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FAST TIME-OF-FLIGHT CAMERA LENS ASSEMBLY

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SUMMARY

[0001] A four-element lens assembly for implementation in a time-of-flight (ToF) camera for a head mounted display (HMD) device provides a wide field of view (FOV), high contrast and illumination at high resolution across the FOV over a relatively long working distance, a sufficiently small package/form factor so as to permit implementation in an HMD device, and relative insensitivity to ambient illumination other than that emitted by the ToF light source

BACKGROUND

[0002] Three-dimensional (3D) time-of-flight (ToF) cameras acquire depth images of a local environment by reflecting radiation (typically infrared or visible light) off of objects in the local environment and measuring the "time-of-flight" of the radiation as a measure of the distance information. As such, a ToF camera typically utilizes a light source to project the radiation, an imaging sensor to capture reflected radiation information, and a lens assembly to focus incident reflected radiation on the imaging sensor. The recent implementation of ToF cameras in head mounted display (HMD) devices introduces a number of challenges.

DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1 is a diagram illustrating a front plan view of a head mounted display (HMD) device implementing a ToF camera.

[0004] FIG. 2 is a diagram illustrating a front plan view of a head mounted display (HMD) device implementing a ToF camera.

[0005] FIG. 3 is a diagram illustrating a cross-section view of the ToF camera of the HMD device of FIGs. 1 and 2.

[0006] FIG. 4 is a diagram illustrating a cross-section view of a lens assembly of the ToF camera of the HMD device of FIGs. 1, 2, and 3.

DESCRIPTION

[0007] FIGs. 1 and 2 illustrate example front plan view 101 and back plan view 201, respectively, of an example implementation of an HMD device 100 in a HMD form factor in accordance with at least one embodiment of the present disclosure. The HMD device 100 may be implemented in other form factors, such as a smart phone form factor, tablet form factor, a medical imaging device form factor, and the like, which implement configurations analogous to those illustrated.

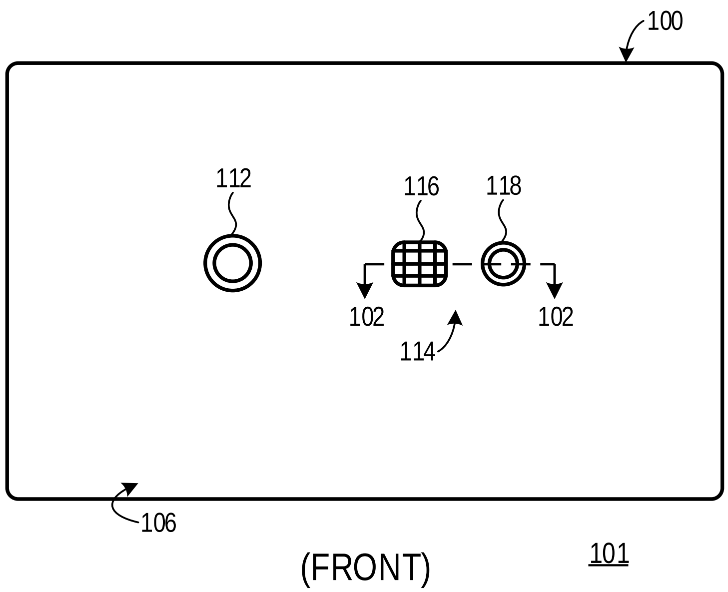

FIG. 1

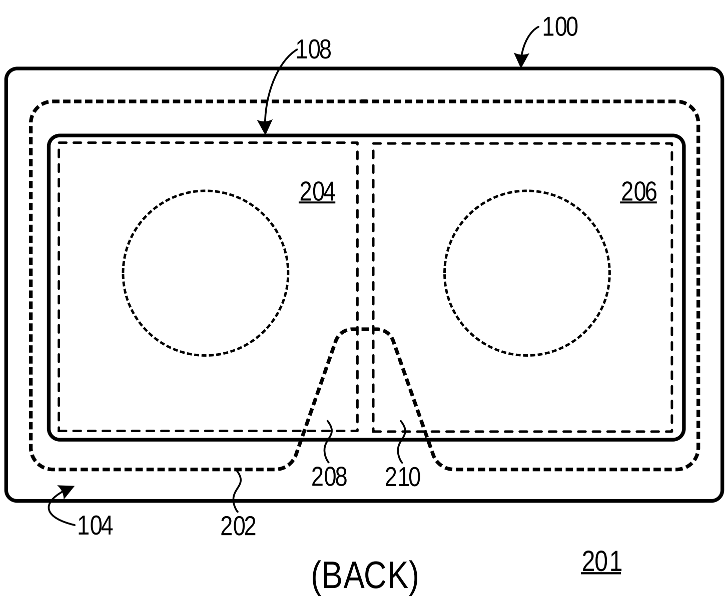

FIG. 2

[0008] In the depicted example, the HMD device 100 includes a housing 102 having a surface 104 opposite another surface 106, as well as a set of straps or a harness (omitted from FIG. 1 for clarity) to mount the housing 102 on the head of a user so that the user faces the surface 104 of the housing 102. In the example thin rectangular block form-factor depicted, the surfaces 104 and 106 are substantially parallel and the housing 102. The housing 102 may be implemented in many other form factors, and the surfaces 104 and 106 may have a non-parallel orientation. For the illustrated HMD system implementation, the HMD device 100 includes a display device 108 disposed at the surface 106 for presenting visual information to the user. Accordingly, for ease of reference, the surface 106 is referred to herein as the "forward-facing" surface and the surface 104 is referred to herein as the "user-facing" surface as a reflection of this example orientation of the HMD device 100 relative to the user, although the orientation of these surfaces is not limited by these relational designations.

[0009] The HMD device 100 includes a plurality of sensors to obtain information regarding a local environment of the HMD device 100. The HMD device 100 obtains visual information (imagery) for the local environment via one or more imaging sensors, such one or more visible-light imaging sensors 112. The HMD device 100 further includes a ToF camera 114 to capture depth information for the local environment, where the ToF camera 114 includes a modulated light projector 116 and an infrared camera 118. Although front plan view 101 of FIG. 1 illustrates the imaging sensor 112, the modulated light projector 116, and the infrared camera 118 aligned along a straight line for the benefit of an example cross-section view in FIG. 3, these components may be offset relative to each other.

[0010] As illustrated by the back plan view 201 of FIG. 2, the HMD device 100 can include the display device 108 disposed at the surface 104, a face gasket 202 for securing the HMD device 100 to the face of the user (along with the use of straps or a harness), and eyepiece lenses 204 and 206, one each for the left and right eyes of the user. As depicted in the back plan view 201, the eyepiece lens 204 is aligned with a left-side region 208 of the display area of the display device 108, while the eyepiece lens 206 is aligned with a right-side region 210 of the display area of the display device 108.

[0011] The ToF camera 114 is used to provide depth information for the objects in the local environment. To this end, the ToF camera 114 uses the modulated light projector 116 to project modulated light patterns from the forward-facing surface 106 into the local environment, and uses the IR camera 118 to capture reflections of the modulated light patterns as they reflect back from objects in the local environment. These modulated light patterns can be either spatially-modulated light patterns or temporally-modulated light patterns. The captured reflections of a modulated light flash are referred to herein as "depth images" or "depth imagery." A processing component (not shown) connected to the ToF camera 114 then may calculate the depths of the objects, that is, the distances of the objects from the HMD device 100, based on the analysis of the depth imagery (e.g., through a phase-shift analysis). The resulting depth data obtained from the ToF camera 114 may be used to calibrate or otherwise augment depth information obtained from multiview analysis (e.g., stereoscopic analysis) of the image data captured by the one or more imaging sensors 112. Alternatively, the depth data from the ToF camera 114 may be used in place of depth information obtained from multiview analysis.

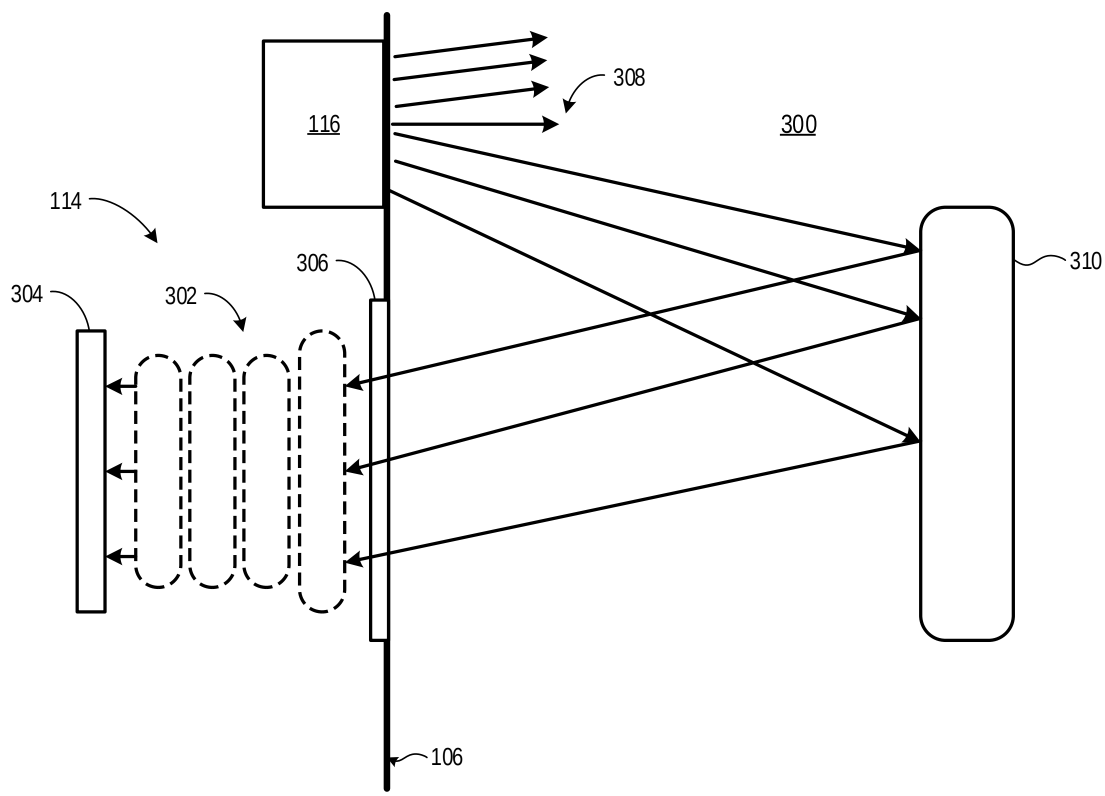

FIG. 3

[0012] FIG. 3 illustrates an example cross-section view 300 along line 102 (FIG. 1) at the surface 106 of the ToF camera 114 as implemented in the HMD device 100 depicted in the plan views of FIGs. 1 and 2. The ToF camera 114 includes the modulated light projector 116, a lens assembly 302, and an imaging sensor 304. The lens assembly 302 and imaging sensor 304 are aligned with a cover glass 306 for the ToF camera 114 at the surface 106 of the HMD device 100. As depicted, the modulated light projector 116 is configured to project modulated IR light 308 (that is, light radiation having a wavelength between 700 nanometers to 1 millimeter, and more preferably around 800-900 nanometers) from the surface 106 into the local environment, whereupon the emitted modulated IR light 308 reflects off of various objects 110 in the local environment. Reflected modulated IR light incident on the cover glass 306 (which may include an IR filter coating to filter out non-IR light) is focused by the lens assembly 302 onto the imaging sensor 304, which digitizes the incident IR light into imagery is then processed to extract depth information for the objects 110 using any of a variety of well-known methods.

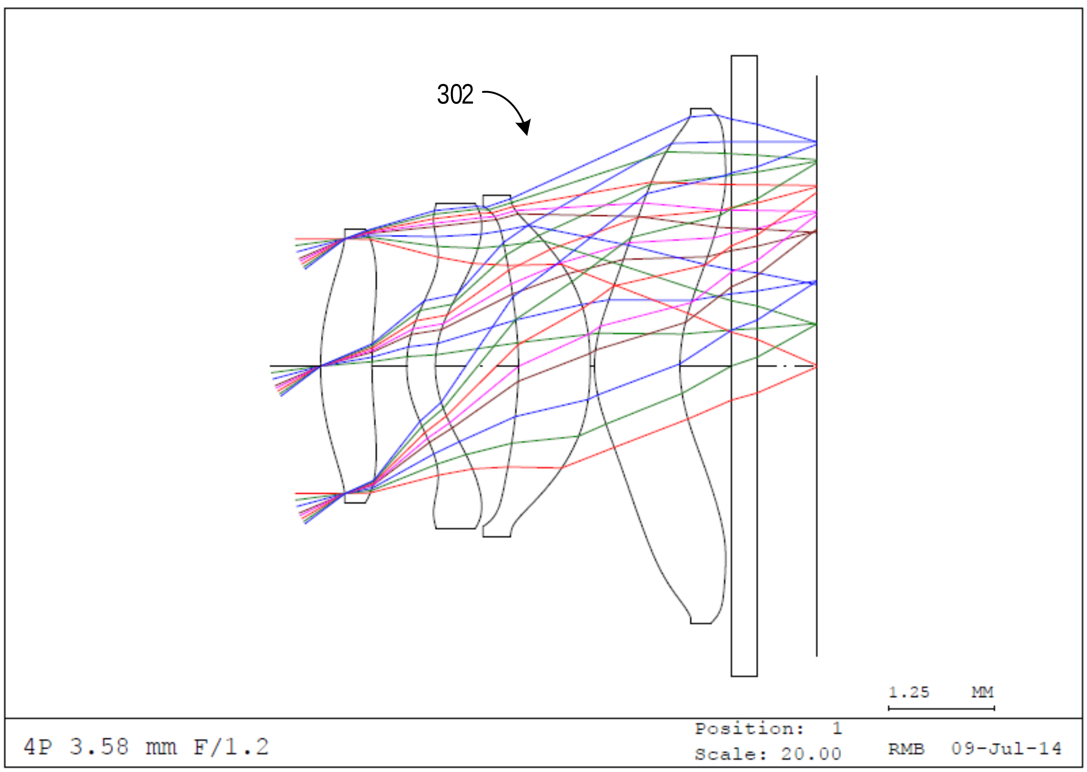

FIG. 4

[0013] As noted above, implementation of the ToF camera 114 in a HMD form-factor introduces particular requirements, especially for the lens assembly 302. FIG. 4 illustrates a cross-section of a particular configuration for this lens assembly 302 utilizing four lenses in the depicted configuration, and which beneficially addresses the particular requirements of an HMD implementation, such as a wide has a sufficiently wide field of view (FOV)(e.g., 65 deg x 45 deg); high contrast and illumination at high resolution across the field of view over a relatively long working distance (e.g., 0.6 meters to 1.4 meters); a sufficiently small package/form factor so as to permit implementation in an HMD device; and relative insensitivity to ambient illumination other than that emitted by the ToF light source.

[0014] Table 1 below illustrates example specifications for the lens assembly 302 (and imaging sensor 304) of FIG. 4:

Table. 1: Specifications of Lens Components

Parameter	**Specification**
System configuration	Image sensor, IR filter and camera lens.
Wavelength (nm)	840 – 860 (weighted 1,1)
Full Field of view (FFOV) deg	60*45
Sensor active area size (mm)	4.2*3.15(Reference)
Pixel size (µm)	17.5*17.5(Reference)
Resolution (pixels)	240*180
Depth of Field (m)	0.6 - 10
Max Chief Ray angle (deg)	18
F/#	1.6
Worst case MTF (lp/mm) of depth of field 0.6-4 m	0.25
Max lens barrel diameter (mm)	9 (M9 packing)
Total Track Length (mm)	5,1
Lens material	Plastic
IR filter	
Material	Glass
Thickness (mm)	0.3
Transmission (%)	>90

[0015] The disclosed infrared lens design has a wide field of view (FOV) of 60 x 45 degrees for a TOF camera sensor with demanding performance such as high contrast and illumination at high resolution across the FOV over a long working distance of 0.6 m to 10 m, within a tiny package of size 9 mm diameter x 5.9 mm length. The lens and camera are designed to be insensitive to ambient illumination other than in the infrared band of 840-860 nm. The camera lens system is not bulky and has significantly high performance in terms of contrast, resolution, field of view and working distance in a lens with a diameter of just 9 mm. The cost and weight of the camera can be reduced using the disclosed design.