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July 2023

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Recommended Citation
"MULTIPLEXED OPTICAL COHERENCE TOMOGRAPHY (OCT) IMAGING SYSTEM", Technical Disclosure Commons, (July 25, 2023)
https://www.tdcommons.org/dpubs_series/6077

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MULTIPLEXED OPTICAL COHERENCE TOMOGRAPHY IMAGING SYSTEM

DETAILED DESCRIPTION

[0001] Embodiments of multiplexed Optical Coherence Tomography (OCT) are described herein. In the following description, numerous specific details are set forth to provide a thorough understanding of the embodiments. One skilled in the relevant art will recognize, however, that the techniques described herein can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring certain aspects.

[0002] Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0003] Implementations of systems and methods of multiplexed OCT systems are disclosed herein. The field of view (FOV) and/or the wavelength of multiple OCT systems may be multiplexed. In contexts where the human eye will be imaged, power safety limits constrain the signal-to-noise (SNR) and/or speed of the OCT imaging. For retinal imaging, near-infrared wavelengths of 800 nm - 1100 nm may be used. For non-retinal imaging, 1200 nm – 1800 nm may be more typical.

[0004] In implementations of the disclosure, a wavelength and FOV multiplexed OCT system generates whole eye biometry. The whole eye biometry may be at a first wavelength (e.g. approximately 1060 nm) and a face-biometry may be at a second wavelength (e.g. approximately 1300 nm). The eye biometry systems may include eye or pupil tracking sub-systems and pupil steering elements. One or both eye biometry systems may be moveable to allow for different inter-pupillary distances.

[0005] The eye biometry combined with the face-biometry may allow for increased accuracy in modeling for optics, opto-mechanics of near-eye displays, and/or sensors. The increased accuracy may assist in personalizing head mounted device for virtual reality (VR), augmented reality (AR), mixed reality (MR), or other head mounted devices (e.g. smartglasses) and/or for manufacturing a broader range of products that are inclusive of different sizes.

[0006] FIG. 1 illustrates an imaging system 100 having three OCT systems, in accordance with implementations of the disclosure. OCT system 180 is a face scanning system for capturing volumetric face images of a face of a user 101. The volumetric face images may also image glasses/spectacles worn by user 101. The volumetric face image(s) may be provided to input/output port X3 of processing logic 199. OCT system 180 may operate with face-wavelengths of light between 1150 nm and 1800 nm. In some implementations, the face-wavelengths are between 1100 nm and 1800 nm. OCT system 180 may include a light source (e.g. laser light source) that emits the face-wavelength. The light source may be swept-source light source. The light source (not particularly illustrated) may have a broad bandwidth that, at any given time, emits a narrow-band wavelength having a linewidth that is less than 1 nm. Other portions of the

OCT system 180 such as the interferometer and reference arm are not particularly illustrated, but may be included in OCT system 180. FIG. 1 illustrates the sample arm portion of the OCT system 180.

[0007] OCT system 180 may include scanning mechanism (e.g. a galvo pair), focusing optics, and a dichroic reflector 130 that reflects wavelengths greater than 1150 nm and passes wavelengths that are less than 1150 nm. In the illustrated implementation, OCT system 180 operates with a face-wavelength of 1300 nm (green rays in FIG. 1).

[0008] FIG. 1 illustrates that imaging system 100 includes OCT system 160 configured to capture a volumetric eye image of a left eye 106B of user 101. The volumetric eye image(s) generated by OCT system 160 may be provided to input/output port X1 of processing logic 199. FIG. 1 also illustrates that imaging system 100 includes OCT system 170 configured to capture a volumetric eye image of a right eye 106A of user 101. The volumetric eye image(s) generated by OCT system 170 may be provided to input/output port X2 of processing logic 199. Together, OCT system 160 and 170 form a binocular eye biometry system that may operate at a wavelength between 700 nm and 1100 nm. In some implementations, a same light source (e.g. a laser light source) provides input light to both OCT system 160 and 170. The light source may be swept-source light source. Portions of OCT system 160 and 170 such as the interferometer and reference arm are not particularly illustrated, but may be included, as understood by those skilled in the art. FIG. 1 illustrates the sample arm portion of OCT systems 160 and 170.

[0009] In the illustrated implementations, OCT system 160 is configured to utilize a first polarization orientation (e.g. S-polarized light) of the eye wavelength to image a retina depth-of-field 112B and utilize a second polarization orientation (e.g. P-polarized light) of the eye wavelength to image a cornea depth-of-field 111B. Similarly, OCT system 167 is configured to utilize a first polarization orientation (e.g. S-polarized light) of the eye wavelength to image a retina depth-of-field 112A and utilize a second polarization orientation (e.g. P-polarized light) of the eye wavelength to image a cornea depth-of-field 111A.

[0010] Imaging system 100 may include cameras 190 configured to generate pupil data that may include images of the pupil. The pupil data may aid in alignment of OCT systems 160, 170, and/or 180. OCT system 160, 170, and/or 180 may be adjusted in response to the pupil data in order to have the FOV of each OCT system have the suitable FOV with respect to the face and eyes of user 101. The pupil data may also be utilized in motion correction in post-processing. In the illustrated implementation, pupil cameras 190 may operate a wavelength below 850 nm (e.g. 800 nm) and send/receive light via dichroic reflector 132 that reflects light less than 850 nm and passes light above 850 nm.

[0011] Processing logic 199 of imaging system 100 may drive each OCT system 160, 170, and 180 to acquire the respective volumetric images. Processing logic 199 may receive the volumetric images from OCT system 160, 170, and 180. Processing logic 199 may perform/execute processing to generate eye models of eyes 106A and 106B and also align eye optical models with the face of user 101 in space.

[0012] In an implementation, processing logic 199 is configured to receive the one or more volumetric eye images and generate an anterior chamber and retinal optical model of the eye(s) based on the volumetric eye image. Generating the anterior chamber optical model may include segmenting the first volumetric eye image into (1) a cornea; (2) a sclera (3) an iris; and (4) a front surface of the lens.

[0013] In an implementation, processing logic 199 is configured to receive a first volumetric eye image (e.g. from OCT system 160), receive a second volumetric eye image (e.g. from OCT system 170), receive a volumetric face image (e.g. from OCT system 180), and generate a combined face image 193. Generating the combined face image may include spatial registration of a first anterior chamber in the first volumetric eye image and a second anterior chamber the second volumetric eye image with respect to the volumetric face image.

[0014] FIG. 2 illustrates an imaging system 200, in accordance with implementations of the disclosure. Imaging system 200 includes OCT systems 260, 270, and 280 that may have similar attributes and functionality as OCT systems 160, 170, 180. Pupil cameras 290 of imaging system 200 may be similar to pupil cameras 190. Imaging system 200 includes displays with tunable focus for accommodation and physical fixation targets to project shadows on the retinas of eyes 106A and 106B. FIG. 2 illustrates that smaller dichroics and added optics may be utilized to incorporate the displays and physical fixation targets.

[0015] FIG. 3 provides acquisition and post-processing elements that may be performed by imaging systems 100 and 200. Processing logic 199 or 299, may execute all or a portion of the processing elements provided in FIG. 3, for example.

[0016] FIGs. 4-11 illustrate an example OCT systems that may be used for whole-eye imaging. FIG. 4 illustrates an optical layout for an example OCT systems for imaging the eye of a user to generate a personalized 3D optical model. The OCT system may image a retina depth-of-field and a cornea depth-of-field.

[0017] FIG. 5 illustrates an example optical layout for imaging the retina depth-of-field. FIG. 6 illustrates an example optical layout for imaging the retina during gazing (where the eye is not focused straight ahead). FIG. 7 illustrates an example optical layout for imaging the cornea depth-of-field.

[0018] FIG. 8 illustrates an example optical bench configuration of a portion of an OCT imaging system. FIG. 9 illustrates an example optical bench configuration of a portion of an OCT imaging system imaging the cornea. FIG. 10 illustrates an example optical bench configuration of a portion of an OCT imaging system imaging the retina. FIG. 11 illustrates an example optical bench configuration of a portion of an OCT imaging system imaging the retina and the cornea.

[0019] Embodiments of the invention may include or be implemented in conjunction with an artificial reality system. Artificial reality is a form of reality that has been adjusted in some manner before presentation to a user, which may include, e.g., a virtual reality (VR), an augmented reality (AR), a mixed reality (MR), a hybrid reality, or some combination and/or derivatives thereof. Artificial reality content may include completely generated content or generated content combined with captured (e.g., real-world) content. The artificial reality content may include video, audio, haptic feedback, or some combination thereof, and any of which may be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional effect to the viewer). Additionally, in some embodiments, artificial reality may also be associated with applications, products, accessories, services, or some combination thereof, that are used to, e.g., create content in an artificial reality and/or are otherwise used in (e.g., perform activities in) an artificial reality. The artificial reality system that provides the artificial reality content may be implemented on various platforms, including a head-mounted display (HMD) connected to a host computer system, a standalone HMD, a mobile device or computing system, or any other hardware platform capable of providing artificial reality content to one or more viewers.

[0020] The term “processing logic” in this disclosure may include one or more processors, microprocessors, multi-core processors, Application-specific integrated circuits (ASIC), and/or Field Programmable Gate Arrays (FPGAs) to execute operations disclosed herein. In some embodiments, memories (not illustrated) are integrated into the processing logic to store instructions to execute operations and/or store data. Processing logic may also include analog or digital circuitry to perform the operations in accordance with embodiments of the disclosure.

[0021] A “memory” or “memories” described in this disclosure may include one or more volatile or non-volatile memory architectures. The “memory” or “memories” may be removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules, or other data. Example memory technologies may include RAM, ROM, EEPROM, flash memory, CD-ROM, digital versatile disks (DVD), high-definition multimedia/data storage disks, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transmission medium that can be used to store information for access by a computing device.

[0022] Networks may include any network or network system such as, but not limited to, the following: a peer-to-peer network; a Local Area Network (LAN); a Wide Area Network (WAN); a public network, such as the Internet; a private network; a cellular network; a wireless network; a wired network; a wireless and wired combination network; and a satellite network.

[0023] Communication channels may include or be routed through one or more wired or wireless communication utilizing IEEE 802.11 protocols, BlueTooth, SPI (Serial Peripheral Interface), I^2C (Inter-Integrated Circuit), USB (Universal Serial Port), CAN (Controller Area Network), cellular data protocols (e.g. 3G, 4G, LTE, 5G), optical communication networks, Internet Service Providers (ISPs), a peer-to-peer network, a Local Area Network (LAN), a Wide Area Network (WAN), a public network (e.g. "the Internet"), a private network, a satellite network, or otherwise.

[0024] A computing device may include a desktop computer, a laptop computer, a tablet, a phablet, a smartphone, a feature phone, a server computer, or otherwise. A server computer may be located remotely in a data center or be stored locally.

[0025] The processes explained above are described in terms of computer software and hardware. The techniques described may constitute machine-executable instructions embodied within a tangible or non-transitory machine (e.g., computer) readable storage medium, that when executed by a machine will cause the machine to perform the operations described. Additionally, the processes may be embodied within hardware, such as an application specific integrated circuit ("ASIC") or otherwise.

[0026] A tangible non-transitory machine-readable storage medium includes any mechanism that provides (i.e., stores) information in a form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). For example, a machine-readable storage medium includes recordable/non-recordable media (e.g., read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, flash memory devices, etc.).

[0027] The above description of illustrated embodiments of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

[0028] These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. An imaging system comprising:

a first Optical Coherence Tomography (OCT) system configured to capture a first volumetric eye image of a left eye a user in first field of view (FOV) of the first OCT system;

a second OCT system configured to capture a second volumetric eye image of a right eye of the user in second FOV of the second OCT system; and

a third OCT system configured to capture a volumetric face image, wherein a third FOV of the third OCT system overlaps the first FOV and the second FOV.

2. The imaging system of claim 1, wherein the first OCT system and the second OCT system operate with eye-wavelengths between 700 nm and 1100 nm, and wherein the third OCT system operates with a face-wavelength between 1100 nm and 1800 nm.

3. The imaging system of claim 1, wherein the first OCT system has a first cornea depth-of-field for imaging the left cornea of the left eye of the user and a first retina depth-of-field for imaging the left retina of the left eye,

and wherein the second OCT system has a second cornea depth-of-field for imaging the right cornea of the right eye of the user and a second retina depth-of-field for imaging the right retina of the right eye.

4. The imaging system of claim 3, wherein the first cornea depth-of-field is imaged with a first polarization orientation, and wherein the first retina depth-of-field is imaged with a second polarization orientation different from the first polarization orientation.

5. The imaging system of claim 3, wherein the first polarization orientation is orthogonal to the second polarization orientation.

6. The imaging system of claim 1 further comprising:

pupil scanning cameras configured to generate pupil data, wherein the first OCT system and the second OCT system are adjusted in response to the pupil data.

7. The imaging system of claim 1 further comprising:

displays with tunable focus point to allow the first OCT system and the second OCT system to image the right eye and the left eye at different accommodations.

8. The imaging system of claim 1 further comprising:

processing logic configured to:

receive the first volumetric eye image; and

generate an anterior chamber optical model of the left eye based on the first volumetric eye image, wherein generating the anterior chamber optical model includes segmenting the first volumetric eye image into (1) a cornea; (2) a sclera; (3) an iris; and (4) a front surface of a lens.

9. The imaging system of claim 1 further comprising:

processing logic configured to:

receive the first volumetric eye image;

receive the second volumetric eye image;

receive the volumetric face image; and

generate a combined face image, wherein generating the combined face image includes spatial registration of a first anterior chamber in the first volumetric eye image and a second anterior chamber the second volumetric eye image with respect to the volumetric face image.