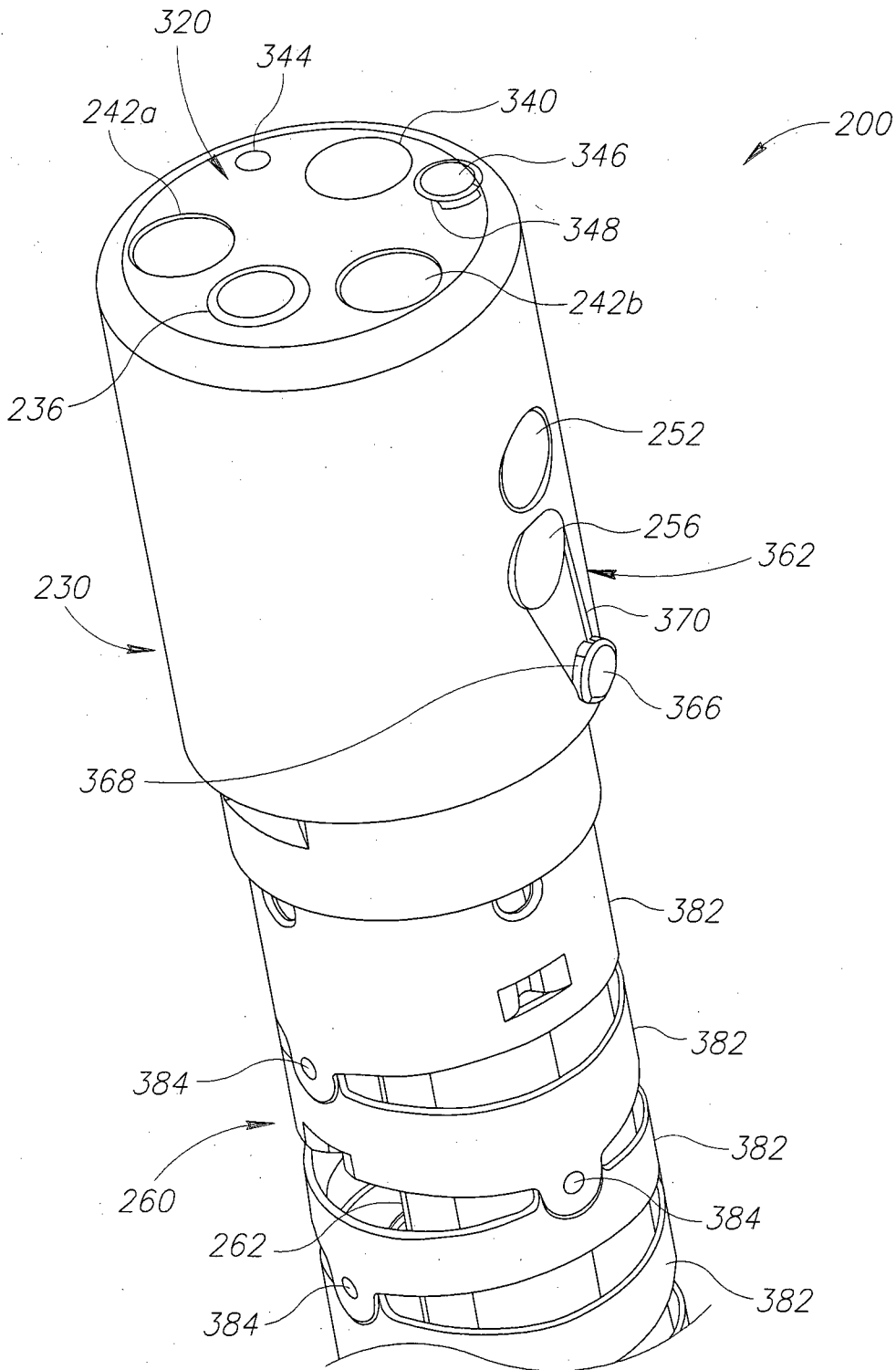


FIG.1A

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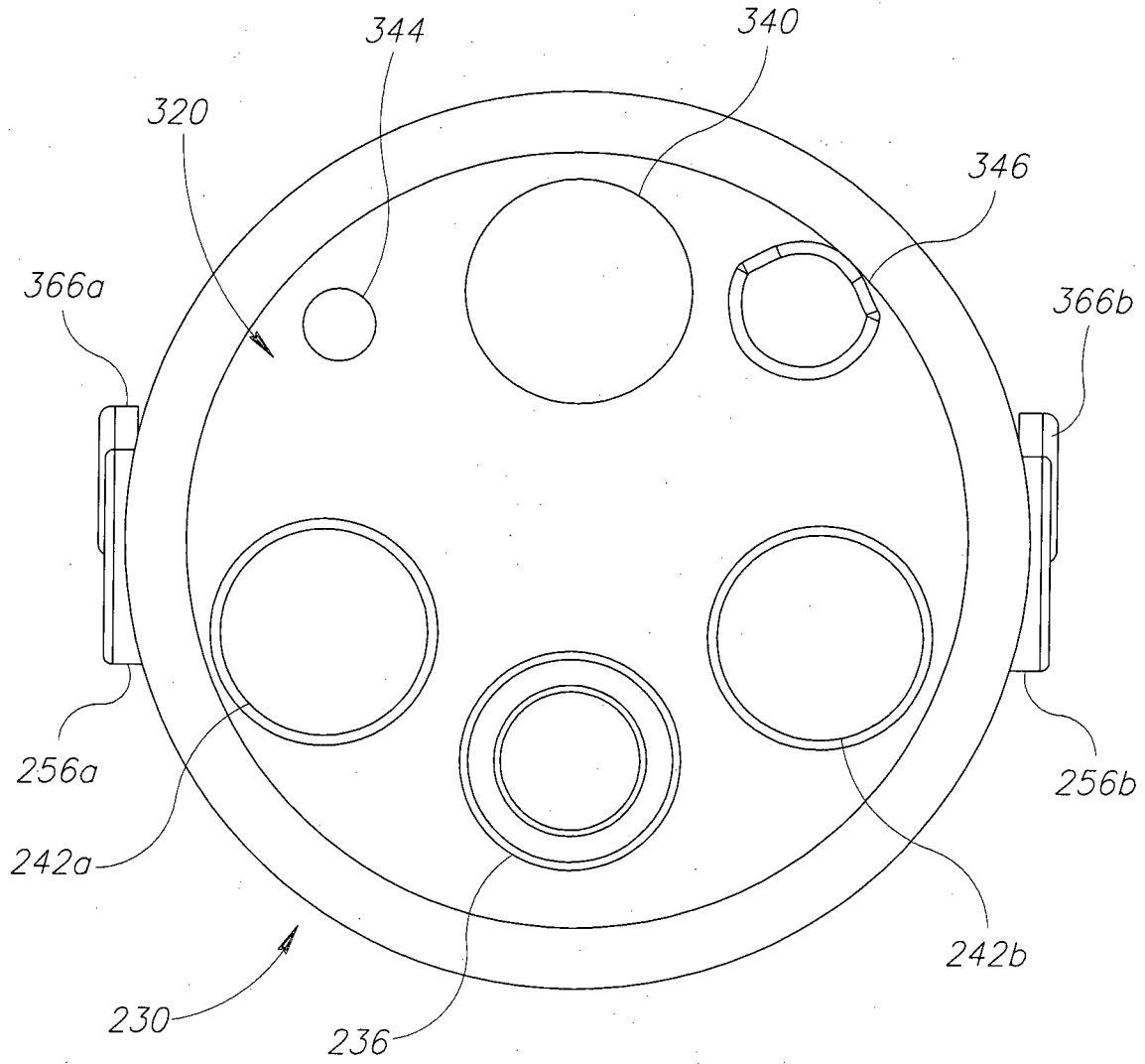


FIG.1B

3/11

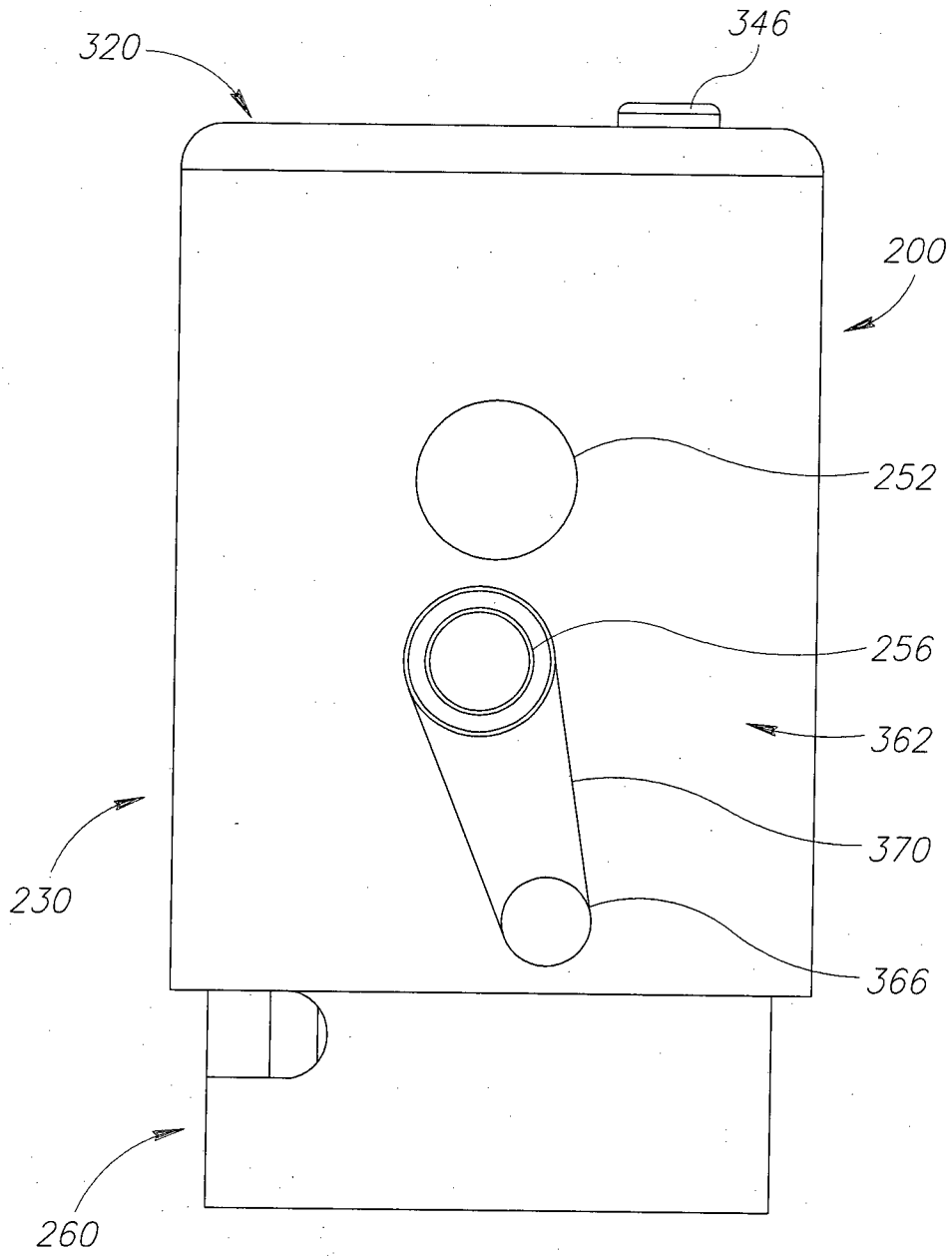


FIG.1C

4/11

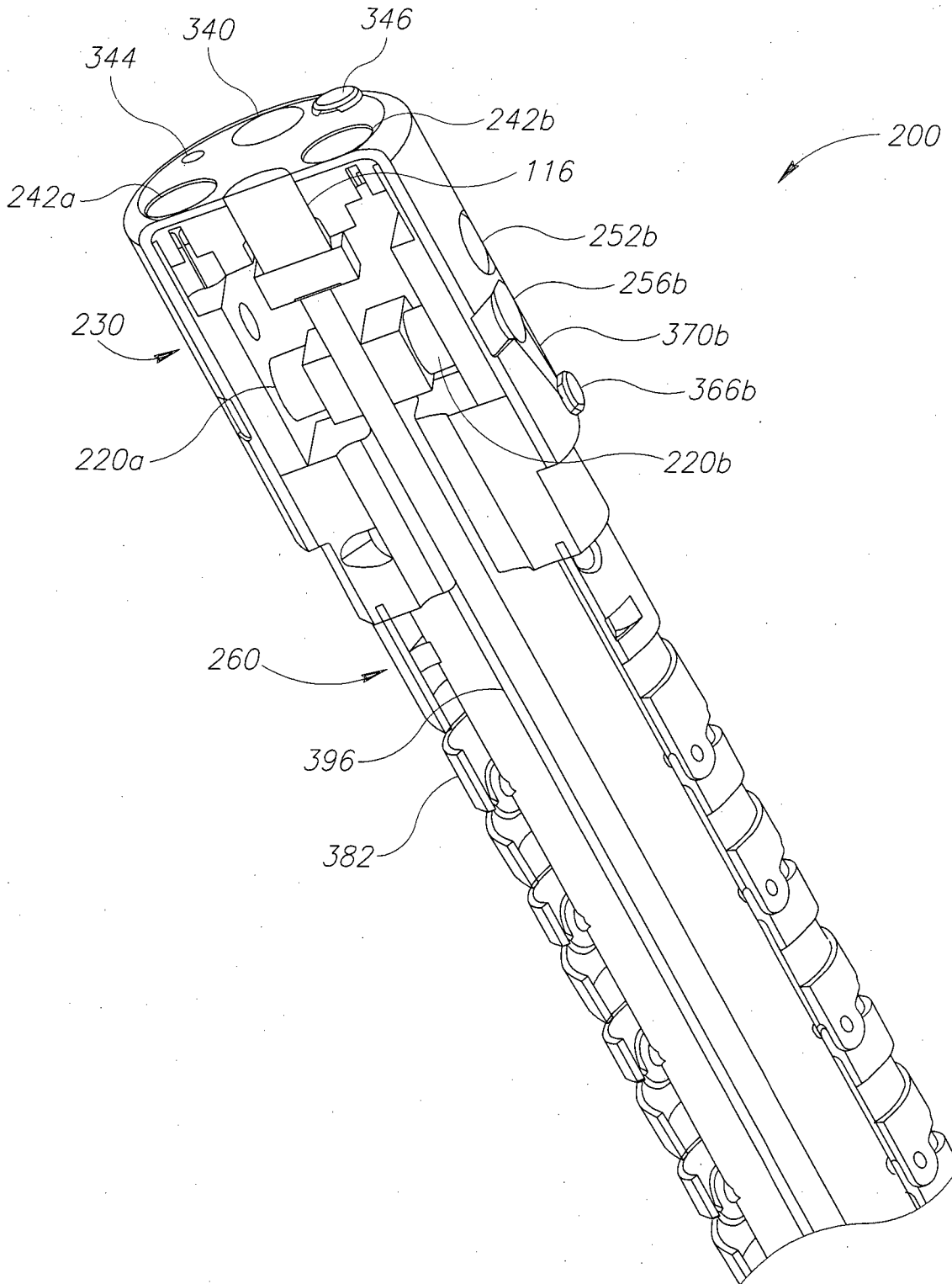


FIG. 2A

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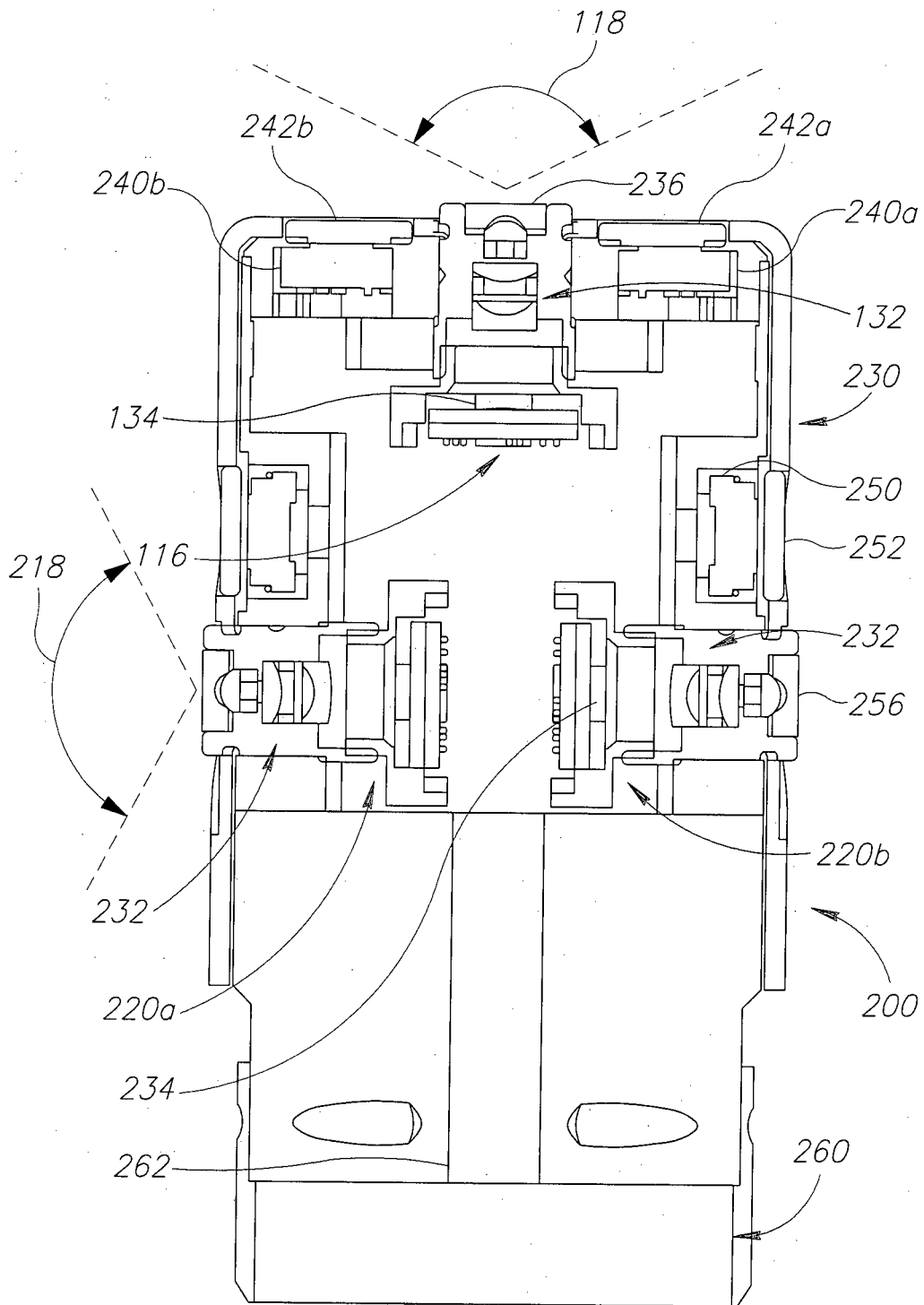


FIG. 2B

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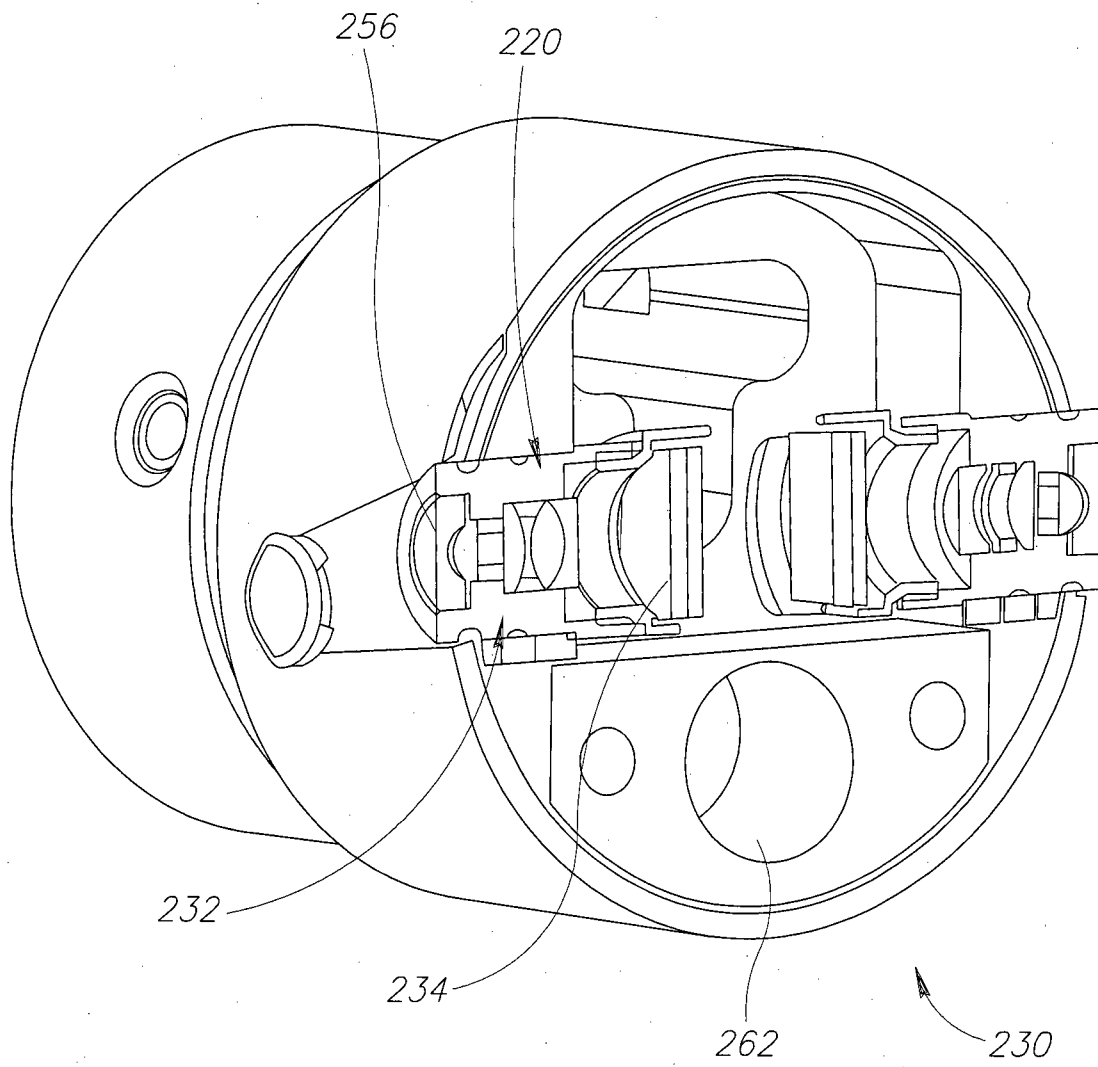


FIG. 2C

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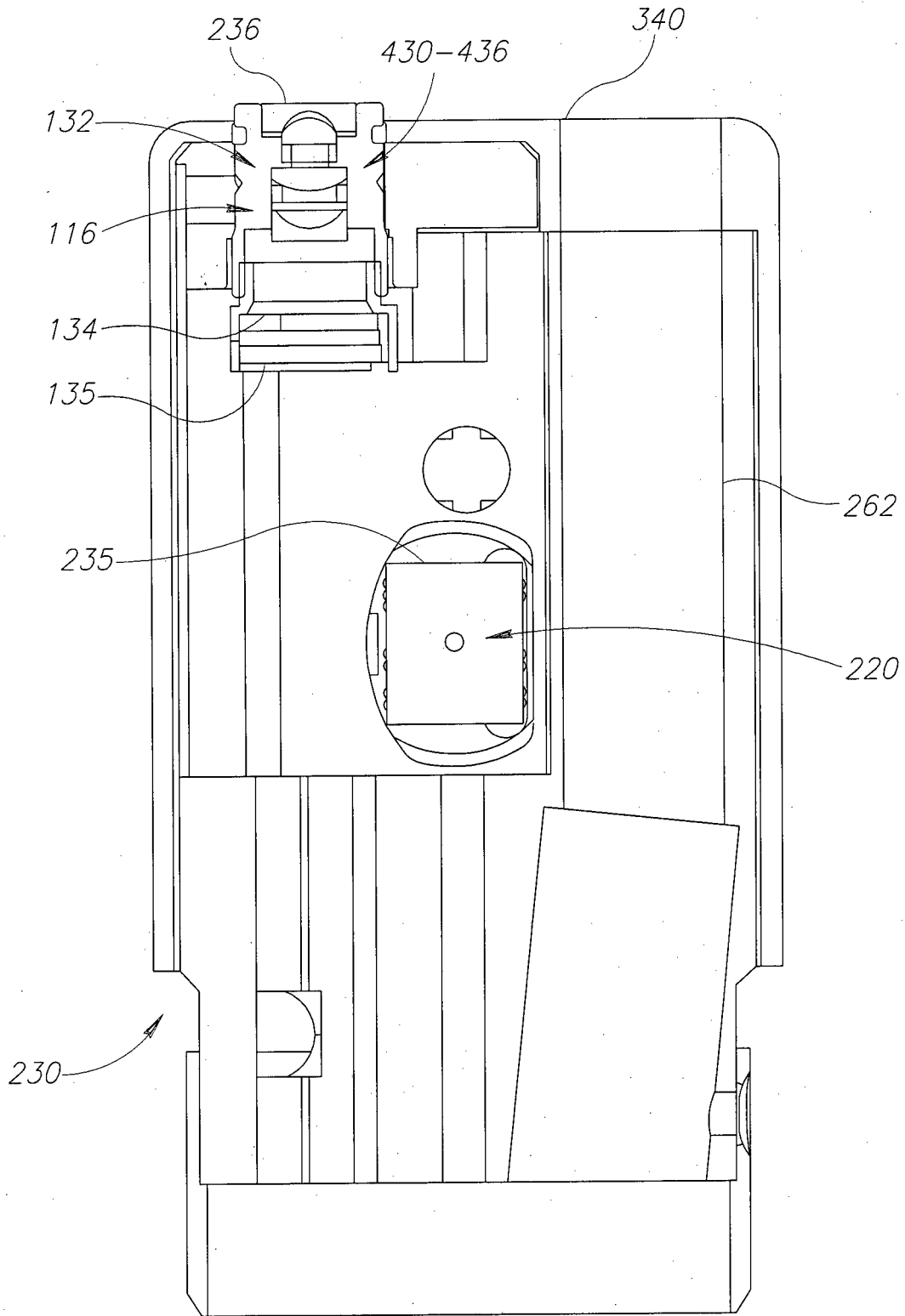


FIG. 2D

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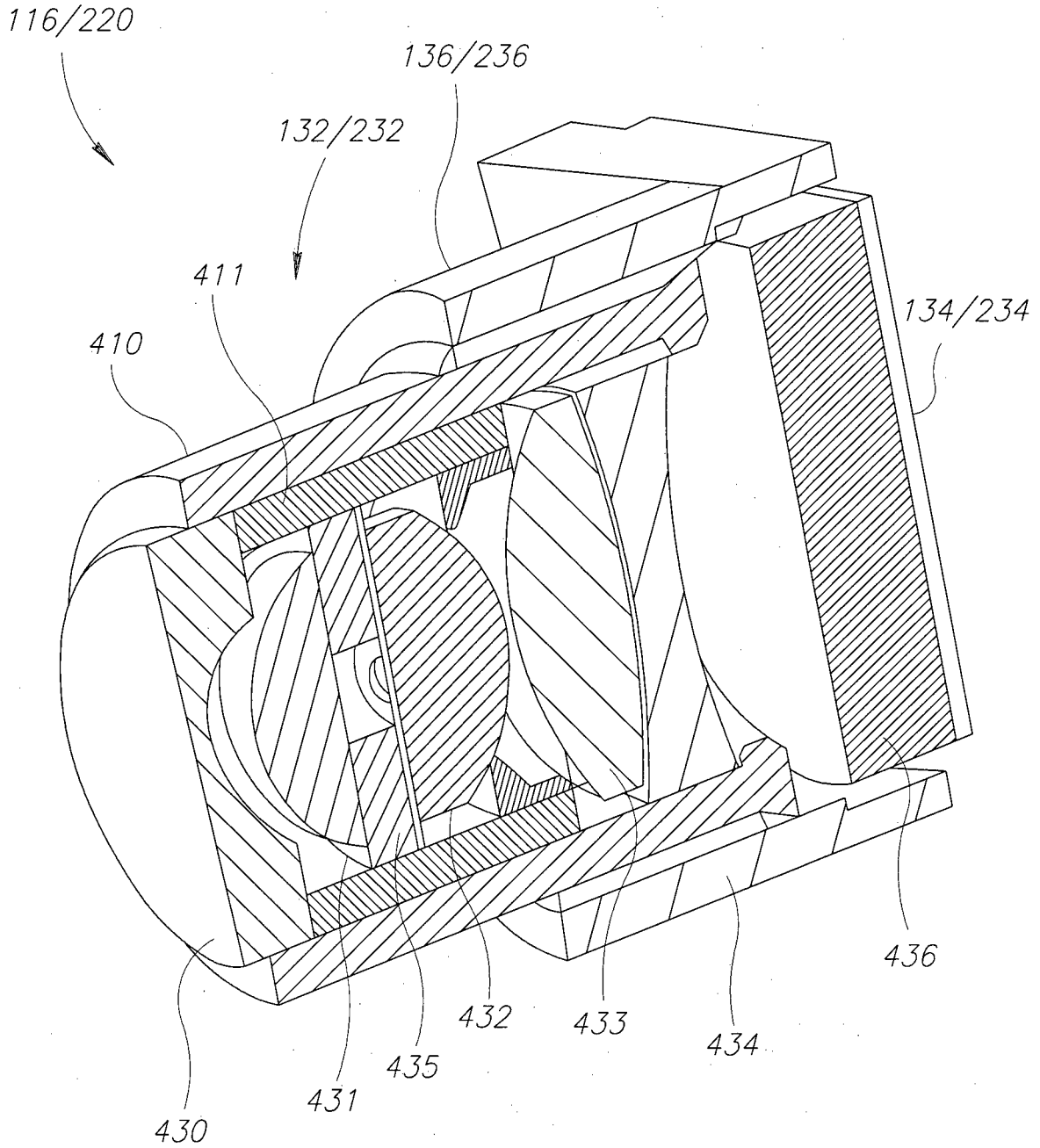


FIG.3

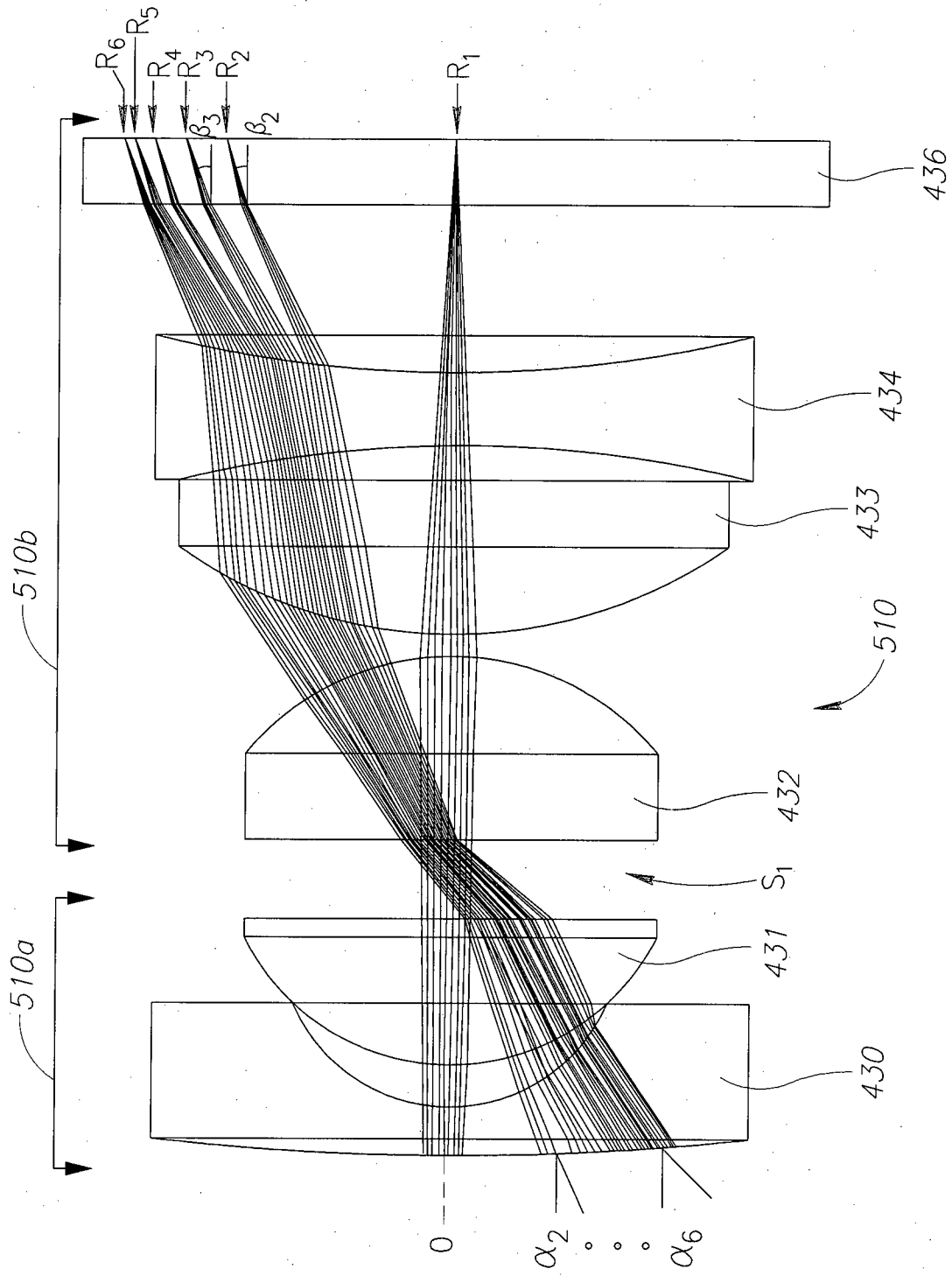


FIG. 4A

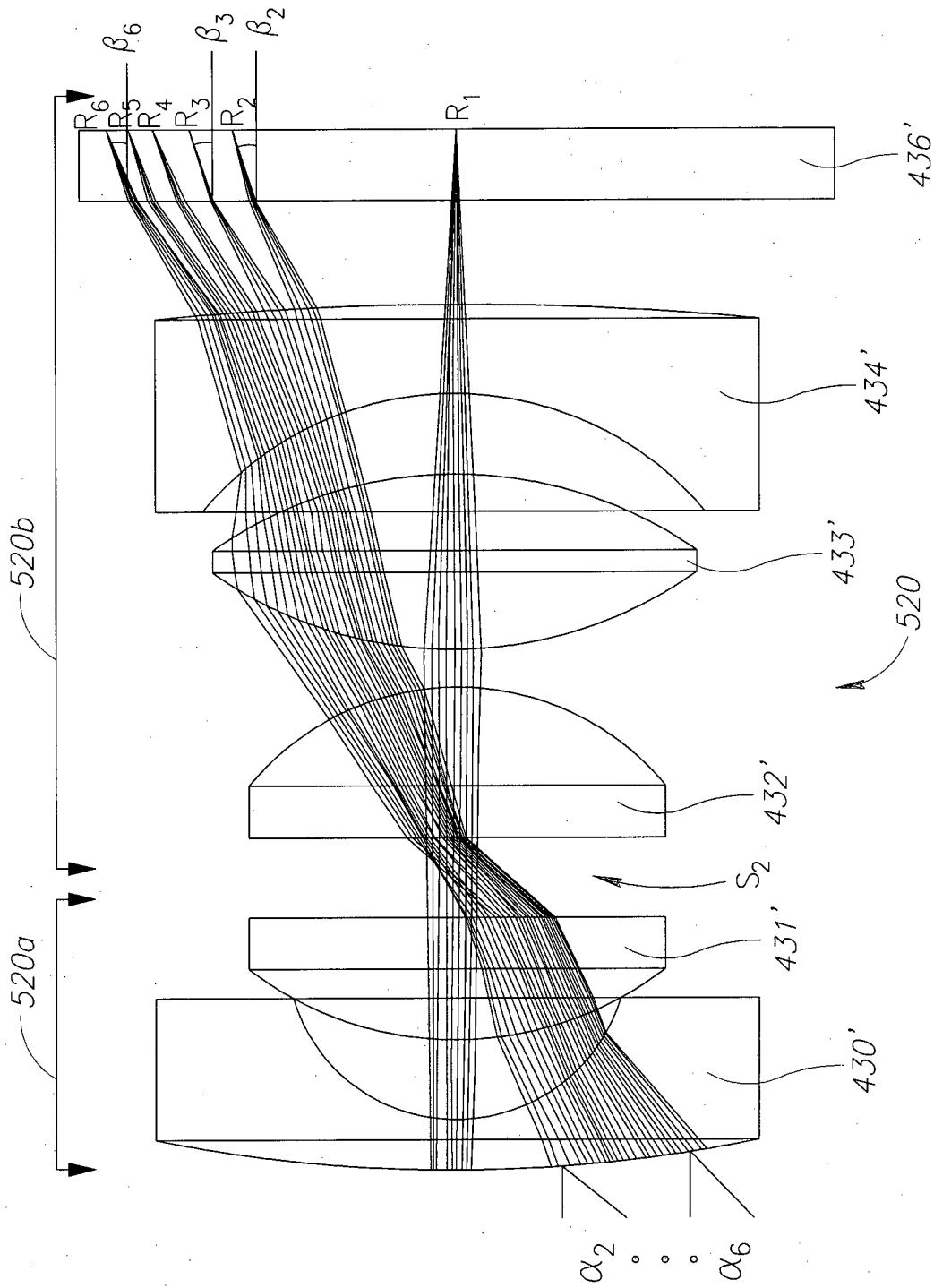


FIG. 4B

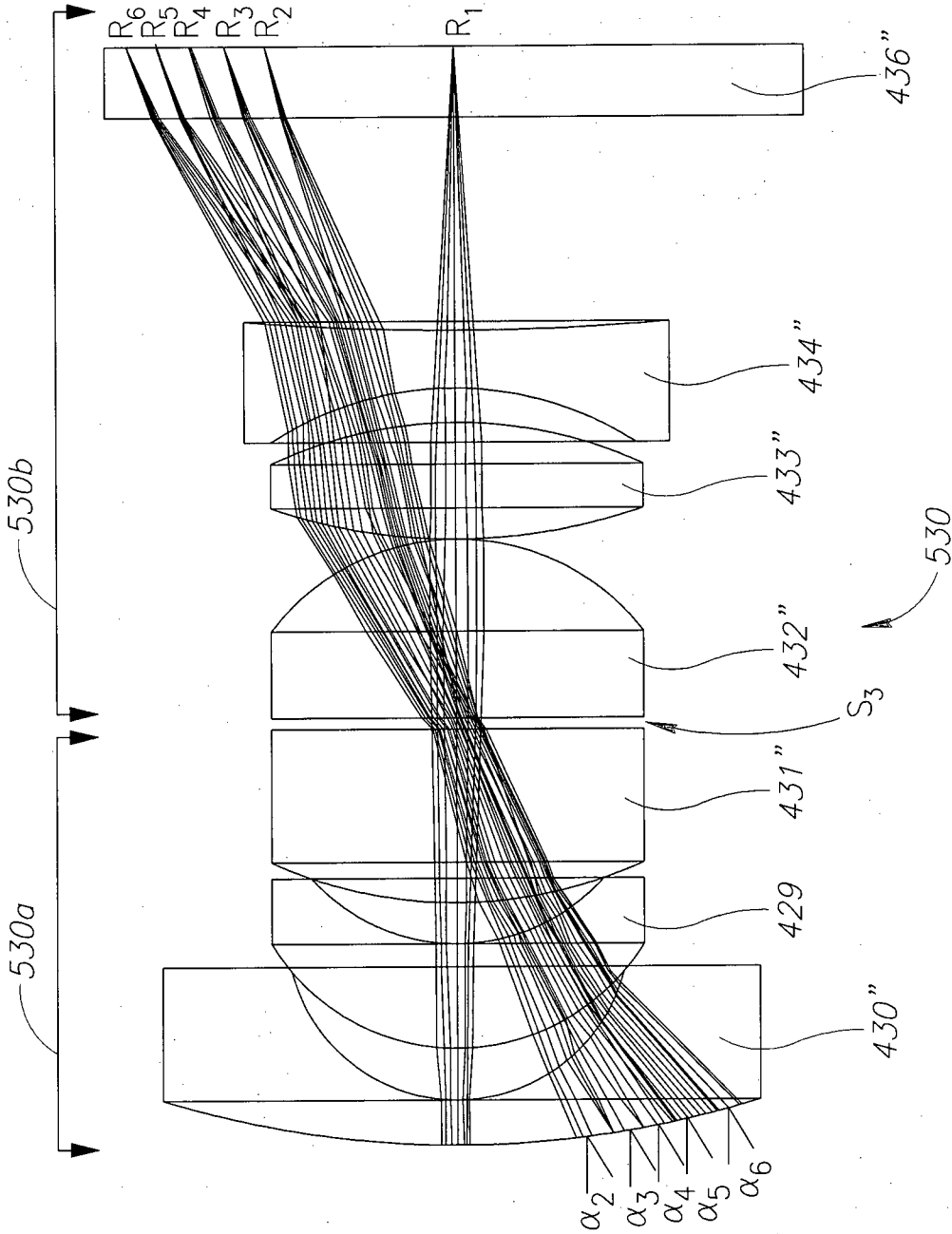


FIG.4C