Plenoptic imaging of the retina: can it resolve depth in scattering tissues?

Marshall, Richard; Styles, Iain; Claridge, Ela; Bongs, Kai

DOI:
10.1364/BIOMED.2014.BM3A.60

Document Version
Peer reviewed version

Citation for published version (Harvard):
Marshall, R, Styles, I, Claridge, E & Bongs, K 2014, Plenoptic imaging of the retina: can it resolve depth in scattering tissues? in *Proceedings of Biomedical Optics 2014* ., BM3A.60, Optical Society of America (OSA), Biomedical Optics 2014, Miami, Florida, United Kingdom, 26/04/14.
https://doi.org/10.1364/BIOMED.2014.BM3A.60

Plenoptic imaging of the retina: can it resolve depth in scattering tissues?

Richard Marshall[1], Iain Styles[1, 2], Ela Claridge[1, 2] and Kai Bongs[3]

[1] *PSIBS Doctoral Training Center, University of Birmingham, Birmingham, UK, B15 2TT*
[2] *School of Computer Science, University of Birmingham, Birmingham, UK, B15 2TT*
[3] *School of Physics and Astronomy, University of Birmingham, Birmingham, UK, B15 2TT*
rjm836@bham.ac.uk

Abstract: A feasibility study into using plenoptic imaging as an alternative to optical coherence tomography to diagnose common diseases causing blindness. Simulations have been run to determine if depth measurements can be made into scattering tissue.

OCIS codes: 110.1758, 170.4460, 170.4470.

1. Introduction

Plenoptic imaging is a relatively new imaging technique, in which both position and direction of a ray of light are recorded. By capturing this extra information, more comprehensive post processing analysis of the scene can take place from a single image acquisition, including digital refocusing, change of perspective, increased depth of field, depth maps and a topographic surface image. Many of these attributes could provide significant advantages for retinal imaging. Firstly, as all the information is collected in a single image acquisition, this will reduce motion artifacts of the eye which can occur in methods which require many pictures or have to raster across the retina. The increased depth of field is achieved with a large numerical aperture, which will reduce acquisition time or increase the intensity of light recorded compared to a standard image with the same acquisition time and depth of field of the plenoptic image. In the context of retinal imaging applications, an important aspect is the ability to determine the thickness of the neural retina. Optically it is a moderately scattering layer ($\mu_s = 5.735 \times 10^3 \text{cm}^{-1}$ at 800nm) 240μm thick [1], bound by two interfaces: the ocular media and the retinal pigment epithelium (RPE). The shape of the retinal surface and the thickness of the retina are important factors in the diagnosis of common diseases that may lead to blindness such as diabetes and glaucoma. Currently the main imaging modality is optical coherence tomography (OCT). With the cost of plenoptic cameras being considerably cheaper than an OCT, plenoptic retinal imaging could prove to be a very useful technique for ophthalmologists on a budget. However, previous studies into plenoptic imaging have only concentrated on opaque objects in free-space models. The aim of this investigation is to establish what geometric information can be obtained by applying plenoptic imaging to scattering media, more specifically of the retina.

2. Plenoptic imaging theory

The plenoptic function is derived from the five dimensional Light Field function, $\text{L}(x, y, z, \theta, \phi)$ representing both position and direction of the radiance, however when recorded it is restricted to four dimensions as in the absence of occluders, the radiance of a single ray of light becomes constant between two points along the length of the ray. One method of recording these extra dimensions is in the form of a plenoptic camera, in which a microlens array is placed between the objective lens of the imaging system and the sensor, with the traditional and focused configurations shown in Fig. 1 [2–4]. In the traditional plenoptic camera, the microlens array is placed on the image plane formed by the objective lens of the object, and the sensor one microlens focal length from the microlens array. When set up in this configuration, the pixels under each microlens array represent the directional information, with the spatial resolution determined by the number of microlenses. In the focused plenoptic camera, the microlens array is placed so that it forms a relay system with the image plane formed by the objective lens, decoupling the spatial resolution from the number of microlenses. There is always a trade off between spatial and directional resolution, so choosing the right configuration depends upon application. In both cases, images that can be digitally refocused and perspective shifted after the image has been taken are possible, depth maps can be generated, and 3D topographic images can be produced, all from a single acquisition.

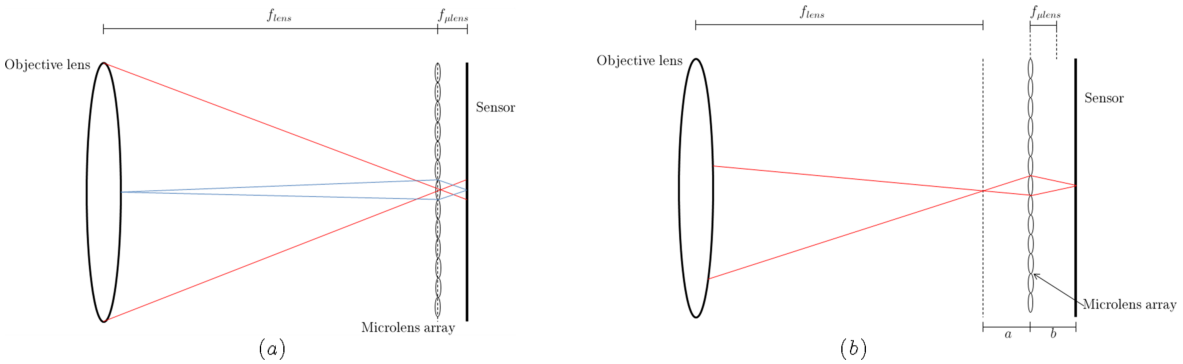

Fig. 1. Configurations of two different plenoptic cameras: *(a)* The traditional plenoptic camera. *(b)* The focused plenoptic camera.

3. Plenoptic imaging for retinal diseases

Optical coherence tomography has given a wealth of new information for ophthalmologists, one of which being the early detection of diabetic macular edema (DME) by visualizing retinal thickening [5]. Fig. 2 (a) and (b) show an OCT of a normal retina and one thickened by DME respectively. In order for plenoptic imaging to provide information similar to this, accurate measurements determining the depth of both the retinal surface and of the RPE are essential. OCT can also help to diagnose glaucoma by looking at the cup-to-disc ratio of the optic disc as shown in Fig. 2 (c). For computing of this ratio it is necessary to know only the depth of the retinal surface, which is available from the topographic surface data obtained by plenoptic imaging.

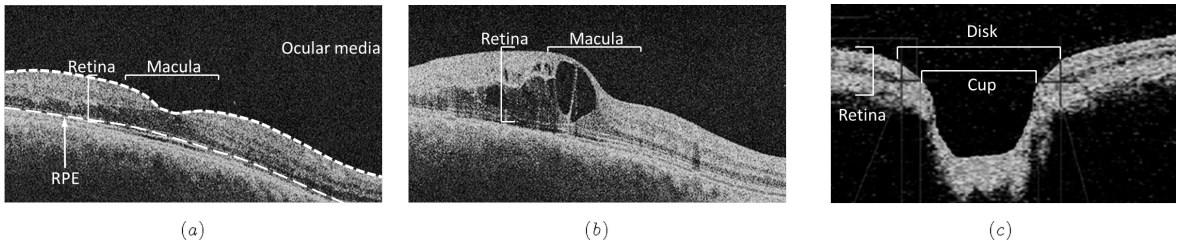

Fig. 2. *(a)* OCT of a normal healthy retina. *(b)* OCT of a retina with retinal thickening due to DME. *(c)* OCT image of the optic disc

4. Capabilities and limitations of plenoptic imaging in the field of retinal imaging

Plenoptic imaging has already proven its capabilities to determine depth and give 3D topographic information in free space models, however no study has shown how it would perform through scattering media such as the retina. In order to study this, simulations were performed using MCML, a multi-layered Monte Carlo modeling software [6]. One of the aims of this study is to determine whether retinal thickening could be detected using plenoptic imaging, so different experiments were undertaken by varying the thickness of the neural retina, hence changing the distance between the surface of the retina and the retinal pigment epithelium (RPE). The parameters characterising the properties of retinal layers and used in Monte Carlo (MC) simulation have been taken from Styles *et al*. [1].

The first experiment is looking at the undeviated (straight through) photons as they travel through the neural retina to the RPE whilst varying the distance to the RPE. This experiment is important as plenoptic cameras can only deduce the depth from the last point of scattering, so if few or no photons reach the RPE unscattered, then a quantitative distance cannot be calculated. Fig. 3 (a) shows the results of this first experiment. The second of these experiments was to investigate whether the angular distribution of the reflected photons changes as a function of retinal thickness. As plenoptic imaging records not only spatial information but also angular information, if the angular distribution has

any dependence on thickness, it could be deduced that plenoptic imaging may be able to distinguish between regions of different depths. The results of this can be seen in Fig. 3 (b).

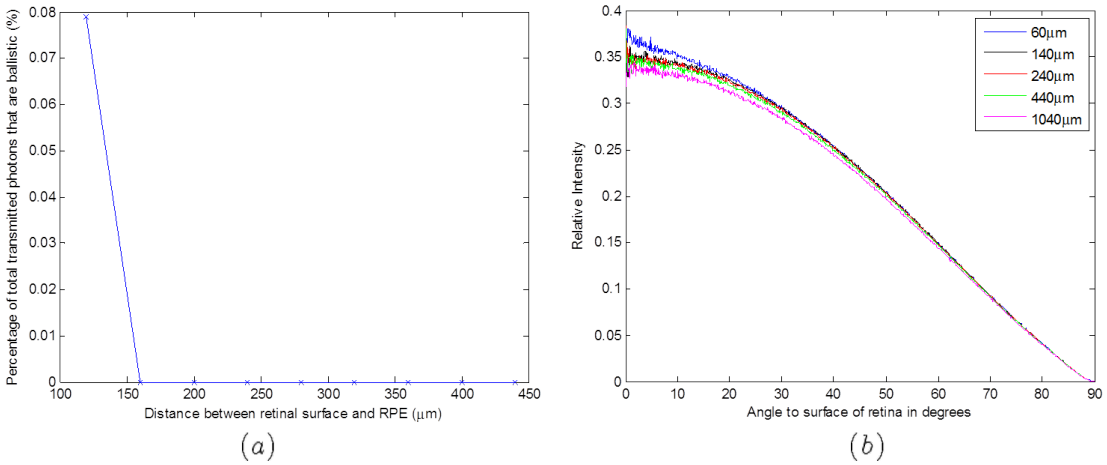

Fig. 3. *(a)* The amount of undeviated photons transmitted through to the RPE at varying distance from retinal surface to RPE. This experiment was performed at 800nm and with 10,000,000 photons. *(b)* The angular distributions of light reflected from the surface of the retina at different thicknesses. This experiment was performed at 800nm and with 50,000,000 photons

5. Results and Conclusions

This first experiment has given conclusive evidence that plenoptic imaging would not be able to use digital refocusing to focus on the RPE, as any distance between the retinal surface and RPE above 150μm yields no undeviated photons, and even below this distance, the amount of photons is less than 0.1% of the total transmitted intensity. After analysis of the results from the second experiment, it can be deduced that whilst magnitude changes as a function of thickness, their normalised angular distributions are the same. This implies the angular properties of remitted light do not depend on the thickness of the layer. This along with the results of the previous experiment present quite conclusive evidence that plenoptic imaging cannot be used to detect diseases such as DME by assessing retinal thickening. However, as the angular distribution on the surface of the retina is independent of the layers below, plenoptic imaging could produce topographic images of the surface of the retina, without any errors due to light reflected from layers below the surface. This could be beneficial in the field of retinal imaging in areas such as the early detection of glaucoma, which is enhanced greatly by three dimensional quantitative measures of the cup-to-disc ratio, not easily available using standard retinal photography.

References

1. I. B. Styles, et al. “Quantitative analysis of multi-spectral fundus images.” *Medical Image Analysis* 10.4 (2006): 578-597.
2. R. Ng, et al. “Light field photography with a hand-held plenoptic camera,” *Computer Science Technical Report CSTR* 2.11 (2005).
3. A. Lumsdaine, and T. Georgiev. “The focused plenoptic camera.” *Computational Photography (ICCP), 2009 IEEE International Conference on.* IEEE, 2009.
4. E. H. Adelson, and J. Y. A. Wang. “Single lens stereo with a plenoptic camera.” *IEEE transactions on pattern analysis and machine intelligence* 14.2 (1992): 99-106.
5. M. D. Abrmoff, M. K. Garvin, and M. Sonka. “Retinal imaging and image analysis.” *Biomedical Engineering, IEEE Reviews in* 3 (2010): 169-208.
6. L. Wang, S. L. Jacques, and L. Zheng. “MCML - Monte Carlo modeling of light transport in multi-layered tissues.” *Computer methods and programs in biomedicine* 47.2 (1995): 131-146.