EE367 Project Proposal
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Simulation of Light field Fundus Photography

Motivation

Retinal imaging is important in the diagnosis and monitoring of retinal health. A fundus camera is a complex optical system that makes use of the principle of reflex free indirect ophthalmoscopy to image the retina. Imaging the retina presents a unique design challenge for many reasons. A few relevant ones are briefly discussed below:

- *Low signal to noise ratio*. The retina is not directly accessible because it is located at the posterior of the eye. To image the retina in a noninvasive manner the retina must be illuminated and imaged simultaneously [1]. The retina itself is a minimally reflectively and highly scattering surface. [2-3] which impose two necessary requirements (1) imaging and illumination optical path need to be spatially separated (2) all sources of ghost reflections and stray light in the imaging path need to be identified and eliminated
- *Limited field of view*. Since retinal imaging conjugates the near spherical retina to planar camera sensor, the camera field of view is usually limited to about 30 degree.
- *Difficult to reconstruct 3D image*. Since the retinal funds has depth variations and also due to the fact that the intensity and color of the same physical positions may vary considerably across consecutive images. Depth estimation and 3D retinal image reconstruction through a series of 2D image are technically challenging [4].
- *Inherent optical aberration inside the system*. Imaging the retina requires the optics of the eye to be used as the objective for the imaging system. More than 50% of the general population has refractive error necessitating correction [5]. As a result any device used for retinal imaging in the general population must be able to accommodate for the largest sources of refractive error, defocus and astigmatism.

The light field camera can simultaneously record the angle and position of light, which enables some unique features such as digital refocusing and aberration correction. These unique features may provide advantages to retinal imaging over traditional digital SLR camera including:

- Remove and reduce glare digitally
- Expand the camera field of view
- Create stereographic photography with a single exposure
- Compensate for optical aberrations digitally
- Generate images of one or more layers within the retinal thickness with a single acquisition.
- Relieve the requirements on eye alignment system
- Simplify the illumination and imaging optics

Given these potential benefits, we decided to study the feasibility of light field fundus photography.

Related work

So far we discovered very limited studies conducted in this specific area. One patent application submitted by Carl Zeiss Corporation in 2012 proposed the original idea (?) of using light field camera for fundus photography and discussed the potential benefits [6]. Turola and Gruppetta studied the 4D light field retina imaging through some simple numerical simulation [7]. A group from UVEG showed some experimental setup on Plenoptic Fundus Camera [8]. Overall, there are little peer reviewed studies we can use as reference.

On the clinical side, Wills Eye started fundus Plenoptic photography clinical study in February of 2017 trying to establish the quality of fundus images produced by Lytro camera [9], indicating continue commercial interest of such device in the industry. Unfortunately, detailed information of such study is usually confidential and will not be disclosed.

Project overview

For this project, we intend to study the feasibility of the light field technique for retina imaging. The study would be primarily simulation based. We will be building numerical models to explore the potential design approaches and give some quantitative predictions on the performance of light field fundus photography. The model will be either Matlab based or the combination of Matlab and Zemax. The model will represent the simplified imaging path for retina imaging, which includes an eye, imaging lens, microlens array and sensor. Pending on the further study, we will also limit our simulation to a few specific performance areas listed in the previous page instead of giving a comprehensive evaluation. We will also try to explore the different microlens array design to optimize the system performance.

Milestones, timeline & goals

Milestone 1: Literature review, decide modeling methods and approach, decide key performance parameters to study 02/20
Milestone 2: Modeling building, initial design of the camera 03/06
Milestone 3: Detailed exploration, performance comparisons and design improvements 03/12
Milestone 4: final report 03/15

References

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[2]: F. C. Delori and K. P. Pflibsen, "Spectral reflectance of the human ocular fundus," Appl. Opt. **28**, 1065-1077 (1989).
[3]: M. Hammer and D. Schweitzer, "Quantitative reflection spectroscopy at the human," Phys. Med. Biol. **47**, 179-191 (2002).
[4]: T. E. Choe, etc, "2-D registration and 3-D shape inference of the Retinal Fundus from fluorescein images", Med Image Anal. **12(2)**, 174-190 (2008)
[5]: D. A. Atchison and G. Smith, "Optics of the Human Eye," (Butterworth-Heinemann, 2000)
[6]: Alexandre R, etc, "Light field camera for fundus photography ", US8998411 B2
[7]: Massimo Turola and Steve Gruppetta, "4D Light Field Ophthalmoscope: a Study of Plenoptic Imaging of the Human Retina", Frontiers in Optics 2013/Laser Science XXIX, Volume: JW3A.36, 2013
[8]: https://www.youtube.com/watch?v=riefZrlBa2s

[9]: FDA clinical trial database, https://clinicaltrials.gov/ct2/show/NCT03037268