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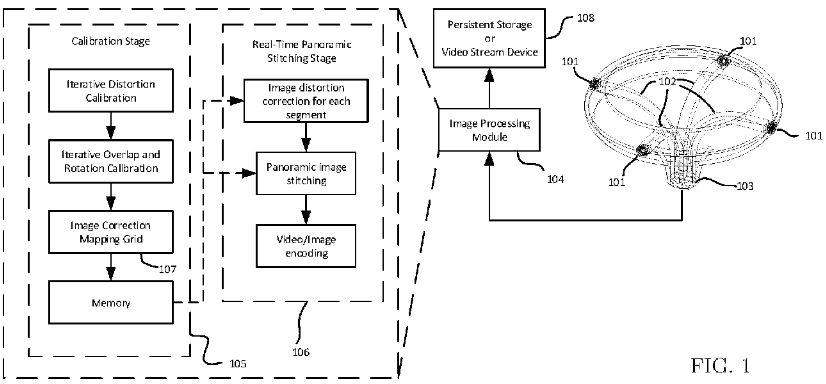

FIG. 1

(57) Abstract: A panoramic imaging method and device is disclosed to capture panoramic scene. The panoramic camera device comprises of a set of two or more optical lens units to collect a set of the panoramic scene segments, an optical image conduit module comprising a plurality of optical waveguides that are optically coupled to each optical lens unit and transfer to a main image sensor to form digital image signal. An image processing module reconstruct the panoramic image from the digital image signal.

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METHOD AND DEVICE FOR PANORAMIC IMAGING

FIELD OF THE INVENTION

[0001] The subject disclosure relates to an imaging method and device for forming panoramic images or videos with single or multiple image sensors.

BACKGROUND OF THE INVENTION

[0002] Panoramic imaging methods and devices have been devised in the past. The existing conventional methods can be categorized into three types.

[0003] The first type of methods are based on digital image stitching. Multiple images are taken by arranging multiple cameras pointing to different directions. A panoramic image can be generated by stitching these images together. This type of method increases system complexity, size, power consumption and cost, therefore it is not suitable for applications that are sensitive to aforementioned factors.

[0004] The second type of methods are based on ultra wide-angle lens, which creates a wide panoramic or hemispherical image but with strong visual distortion.

[0005] The third type of methods are similar to the second. Instead of using the wide-angle lens, a mirror is utilized to direct the field of view onto the image sensor. Besides the same disadvantage as the wide-angle methods, this type of methods suffer from a blind area in the center of the image sensor.

OBJECTS OF THE INVENTION

[0006] It is an object of this invention to provide a panoramic imaging system with high picture quality yet low cost and low power-consumption.

SUMMARY OF THE INVENTION

[0007] This present invention discloses an innovative camera device that instantaneously and continuously captures panoramic scene. The panoramic camera device comprises of a set of two or more optical lens units, respectively, wherein each lens includes one or more optical elements to collect a portion of the panoramic scene and form a subimage on an image surface; an optical image conduit module comprising a plurality of optical fiber waveguides that are optically coupled to each optical lens unit to receive the light from the image surface, respectively, wherein each optical fiber waveguide is bent and/or twisted by suitable angles to transfer the light away from its input facet onto the output facet, which points towards the main image sensor; an optical conduction mechanism for transmitting the light emitted from the output facet of the optical image conduit onto the main image sensor; a main image sensor for converting the received light signal into the digital image; a supporting fixture for fastening the optical image conduit and the optical conduction mechanism; and an image processing module for constructing the panoramic image from the digital image signal.

[0008] In the optical image system, two or more lenses are arranged apart in space with desired constellation, to capture individual images simultaneously, which are used to reconstruct a panoramic image. Several configurations but not limited to those are disclosed to form 360-degree panoramic scene, hemisphere panoramic scene and full-sphere panoramic scene respectively. Furthermore, an optical image conduit module comprising a plurality of optical fiber waveguides transfers multiple desired field of views to the single image sensor. The image sensor consequently converts the light into digital signal for further processing.

[**0009**] The digital image signal is subsequently divided into multiple segments. The image distortions caused by lenses, both in geometry and light intensity, are corrected by software algorithm. The software correction parameters can be obtained from manufacturing calibration process. All the segments are stitched in a suitable order to reconstruct the panoramic image after distortion correction. Comparing to conventional stitching approaches, the disclosed method has both low computation demand and less distortion advantages. This image or image sequence is then compressed for storage or transmission.

[**0010**] Other objects, features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed descriptions that follow below.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0011**] For a more complete understanding of the invention, reference is made to the following description and accompanying drawings, in which:

[**0012**] FIG. 1 shows a flow diagram according to an embodiment of the present invention wherein a camera device receives segmented panoramic image via a plurality of lens and transfer through an optical image conduit module comprising a plurality of optical waveguides to a main image sensor, and processes the image in order to recreate seamless panoramic image ;

[**0013**] FIG. 2 illustrates a coordination system for describing a lens orientation and the field of view of a lens according to an embodiment of the panoramic camera device;

[**0014**] FIG. 3 illustrates an optical waveguide is bent along its center line by θ degree according to an embodiment of the panoramic camera device;

[**0015**] FIG. 4 illustrates an optical waveguide is twisted by γ degree according to an embodiment of the panoramic camera device;

[**0016**] FIG. 5 illustrates an optical waveguide is firstly twisted by γ_i degree and then bent by θ_i degree according to an embodiment of the panoramic camera device;

[**0017**] FIG. 6 illustrates an exemplary panoramic optical system to create 360-degree panoramic image in accordance with an embodiment of the present invention;

[**0018**] FIG. 7 illustrates of the exterior view of a 360-degree panoramic camera device in accordance with an exemplary embodiment ;

[**0019**] FIG. 8 illustrates two configurations that transfer image from an optical image conduit module to the image sensor according to an embodiment of the panoramic camera device; FIG. 8-A illustrates an optical image conduit module where its output facet is directly bonded on the image sensor; FIG. 8-B illustrates an indirect relay lens approach that transfer the light of image from the output facet of the optical image conduit module to the image sensor via a relay lens ;

[**0020**] FIG. 9 illustrates an embodiment of optical image camera system that captures the field of view of the half sphere; FIG. 9-A shows an exemplary waveguide bundle configuration where the output facet aspect ratio is 4:3; In another example, FIG. 9-B shows an exemplary waveguide bundle configuration where the output facet aspect ratio is 1:1 ;

[**0021**] FIG. 10 illustrates an embodiment of optical image camera system that captures the field of view of the full sphere. FIG. 10-A shows an exemplary waveguide bundle configuration where the output facet aspect ratio is 4:3; In another example, FIG. 10-B shows an exemplary waveguide bundle configuration where the output facet aspect ratio is 1:1 ;

[**0022**] FIG. 11 illustrates an embodiment that the panoramic picture is separated into four segments and projected onto single image sensor;

[**0023**] FIG. 12 illustrates the procedures of the panoramic camera calibration. FIG. 12-A shows the calibration procedure for the direct bonding configuration as shown in FIG. 8-A . FIG. 12-B shows the calibration procedure for the relay lens configuration as shown in FIG. 8-B. FIG. 12-A also represents the adaptive calibration procedure on the user side; and

[**0024**] FIG. 13 illustrates process of digitizing, distortion-correction, and re-construction of panoramic image.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[**0025**] The embodiment showing in this section along with the associated figures are for exemplary illustration. The design of components, the number of lens/fiber optic image conduits and their arrangement may vary in accordance with applications and design requirements.

[**0026**] FIG. 1 shows a panoramic camera system according to an embodiment of the present invention comprising four lenses **101**, an optical image conduit module comprising a plurality of optical fiber waveguides **102**, an image sensor **103**, and an image process module **104** that receives and processes the raw image stream in order to produce panoramic image. During initial characterization of panoramic camera system, the image process module **104** executes the diagram of calibration stage **105** to generate an image correction mapping grid **107** and stores in a memory module. After calibration completes, the image process module **104** executes the diagram of real-time panoramic stitching stage **106** which applies image correction mapping grid **107** to remove the image distortion and stitch a plurality of image segments to generate panoramic image. The panoramic image is further encoded and transfer to a suitable storage device **108**, such as memory card, hard disk drive, or any other data storage means. The encoded panoramic image/video can also be transmitted through streaming methods **108** such as Wi-Fi, bluetooth, high-speed cellular data connection, etc.

[**0027**] The panoramic camera system of the present invention comprises a plurality of optical lenses. FIG. 2 illustrates the field of view (FOV) P_i of a single optical lens unit according to an embodiment of the present invention. A said panoramic scene N is defined as the annular area between two dashed lines **202** on a sphere. The FOV P_i of an optical lens unit **201** is described as,

$$P_i = f(\alpha_i, \beta_i, o_i)$$

, where α_i, β_i and o_i are horizontal FOV, vertical FOV and the orientation of said individual optical lens unit **201**, respectively. A plurality of optical image lenses are placed in an annulus volume with orientation $o_i = \{\phi_i^z, \phi_i^{xy}\}$, where ϕ_i^z is the angle between z axis **203** and o_i, and ϕ_i^{xy} is the angle between x axis **204** and the projection of o_i on xy plane. Each individual optical lens unit **201** captures a portion of a panoramic scene N, such that a plurality of optical lenses capture a image P that contains the panoramic scene N, i.e.

$$P = \bigcup_i P_i \supseteq N$$

The orientations o_i of said image lenses **201** are separated by suitable angle depending on each said lens unit's horizontal FOV α_k to satisfy

$$\begin{cases} \phi_i^z = \phi_1^z \\ \phi_i^{xy} < \phi_1^{xy} + \frac{\alpha_1 + \alpha_i}{2} + \sum_{k=2}^{i-1} \alpha_k \end{cases}$$

, where $\{\phi_1^z, \phi_1^{xy}\}$ is the orientation of a reference image lens o_1.

[0028] FIG. 3 shows an exemplary bent optical fiber waveguide according to an embodiment of the present invention. An optical fiber waveguide comprises of millions of optical fibers with diameter as small as a few micrometers. Each optical fiber can transmit light rays to the output side with very little loss as a result of the total internal reflection effect of optical fiber. In the example shown, the center line of an optical fiber waveguide **301** is bent with radius r and bending angle θ degree. The light rays that enter from input facet **301** are rotated by θ degree and transmitted to the output facet **302**. In this way, the image from input facet **302** can be transferred to the output facet **303** with orientation changing by θ degree.

[0029] FIG. 4 shows an exemplary twisted optical fiber waveguide according to an embodiment of the present invention. In the example shown, an optical fiber waveguide **401** is twisted along its center line by γ degree. As a result, the image of input facet **402** can be transmitted to the output facet **403** by rotating γ degree.

[0030] FIG. 5 shows an exemplary twisted and bent optical fiber waveguide according to an embodiment of the present invention. In the example shown, an optical fiber waveguide **501** is firstly twisted along its center line by γ_i degree, and its center line is then bent by θ_i degree. As a result, the image of input facet **503** can be transmitted to the output facet **502** with orientation rotating by θ_i and γ_i degree relative to z_i^1 and x_i^1 respectively. Using optical fiber waveguide **501**, the input facet **502** can be orientated to point to an arbitrary direction whereas the orientation of the output facet **503** is fixed.

[0031] FIG. 6 shows an exemplary panoramic camera system according to an embodiment of the present invention. In the example shown, four optical lenses **601**, **602**, **603**, and **604** are evenly placed in an annulus volume. Each optical lens is designed to capture over 90-degree horizontal FOV. The orientations of the four optical lens in the example shown are

$$o_1 = \{90, 0\}, o_2 = \{90, 90\}, o_3 = \{90, 180\}, \ and\ o_4 = \{90, 270\},$$

where o_1 is orientation of optical lens **601**, o_2 is orientation of optical lens **602**, o_3 is orientation of optical lens **603**, and o_4 is orientation of optical lens **604**. As the horizontal FOV is greater than the separation angle of neighboring optical lens, the set of four optical lenses in the shown example is able to capture 360-degree image. The image captured by each individual lens are transmitted through an optical image conduit module comprising four optical fiber waveguides **605**, **606**, **607**, and **608** to the main image sensor **609**. In the example shown, **605** and **607** are bended optical fiber waveguide with bending angle $\theta = 90$ degree; **606** and **608** are twisted and bended optical fiber waveguide with twisting angle $\gamma = 90$ degree and bending angle $\theta = 90$ degree. The four optical fiber waveguides are bonded together with suitable optical adhesive to make a common output facet. The output facet is polished and bonded to the main image sensor **609**. In another example where input and output facets of the optical fiber waveguides are of square format, the optical image conduit module comprises four bended optical fiber waveguide with bending angle $\theta = 90$ degree. In another example, more than four optical lenses can be used to capture 360-degree image. The separation angle of neighboring optical lens is determined by $360/M$ where M is the total number of optical lenses. The horizontal FOV α_i is required to be larger than $360/M$ to cover the said panoramic scene.

[**0032**] FIG. 7 shows an exemplary embodiment of exterior view of the panoramic camera system according to an embodiment of the present invention. Four lenses **601**, **602**, **603**, and **604** are evenly mounted on their lens holders. Due to assembly variation, it is subject to have tolerable assembly errors in six degree-of-freedom (rotation in pitch, yaw, roll and displacement in (x, y, z) and resulting in the shift of desired picture in x and y axes. The assembly deviation from the normal positions can be optimized in the manufacturing processes and the resulted optical performance is acceptable to the optics design.

[**0033**] In the exemplary embodiment, the entire enclosure is waterproof, insensitive to temperature and robust to shock, which allows the device to be mounted on exterior wall, vehicle, helmet, remote controlled mobile robots, and can be used in hazard environments such as high elevation or under water.

[**0034**] In the exemplary embodiment, the top cover is flat and can be magnetic for ease of attachment to metal surface. Four lens holders are even drilled on side of the enclosure. Optical lenses are mounted into the lens holders where suitable waterproof bonding material may be used to prevent water leaking. The location and tilt angle of the optical lenses can be configured differently depending on various applications and environments where the camera is installed. For example, the camera can be configured to capture lower hemisphere of view if installed on ceiling. The lower part of the enclosure encloses the fiber optic image conduits and an image sensor. It is sealed and enforced to provide water, pressure, shock resistance.

[**0035**] In the exemplary panoramic camera system shown in FIG. 6 , the output facet of optical image conduit module transmit to image sensor **609**. In order to successfully couple light from an imaging fiber bundle to the image sensor, the image sensor and fiber bundle must be in very close proximity. Light emerges from the individual fibers at large angles, and a gap between fiber and image sensor will lead to a loss in resolution. FIG. 8 shows two types of approaches to couple the fiber bundle and image sensor according to an embodiment of the present invention to get satisfactory result.

[**0036**] FIG. 8-A illustrates the output facet of the optical image conduit module is directly bonded to the image sensor **609** with suitable optical adhesive. To ensure satisfactory quality, the bonding procedure should be performed in a clean room environment in order to avoid dust particles from getting trapped in the bonding layer. The selection of the optical adhesive for bonding should consider those that have a low shrinkage upon curing, high transparency for the luminescent light and low viscosity. The bonding adhesive are also expected to be thermal and chemical stable, and has a high mechanical strength and low coefficient of thermal expansion. Comparing to traditional lens, fiber optic provide much higher light collecting efficiency ranging from 50% to 90%. In low light applications, the benefit of direct bonding can be more evident.

[**0037**] FIG. 8-B illustrates an indirect relay lens approach that transfer the light of image from the output facet of the optical image conduit module to the image sensor **609** via a relay lens **801**. Comparing to the direct bonding approach in FIG. 8-

A, this approach increases spacing to connect the output facet of the optical image conduit module to the image sensor, therefore it may increase the overall size of the panoramic camera. On the other hand, the indirect relay lens approach offers better design flexibility. In the example shown, the magnification ratio r is determined by the distance b from the output facet of the optical image conduit module to the relay lens **801** and the distance a from relay lens **801** to the image sensor **609** with the following equation

$$r = \frac{a}{b}.$$

By adjusting magnification ratio r, this approach allows to choose different size of image sensor **609** and optical fiber waveguide, and therefore provides more design flexibility.

[**0038**] FIG. 9 shows an exemplary hemisphere camera system according to an embodiment of the present invention. In the example shown, four optical lenses **901**, **902**, **903**, and **904** are evenly placed in an annulus volume. Each optical lens is designed to capture over 90-degree horizontal FOV. The orientations of the four optical lens in the example shown are

$$o_1 = \{45, 0\}, o_2 = \{45, 90\}, o_3 = \{45, 180\}, \ and \ o_4 = \{45, 270\},$$

where o_1 is orientation of optical lens **901**, o_2 is orientation of optical lens **902**, o_3 is orientation of optical lens **903**, and o_4 is orientation of optical lens **904**. The FOV of each individual lens are designed to have horizontal FOV $\alpha_i > 90$ and vertical FOV $\beta_i > 90$.

[**0039**] As most commercially available image sensors use unequal aspect ratio format, for example 4:3 or 16:9. In order to optimize the image sensor utilization efficiency, FIG. 9-A shows an exemplary optical image conduit module configuration according to an embodiment of the present invention. In the example shown, four optical fiber waveguides are bundled together to transfer the received images from four optical lenses to the output facets. The input and output facets of each individual optical fiber waveguide use the same aspect ratio format as image sensor. **905** and **907** are bent optical fiber waveguide with bending angle $\theta = 90$ degree; **906** and **908** are twisted and bent optical fiber waveguide with twisting angle $\gamma = 90$ degree and bending angle $\theta = 45$ degree. The four optical fiber waveguides are bonded together with suitable optical adhesive to form a common output facet, which ensures bonded output facet maintains the same aspect ratio as image sensor.

[**0040**] FIG. 9-B shows another exemplary optical image conduit module configuration according to an embodiment of the present invention. In the example shown, four optical fiber waveguides are bonded together to transfer the captured images from four optical lens to the output facets. The input and output facets of each individual optical fiber waveguide use the aspect ratio 1:1. Due to choice of the aspect ratio, four optical fiber waveguides **915**, **916**, **917**, and **918** are all bent optical fiber waveguide with bending angle $\theta = 90$ degree. Choice of this configuration may help reduce optical fiber waveguide manufacturing cost. However, if the camera system uses commercial available image sensor with aspect ratio of 4:3 or 16:9, using the optical fiber waveguide with aspect ratio 1:1 , the sensor format efficiency could loss 25% to 45%. In order to maximize the sensor utilization efficiency, image sensor **905** may be designed to have aspect ratio of 1:1.

[**0041**] Both examples of FIG. 9 shows that the image from the bonded output facet is transferred through the optical relay lens to the image sensor. In another embodiment, similar to the example of FIG. 8-A, said bonded output facet of optical fiber waveguide bundles can be directly bonded to said image sensor with appropriate optical adhesive.

[**0042**] In another embodiment, FIG. 10 shows an exemplary full-sphere camera system according to an embodiment of the present invention. Two said hemisphere camera systems are mounted side by side to capture a full-sphere view, where the upper and lower one receive upper and lower hemisphere view respectively, and transfer images to their corresponding image sensor for post processing. Two types of optical image conduit module configurations can be applied according to the image sensor aspect ratio format. In one example, FIG. 10-A shows an exemplary optical image conduit module configuration where the output facet aspect ratio is 4:3. In another example, FIG. 10-B shows an exemplary optical image conduit module configuration where the output facet aspect ratio is 1:1.

[**0043**] In another embodiment, said image sensor **103** receives image from said optical image conduit module **102**. FIG. 11-A illustrates an exemplary panoramic image where it is divided into four segments N_1, N_2, N_3 and N_4 according to an embodiment of the present invention. Each segment corresponds to a subimage of 90 degree view angle. FIG. 11-B illustrates the image received by said image sensor **103**. Depending on the configuration of said optical image conduit module described in FIG. 8, each subimage may have different rotation angle. In the example shown, said optical image conduit module comprising four optical fiber waveguides (**605**, **606**, **607**, and **608**) are used for transferring the image from said four optical lenses to the said image sensor **103**, where four subimages P_1, P_2, P_3, and P_4 corresponds to the images that are received from said four optical lenses **601**, **602**, **603**, and **604** respectively. Subimages P_2 and P_3 have180 degree orientation difference comparing to subimages P_1 and P_4.

[**0044**] The said lenses **101** and said relay lens **801** are both subject to standard lens distortion which can be described by camera homography model and lens distortion model. In the practical applications, the camera homography model can change during operation if the camera undergoes mechanical impact which shifts the relative transnational and rotational position between 1) optical lens units **101** and said input facets of optical image conduit; 2) said output facet of optical image conduit and said relay lens **801**; 3) said relay lens **801** and said image sensor **609**. Therefore, the calibration process is necessary for reconstructing panoramic image from subimages. The thorough calibration is done at manufacturing time, and adaptive calibration is done at normal operation time.

[**0045**] In the embodiment illustrated in the flow diagram of FIG. 12, the calibration procedure is part of the manufacturing process. In one embodiment, as in the case of direct bundle as illustrated in FIG. 8-A, the calibration is done after the completion of overall assembly. The camera is placed in the panoramic image calibration environment (step **1201**). As mentioned before, the image that is captured by each lens **601-604** is transferred to the output facet of said optical image conduit. The boundaries between optical fiber waveguides **605-608** at said output facet are identified by searching the dead zones (step **1202**). Multiple pictures are taken using standard lens calibration charts (e.g. numbered checkerboard images) with different orientation to ensure no singularities. Then the camera parameters and lens distortion models are calibrated for each lens based on the subimages using common single camera calibration algorithm (step **1203**). After the verification (step **1204-1205**), each subimage is captured and rotated according to the configuration (step **1206**). Then the overlapping between lenses are determined by finding the matching features among subimages (step **1207**). After the final verification (step **1208-1209**), the final calibration results are stored in the persistent memory (step **1210**).

[0046] In the other embodiment, as in the case of relay lens as illustrated in FIG. 8-B, the camera parameters and lens distortion need to be calibrated separately before the calibration of said optical lens units **101**. During manufacturing process, said image sensor **801** and said relay lens **609** are assembled first (step **1211**) and be placed into single camera calibration environment (step **1212**). Then the camera parameters and lens distortion of the relay lens are calibrated (step **1213**). After the verification (step **1214-1215**), the optical image conduit and input lenses are assembled for the remaining calibration steps **1201-1210**.

[0047] On the user side, the said panoramic camera may be subject to strong mechanical impact such as strong mechanical shock. In the cases of corner temperatures, uneven distortion in the assembly can occur due to the thermal characteristics of the material of housing or lens holder. Both factors can change the camera and lens' parameters especially on said lens units **101** and the optical image conduit because they are further away from the image sensor **609** than the relay lens **801**. In the worst case, the mechanical distortion causes observable image quality degradation to the final panoramic image, such as failure to remove overlapping or losing continuity in stitching the panoramic scene, and radial image distortion, etc. Therefore, it's necessary to perform adaptive calibration to restore the panoramic image quality on the user side. The adaptive calibration on the user side follows the same procedure as illustrated in FIG. 12-A. By using pre-calibrated camera and lens parameters as initial values, the said adaptive calibration procedure can achieve much faster convergence rate on aforementioned parameters.

[0048] The flow diagram FIG. 13 illustrates the process of image digitization and post processing in the digital signal processor in operating mode. Subimages are captured by each said lens unit **101** and directed onto said single image sensor **609** (step **1301-1302**). The raw digital image is then divided into multiple segments (step **1303**). The image processing algorithm applies the lens distortion correction model and overlapping removal model (step **1304**) to all subimages. After correction, the subimages are rotated and stitched to form the final panoramic image (step **1305**).

What is claimed:

1. An optical system for observing the panoramic scene, comprising of:

   a plurality of optical modules, comprising:

   a set of two or more optical lens units, respectively, wherein each lens includes one or more optical elements to collect a portion of the panoramic scene and form a subimage on an image surface;

   an optical image conduit module comprising a plurality of optical fiber waveguides that are optically coupled to each optical lens unit to receive the light from the corresponding image surface, respectively, wherein each optical fiber waveguide is bent and/or twisted by suitable angles to transfer the light away from its input facet onto the output facet, which points towards the main image sensor;

   an optical conduction mechanism for transmitting the light emitted from the output facet of the optical image conduit onto the main image sensor;

   a main image sensor for converting the received light signal into the digital image;

   a supporting fixture for fastening the optical image conduit and the optical conduction mechanism;

   an image processing module for constructing the panoramic image from the digital image signal.

2. The system of claim 1, wherein said individual optical lens unit captures a portion of said panoramic scene. The field of view (FOV) of each said optical

lens unit is,

$$P_i = f(\alpha_i, \beta_i, o_i)$$

, where α_i, β_i and o_i are the horizontal FOV, vertical FOV and the orientation of said individual lens unit, respectively.

3. The system of claim 1, wherein said a plurality of optical image lenses are placed in an annulus volume with orientation $o_i = \{\phi_1^z, \phi_1^{xy}\}$. The orientations o_i of said image lenses are separated by suitable angle depending on each said lens unit's horizontal FOV α_k to satisfy

$$\begin{cases} \phi_i^z = \phi_1^z \\ \phi_i^{xy} < \phi_1^{xy} + \frac{\alpha_1+\alpha_i}{2} + \sum_{k=2}^{i-1} \alpha_k \end{cases}$$

, where $\{\phi_1^z, \phi_1^{xy}\}$ is the orientation of a reference image lens o_1.

4. The system of claim 1, wherein said a set of optical image lenses capture the image that contains the panoramic scene, i.e.

$$P = \bigcup_i P_i \supseteq N$$

, where N represents the panoramic scene.

5. The system of claim 1, wherein the input facet of each said optical fiber waveguide is optically coupled to the image surface of the corresponding optical lens unit by a suitable coupling method including optical adhesive bonding, to receive the light from the corresponding image surface.

6. The system of claim 1, wherein said optical image conduit module combines a plurality of twisted and bent optical fiber waveguides with suitable twisting and bending angles, where their input and output facets allow unequal aspect ratio formats. The output facets of optical fiber waveguides are bonded to form

a common output facet. The object image at said common output facet is then transmitted to said image sensor through said optical conduction mechanism. The said common output facet maintains unequal aspect ratio format.

7. The system of claim 1, wherein said optical image conduit module combines a plurality of bent optical fiber waveguides with suitable bending angles, where their input and output facets allows equal aspect ratio format. The output facets of optical fiber waveguides are bonded to form a common output facet. The object image at said common output facet is then transmitted to said image sensor through said optical conduction mechanism. The said common output facet maintains equal aspect ratio format.

8. The system of claim 1, wherein optical conduction mechanism is to directly bond common facet of said optical image conduit to the image sensor with suitable optical clear adhesive. Said image sensor receives light signal seamlessly from said optical image conduit.

9. The system of claim 1, wherein said optical panoramic imaging system, comprising said optical lens units, said optical image conduit, and said main image sensor, is mounted in said supporting fixture. The top cover of said supporting fixture can be magnetic to attach to suitable surface.

10. The system of claim 1, wherein said a set of optical lens units are placed in an annulus volume with each lens unit captures a portion of the annulus panoramic scene P_i. The union of all portions P_i contains the annulus panoramic scene N.

11. The system of claim 1, where in said a set of optical lens units are placed in a hemisphere volume with each lens unit captures a portion of the hemisphere

panoramic scene P_i. The union of all portions P_i contains the hemisphere panoramic scene N.

12. The system of claim 1, where in said a set of optical lens units are placed in a full-sphere volume with each lens unit captures a portion of the full-sphere panoramic scene P_i. The union of all portions P_i contains the full-sphere panoramic scene N.

13. The system of claim 1, wherein said image processing module removes the distortion and overlap in said digital image from said image sensor.

14. The system of claim 1, wherein said image processing module splits said corrected digital image into multiple segments and rotates and stitch each segment into final said panoramic image.

15. An optical system for observing the panoramic scene, comprising of:

a plurality of optical elements, comprising:

a set of two or more optical lens units, respectively, wherein each lens includes one or more optical elements to collect a portion of the panoramic scene and form a subimage on an image surface;

an optical image conduit module comprising a plurality of optical fiber waveguides that are optically coupled to each optical lens unit to receive the light from the image surface, respectively, wherein each optical fiber waveguide is bent by an angle to transfer the light away from its input facet onto the output facet, which points towards the main image sensor;

a main image sensor for converting the received light signal into the digital image;

a relay lens between the optical image conduit and the image sensor to project the object image from the output facet onto the main image sensor;

a supporting fixture for fastening the optical image conduit and/or the optical conduction mechanism;

an image processing module for constructing the panoramic image from the digital image signal.

16. The system of claim 15, wherein said relay lens, as an alternative solution to claim 8, projects the objective image from said output facet of said optical image conduit onto said image sensor. The magnification ratio is determined by:

$$r = \frac{a}{b}$$

AMENDED CLAIMS
received by the International Bureau on
08 July 2016 (08.07.2016)

What is claimed:

1. An optical system for observing a panoramic scene, comprising of:

   a plurality of optical modules, comprising:

   a set of two or more optical lens units, respectively, wherein each optical lens unit includes one or more optical elements to collect a portion of the panoramic scene and form a subimage on an image surface;

   an optical image conduit module comprising a plurality of optical fiber waveguides that are optically coupled to each optical lens unit to receive light from the corresponding image surface, respectively, wherein each optical fiber waveguide is bent and/or twisted by suitable angles to transfer the light away from its input facet onto an output facet, which points towards the main image sensor;

   an optical conduction mechanism for transmitting the light emitted from the output facet of the optical image conduit onto the main image sensor;

   a main image sensor for converting a received light signal into a digital image;

   a supporting fixture for fastening the optical image conduit and the optical conduction mechanism;

   an image processing module for constructing the panoramic image from the digital image.

2. The system of claim 1, wherein said individual optical lens unit captures a portion of said panoramic scene, the field of view (FOV) of each said optical lens unit is,

$$P_i = f(\alpha_i, \beta_i, o_i)$$

, where α_i, β_i and o_i are the horizontal FOV, vertical FOV and the orientation of said individual lens unit, respectively.

3. The system of claim 1, wherein said a plurality of optical image lenses are placed in an annulus volume with orientation $o_i = \{\phi_i^z, \phi_i^{xy}\}$, the orientations o_i of said image lenses are separated by suitable angle depending on each said lens unit's horizontal FOV α_k to satisfy

$$\begin{cases} \phi_i^z = \phi_1^z \\ \phi_i^{xy} < \phi_1^{xy} + \frac{\alpha_1+\alpha_i}{2} + \sum_{k=2}^{i-1} \alpha_k \end{cases}$$

, where $\{\phi_1^z, \phi_1^{xy}\}$ is the orientation of a reference image lens o_1.

4. The system of claim 1, wherein said a set of optical image lenses capture the image that contains the panoramic scene, i.e.

$$P = \bigcup_i P_i \supseteq N$$

, where N represents the panoramic scene.

5. The system of claim 1, wherein the input facet of each said optical fiber waveguide is optically coupled to the image surface of the corresponding optical lens unit by a suitable coupling method including optical adhesive bonding, to receive the light from the corresponding image surface.

6. The system of claim 1, wherein said optical image conduit module combines a plurality of twisted and bent optical fiber waveguides with suitable twisting and bending angles, where their input and output facets allow unequal aspect ratio formats. The output facets of optical fiber waveguides are bonded to form a common output facet. The object image at said common output facet is then transmitted to said image sensor through said optical conduction mechanism. The said common output facet maintains unequal aspect ratio format.

7. The system of claim 1, wherein said optical image conduit module combines a plurality of bent optical fiber waveguides with suitable bending angles, where their input and output facets allows equal aspect ratio format, the output facets of optical fiber waveguides are bonded to form a common output facet. The object image at said common output facet is then transmitted to said image sensor through said optical conduction mechanism. The said common output facet maintains equal aspect ratio format.

8. The system of claim 1, wherein optical conduction mechanism is to directly bond common facet of said optical image conduit to the image sensor with suitable optical clear adhesive, said image sensor receives light signal seamlessly from said optical image conduit.

9. The system of claim 1, wherein said optical panoramic imaging system, comprising said optical lens units, said optical image conduit, and said main image sensor, is mounted in said supporting fixture, the top cover of said supporting fixture can be magnetic to attach to suitable surface.

10. The system of claim 1, wherein said a set of optical lens units are placed in an annulus volume with each lens unit captures a portion of the annulus panoramic scene P_i, the union of all portions P_i contains the annulus panoramic scene N.

11. The system of claim 1, where in said a set of optical lens units are placed in a hemisphere volume with each lens unit captures a portion of the hemisphere panoramic scene P_i, the union of all portions P_i contains the hemisphere panoramic scene N.

12. The system of claim 1, where in said a set of optical lens units are placed in a full-sphere volume with each lens unit captures a portion of the full-

sphere panoramic scene P_i, the union of all portions P_i contains the full-sphere panoramic scene N.

13. The system of claim 1, wherein said image processing module removes the distortion and overlap in said digital image from said image sensor.

14. The system of claim 1, wherein said image processing module splits said corrected digital image into multiple segments and rotates and stitch each segment into final said panoramic image.

15. An optical system for observing the panoramic scene, comprising of:

a plurality of optical elements, comprising:

a set of two or more optical lens units, respectively, wherein each lens includes one or more optical elements to collect a portion of the panoramic scene and form a subimage on an image surface;

an optical image conduit module comprising a plurality of optical fiber waveguides that are optically coupled to each optical lens unit to receive the light from the image surface, respectively, wherein each optical fiber waveguide is bent by an angle to transfer the light away from its input facet onto the output facet, which points towards the main image sensor;

a main image sensor for converting the received light signal into the digital image;

a relay lens between the optical image conduit and the image sensor to project the object image from the output facet onto the main image sensor;

a supporting fixture for fastening the optical image conduit and/or the optical conduction mechanism;

an image processing module for constructing the panoramic image from the digital image.

16. The system of claim 15, wherein said relay lens, as an alternative solution to claim 8, projects the objective image from said output facet of said optical image conduit onto said image sensor, the magnification ratio is determined by:

$$r = \frac{a}{b}$$

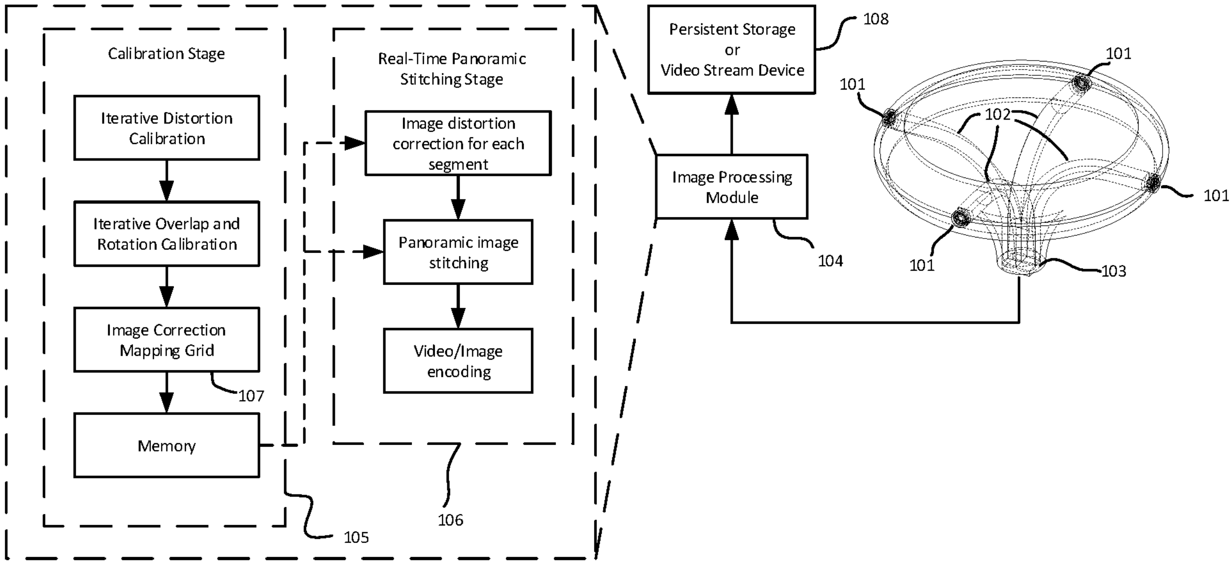

Calibration Stage
Iterative Distortion Calibration
Iterative Overlap and Rotation Calibration
Image Correction Mapping Grid
107
Memory
105
Real-Time Panoramic Stitching Stage
Image distortion correction for each segment
Panoramic image stitching
Video/Image encoding
106
Persistent Storage or Video Stream Device
108
Image Processing Module
104
101
101
102
101
101
103

FIG. 1

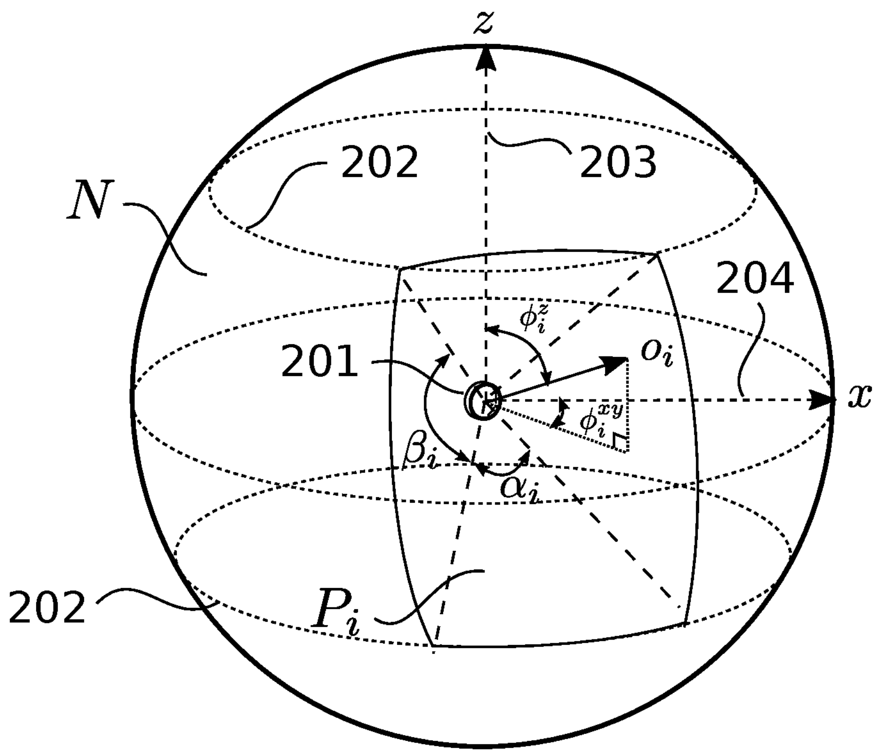

z
202
203
N
204
201
o_i
x
ϕ_i^z
ϕ_i^{xy}
β_i
α_i
202
P_i

FIG. 2

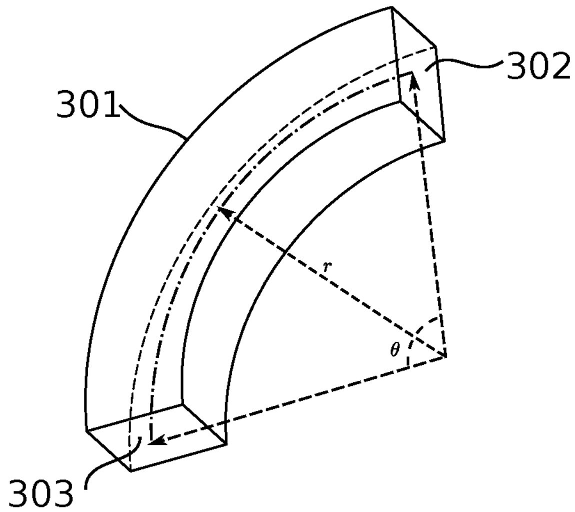


FIG. 3

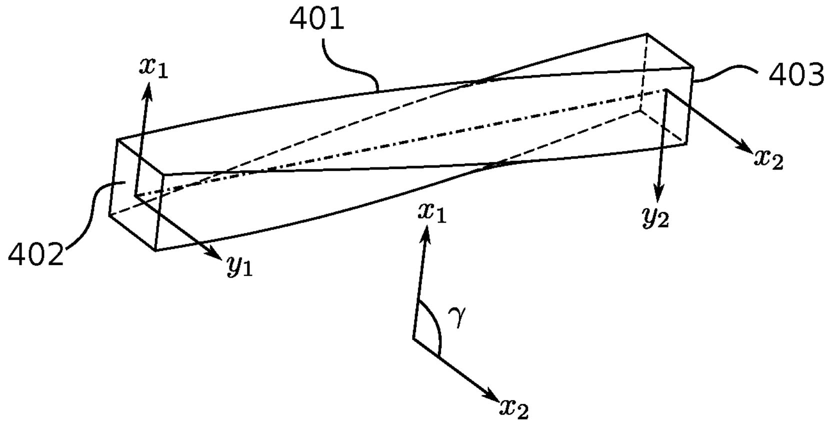


FIG. 4

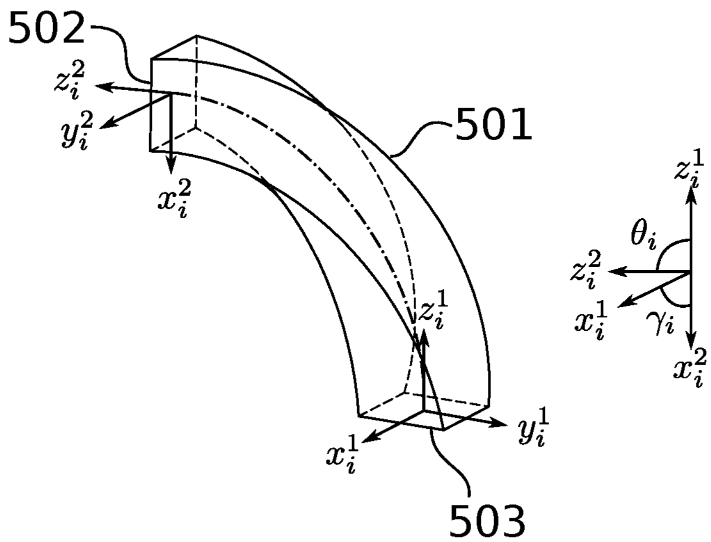


FIG. 5

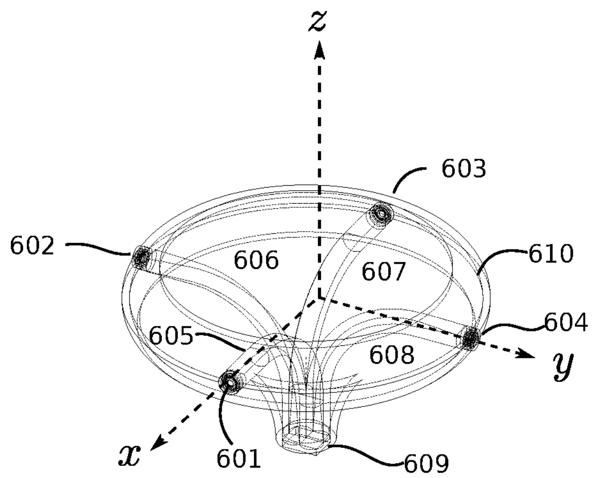


FIG. 6

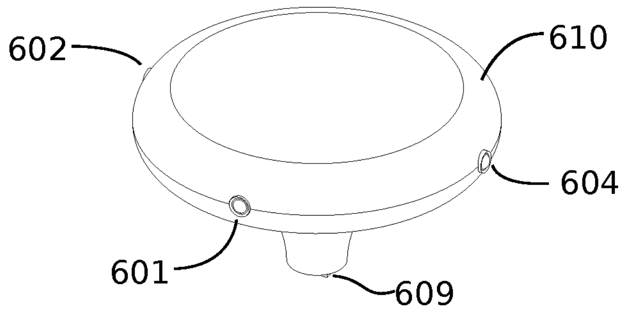


FIG. 7

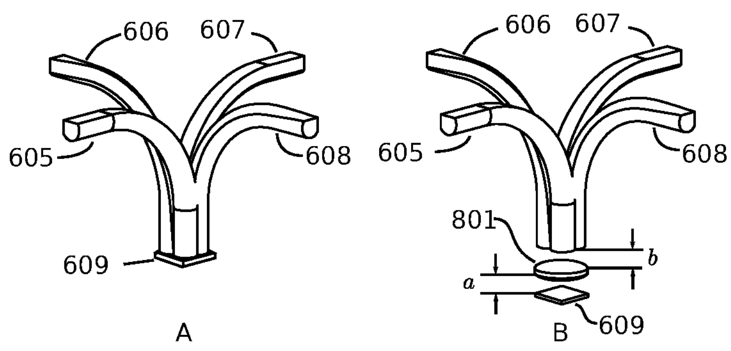
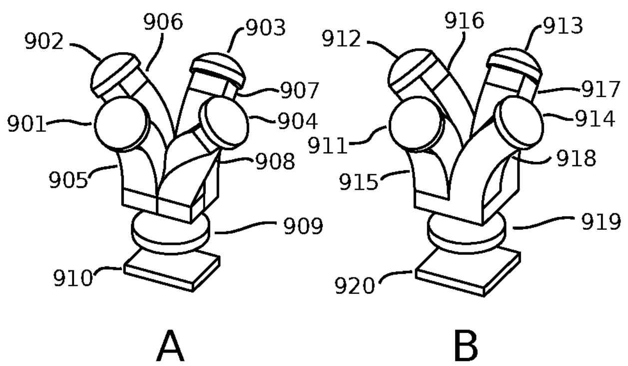


FIG. 8


902
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904
905
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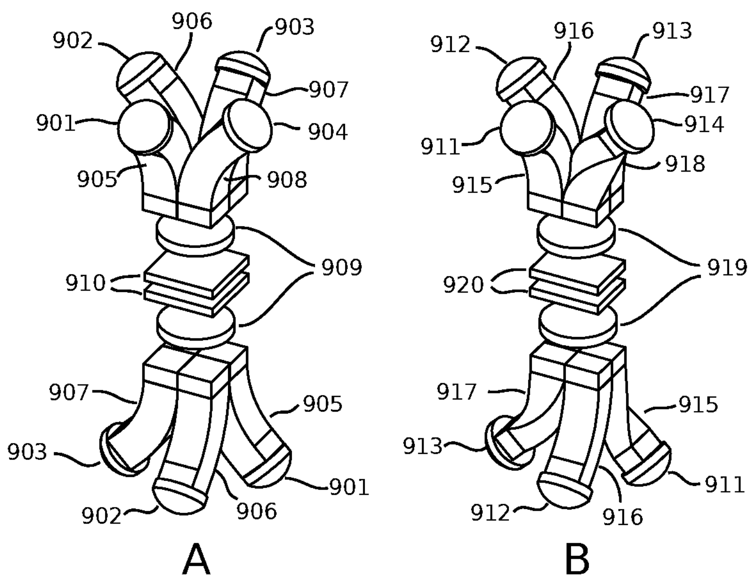
915
918
919
920
A
B

FIG. 9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920
917
915
913
911
912
916
A
B

FIG. 10

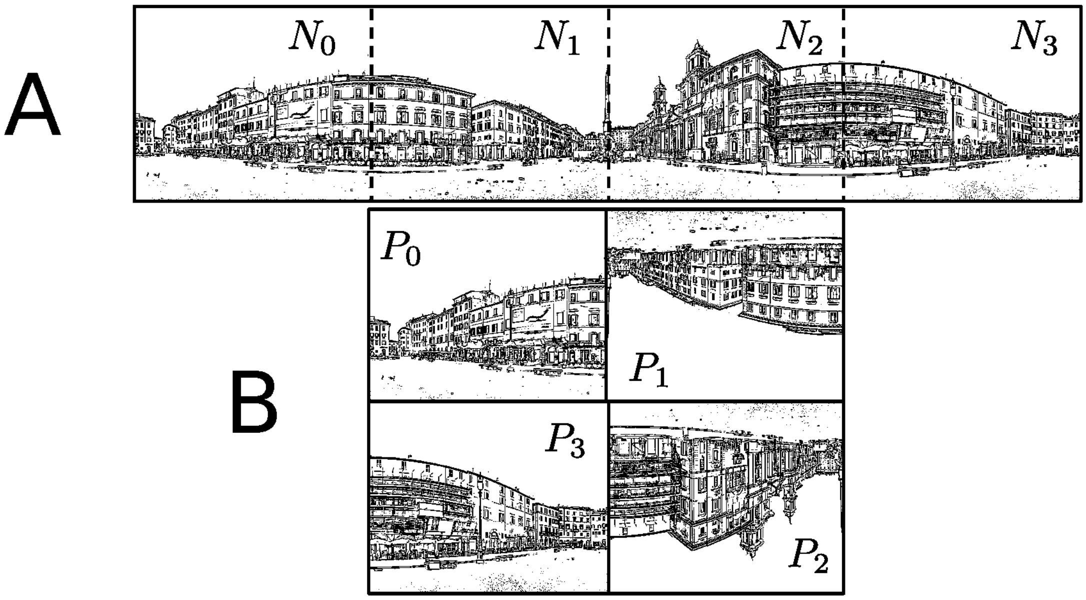
A
N_0
N_1
N_2
N_3
B
P_0
P_1
P_3
P_2

FIG. 11

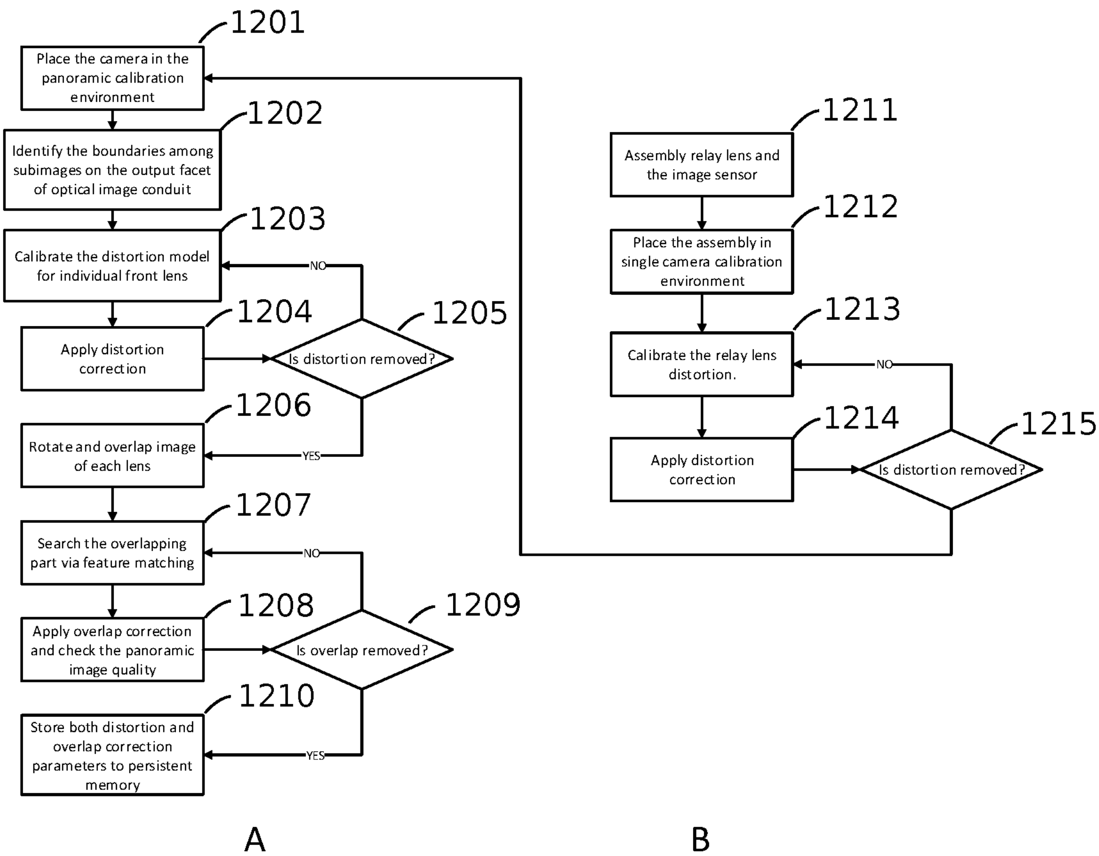
1201
Place the camera in the panoramic calibration environment
1202
Identify the boundaries among subimages on the output facet of optical image conduit
1203
Calibrate the distortion model for individual front lens
1204
Apply distortion correction
1205
Is distortion removed?
NO
YES
1206
Rotate and overlap image of each lens
1207
Search the overlapping part via feature matching
1208
Apply overlap correction and check the panoramic image quality
1209
Is overlap removed?
NO
YES
1210
Store both distortion and overlap correction parameters to persistent memory
1211
Assembly relay lens and the image sensor
1212
Place the assembly in single camera calibration environment
1213
Calibrate the relay lens distortion.
1214
Apply distortion correction
1215
Is distortion removed?
NO
A
B

FIG. 12

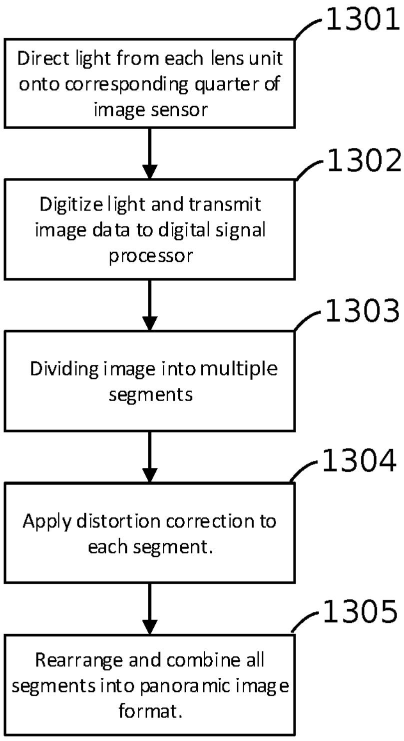
1301
Direct light from each lens unit onto corresponding quarter of image sensor
1302
Digitize light and transmit image data to digital signal processor
1303
Dividing image into multiple segments
1304
Apply distortion correction to each segment.
1305
Rearrange and combine all segments into panoramic image format.

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/20144

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G03B 37/04, 39/06; G02B 13/06 (2016.01)
CPC - H04N 5/2258, 5/23238; G03B 37/04
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)
IPC(8) Classifications: G03B 37/04, 39/06; G02B 13/06; H04N 7/00 (2016.01)
CPC Classifications: H04N 5/2258, 5/23238; G03B 37/04

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)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google Scholar; IEEE; EBSCO
Keywords used: panoramic camera device; optical lens unit; optical fiber waveguides; image sensor; relay lens; image processing module

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/0207990 A1 (THE REGENTS OF THE UNIVERSITY OF CALIFORNIA) July 23, 2015; abstract; figures 1B, 19; paragraphs [0075]; [0087]; [0136]	1-16
A	US 2007/0247519 A1 (RIAZIAT, M et al.) October 25, 2007; figures 7-8; abstract; paragraph [0046]	1-16
A	US 2002/0064341 A1 (FAUVER, M et al.) May 30, 2002; figures 1a-1b; abstract; paragraphs [0006]; [0118]	1-16

☐ 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	Date of mailing of the international search report
30 April 2016 (30.04.2016)	17 MAY 2016

Name and mailing address of the ISA/	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774