Optical Switching Mechanism Based SD-OCT for in Vivo Anterior and Retinal Chamber Imaging

Yongseung Shin, Nam Hyun Cho, Ruchire Eranga Henry Wijesinghe, Jeehyun Kim

Abstract— In this paper, a technique is developed that can take the depth corresponding to two times depth range of the existing system by including an optical switch in spectral domain optical coherence tomography (SD-OCT) system. The results were obtained by conducting an animal experiment. In order to verify the effectiveness of this technology, optical switch was employed to acquire OCT images sequentially at various depths, to range from the cornea to the retina of guinea pig. Optical switch has a role to match the focus at multiple points of the sample arm for acquiring data of the anterior and the posterior chambers of the eye, and it has the capability of recording the images in real-time.

Index Terms— Optical switching mechanism based SD-OCT, anterior chamber, posterior chamber

I. INTRODUCTION

Michelson interferometer based OCT was first developed by the M.I.T. (Massachusetts Institute of Technology) Fujimoto group in 1991.OCT obtains the information of the tomography signal from the sample arm. Light in the wavelength region of near-infrared (800 nm ~ 1550 nm) is incident on the Michelson interferometer, the light is divided into the reference arm and sample arm. The light source beam propagates to the sample arm and backscatters by the depth of the interferometer. The interference signal is generated due to the optical path length difference of the reflection beams from the reference and sample arms respectively. Therefore, the depth of the sample can be obtained by Fourier transforming the interfered signal [1-3].

An image with high resolution of 1~15 μm can be obtained by this imaging method which is considered to be more close to the histology of the imaging object. In general, OCT system is mainly used for several commercial applications such as ophthalmology [4], dentistry [5] and industrial applications [6]. OCT can be classified into a time domain (TD) and frequency domain (FD) OCT according to the structure of the reference arm optics. TD-OCT uses a moving reference mirror for measuring the time it takes for light to be reflected. TD-OCT is a slow mechanical process compared to FD-OCT method.

Manuscript Received on September 2014.

Yongseung Shin, School of Electronics Engineering, IT-2, No 247, Kyungpook National University 1370 Sankyuk-Dong, Buk-Gu, Daegu, South Korea.

Nam Hyun Cho, School of Electronics Engineering, IT-2, No 247, Kyungpook National University 1370 Sankyuk-Dong, Buk-Gu, Daegu, South Korea.

Ruchire Eranga Henry Wijesinghe, School of Electronics Engineering, IT-2, No 247, Kyungpook National University 1370 Sankyuk-Dong, Buk-Gu, Daegu, South Korea.

Jeehyun Kim, School of Electronics Engineering, IT-2, No 247, Kyungpook National University 1370 Sankyuk-Dong, Buk-Gu, Daegu, South Korea.

FD-OCT can be classified into spectral domain OCT (SD-OCT) and swept source OCT (SS-OCT) which have rapid image acquisition compared to TD-OCT [7, 8]. SD-OCT is extensively used for medical imaging as it can provide non-invasive and high-resolution images in real-time and also it is the most applied OCT for commercial application. SD-OCT is mostly used in ophthalmology to obtain images of the anterior and the posterior chambers of the eye [9]. However, it is difficult to examine both the anterior and posterior chambers simultaneously as the beam cannot be focused on both the anterior segment and the retina because the optical design of the anterior chamber imaging method differs from the posterior chamber imaging method. Therefore, it is an essential requirement to use one optical design to fulfill this task. Some clinical and laboratory methods have implemented several methods to obtain the cornea and the retina images using SD-OCT system. Some research groups have measured the retinal nerve fiber layer and thickness using wide field SD-OCT [10]. Some research groups have used dual illumination and interlaced detection for simultaneous imaging of the cornea and retina, but the main drawback of this method is the bulkiness due to the large hardware unit which increases the complexity as well as the cost of the system [11]. Especially the system becomes more complicated when additional optical devices such as dispersion compensators are added to the system. Some groups have presented high-speed OCT imaging for the retinal chamber with an ultrahigh-resolution [12]. On the other hand, it is necessary to measure the distance between the cornea and retina as it is a vital information for ophthalmology which has not been mentioned in the literature so far. The conventional SD-OCT methods do not have the ability to acquire images in a wide range and to obtain the above mentioned requirement. The imaging depth was only 2 mm due to structural limitations and software issues. In this paper, we have implemented the reference arm by inserting an optical switch on it. Therefore, it can visualize the cornea and retina by only changing path length difference through the simultaneous image acquisition. The visualizable depth range of this system was increased two times compared to the conventional methods, and the light can be delivered from the anterior segment towards the retinal layers. A simulation experiment was conducted using an *in-vivo* mouse to measure the distances from cornea to retina, which could be obtained successfully by applying the developed method.

II. EXPERIMENTAL MATERIALS AND METHODS

A. SD-OCT System

The simple structure of the SD-OCT system is shown in Fig.1. First, the wavelength of 850 nm (EXS8510-2411, EXALOS, USA) light source with a bandwidth of 55 nm was used as the

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

broadband light source and 5:5-fiber coupler is used to split the broadband light into reference and sample arms. The spectrometer contains a diffraction grating, collimator, the line scan camera, and the focusing lens. The line scan camera with 2048 pixels, 140 kHz maximum line rate is (Basler's Sprint series) was used as a detector. The signal which was obtained by the detector is transmitted into the signal processing unit of the computer. The Galvano scanners of the sample arm are driven by an analog input/output card (PCI-6353; National Instruments, USA). Moreover, a frame grabber (PCIe-1433; National Instruments, USA) is used to capture the interference fringe. The axial and the lateral resolution values of the above mentioned SD-OCT system are 6.2 µm and 14.2 µm respectively. Also, the SNR of the system is 101.11 dB.

B. Reference Arm Optical Switching Mechanism based SD-OCT and Basic OCT Sample Arm

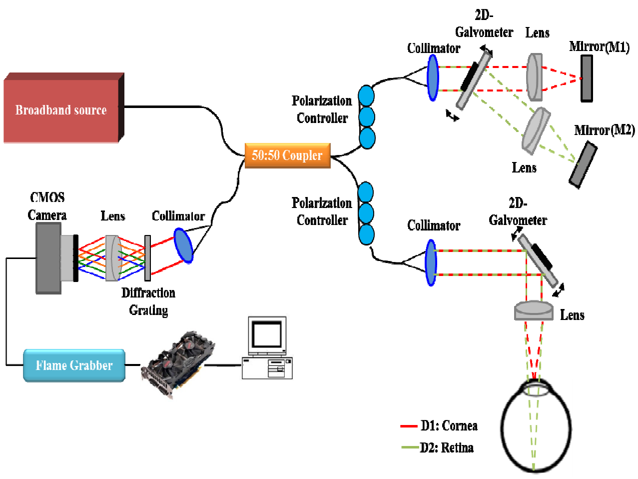
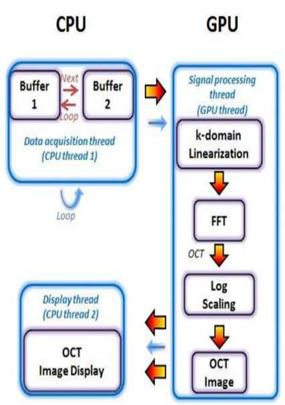


Figure 1 System Configuration of Optical Switching Mechanism based SD-OCT

C. GPU based SD-OCT Software Algorithm

In this system, the signal processing as well as the data acquisition was done by software optimizations. Therefore, according to the below figure, the required time for the data acquisition and display were optimized as well. Figure 2 is a configuration diagram of a program that is used for image processing and system control, which is based on Labview programming. The software contains the initialization part of the system such as, image storing process, hardware initialization, data acquisition, data processing and image processing. By using this method, the data processing of OCT is parallelized, and the signal processing task is distributed among each CPU processing core. The thread which was used for storing gives a separate distribution. Therefore, the images can be saved without decreasing the image acquisition speed. Therefore, the signal processing time is minimized. Table.1 shows the minimization of the time by using GPU method.



Process	CPU (ms)	GPU (ms)
Raw data transfer (CPU->GPU)	-	0.7
k-domain linearization	16	0.1
FFT	6	0.4
Log scaling	40	0.1
OCT data transfer (GPU->CPU)	-	0.3
Total	62	1.6

Figure 2 Configuration Diagram of OCT Program
Table 1 Processing Time Comparison between CPU and GPU

III. RESULT

Figure 3 shows the real-time OCT images which were acquired using developed optical switching mechanism based SD-OCT system. The anterior and the posterior chambers of a Guinea pig eye can be visualized in figure 3(A). Both images consist of 2048 (axial) × 500 lateral pixels. In figure 3(A) the path D1 of the beam shows the image from the upper cornea to the lens. Moreover, finally it was possible to acquire the image of the Guinea pig retina through the route of the beam D2 using the same optical setup. The system is aligned to focus the image with shorter optical reference path.

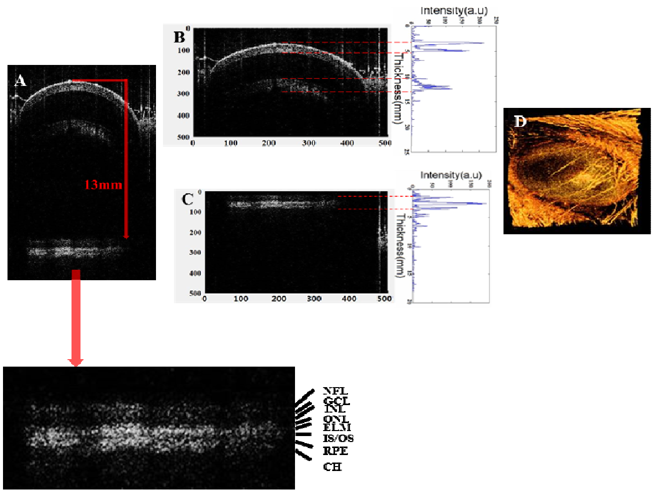


Figure 3 A) Conventional SD-OCT Image of Cornea and Lens. Abbreviations: NFL, Nerve Fiber Layer; GCL, Ganglion Cell Layer; INL, Inner Nuclear Layer; ONL, Outer Nuclear Layer; ELM, External Limiting Membrane; IS/OS, Junction between the Inner and Outer Segments of the Photoreceptors; RPE, Retinal Pigment Epithelium; CH, Choroid. (B) Quantitative Analysis of Anterior. (C) Quantitative Analysis of Posterior. (D) 3D Image of the Guinea Pig Eye

After that the path length difference at two references will form respective images. It can be confirmed, that, depending on the depth of polarization (when moving from D1 to D2) intensity of the signal is reduced when the sample arm is static. The optical path difference was set to 12 mm to 13 mm. An amplitude scanning process was done to analyze the cornea and retina quantitatively. The quantitative analysis results of

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

the cornea and the retina are shown in figure 3(B) and figure 3(C) respectively. This quantitative analysis represents the amplitude variation between the layers, and it can be shown graphically that the intensity fluctuates along with the depth of the image. Also, figure 3(D) shows the 3D rendered image of the guinea pig eye using a 3D image construction image.

IV. Conclusion

In this paper, an optical switching mechanism in SD-OCT system is proposed that provide anterior and posterior chambers of the eye using simplified sample arm. Using this method, the anterior chamber as well as the posterior chamber of the eye can be imaged using a simple OCT sample arm instead of using a complex and bulky sample arm. The Optical switching mechanism based SD-OCT system is fulfilled by using two-reference arms to match the path length with cornea and retina layers separately. Therefore, the system provides images with a long depth which is expanded two times compared to the conventional method. The imaging depth of the spectrometer is 2.5 mm. Software modifications are required to image both the anterior and the posterior chambers simultaneously. Clinical trials also are required to convince the system reliability and to improve the system configurations.

V. Acknowledgment

This study was supported by a grant of the Korea Healthcare technology R&D projects, Ministry for Health, Welfare & Family Affairs, Republic of Korea (A102024), Ministry of Education (MOE) and National Research Foundation of Korea (NRF) through the human resource training project for regional innovation (No2011-05-대-02-026) and also by a grant of the National Institute of Health (No201225940000) , also this research was financially supported by the “Over regional linked 3D convergence industry promotion program” through the Ministry of Trade, Industry&Energy(MOTIE) and Korea Institute for Advancement of Technology(KIAT) (N0.R0001512)and also this study was financially supported by Ministry of Health & Welfare, Republic of Korea through the Korea Healthcare technology R&D project (A102024-1011-0000200).

References

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory and C. A. Puliafito, "Optical coherence tomography," Science, vol. 254, pp. 1178-1181, Nov 22, 1991..

[2] F. Feldchtein, V. Gelikonov, R. Iksanov, G. Gelikonov, R. Kuranov, A. Sergeev, N. Gladkova, M. Ourutina, D. Reitze and J. Warren, "In vivo OCT imaging of hard and soft tissue of the oral cavity," Optics Express, vol. 3, pp. 239-250, 1998.

[3] N. H. Cho, U. Jung, S. Kim, W. Jung, J. Oh, H. W. Kang and J. Kim, "High Speed SD-OCT System Using GPU Accel-erated Mode for in vivo Human Eye Imaging," Journal of the Optical Society of Korea, vol. 17, pp. 68-72, 2013.

[4] A. F. Fercher, W. Drexler, C. K. Hitzenberger and T. Lasser, "Optical coherence tomography-principles and applications," Reports on Progress in Physics, vol. 66, pp. 239, 2003.

[5] I. Hariri, A. Sadr, Y. Shimada, J. Tagami and Y. Sumi, "Effects of structural orientation of enamel and dentine on light attenuation and local refractive index: an optical coherence tomography study," J. Dent., vol. 40, pp. 387-396, 2012.

[6] N. H. Cho, U. Jung, S. Kim and J. Kim, "Non-Destructive Inspection Methods for LEDs Using Real-Time Displaying Optical Coherence Tomography," Sensors, vol. 12, pp. 10395-10406, 2012.

[7] Z. Yaqoob, J. Wu and C. Yang, "Spectral domain optical coherence tomography: a better OCT imaging strategy," Bio-Techniques, 2005.

[8] B. Cense, N. Nassif, T. Chen, M. Pierce, S. Yun, B. Park, B. Bouma, G. Tearney and J. de Boer, "Ultrahigh-resolution high-speed retinal imaging using spectral-domain optical coherence tomography," Optics Express, vol. 12, pp. 2435-2447, 2004.

[9] V. Christopoulos, L. Kagemann, G. Wollstein, H. Ishikawa, M. L. Gabriele, M. Wojtkowski, V. Srinivasan, J. G. Fu-jimoto, J. S. Duker and D. K. Dhaliwal, "In vivo corneal high-speed, ultra–high-resolution optical coherence tomography," Arch. Ophthalmol., vol. 125, pp. 1027-1035, 2007.

[10] B. Cense, T. C. Chen, B. H. Park, M. C. Pierce and J. F. de Boer, "Thickness and birefringence of healthy retinal nerve fiber layer tissue measured with polarization-sensitive optical coherence tomography," Invest. Ophthalmol. Vis. Sci., vol. 45, pp. 2606-2612, Aug, 2004.

[11] H. Jeong, S. Lee and B. Kim, "Spectral-domain OCT with dual illumination and interlaced detection for simultaneous anterior segment and retina imaging," Optics Express, vol. 20, pp. 19148-19159, 2012.

[12] M. Wojtkowski, V. Srinivasan, T. Ko, J. Fujimoto, A. Kowalczyk and J. Duker, "Ultrahigh-resolution, high-speed, Fou-rier domain optical coherence tomography and methods for dispersion compensation," Optics Express, vol. 12, pp. 2404-2422, 2004.

Yongseung Shin, received the B. Sc. degree in the year 2009 in Electronic Engineering from Kyungpook National University, Daegu, South Korea. He is currently working toward M.S. degree in the department of Electronics Engineering at Kyunpook National University,Daegu, South Korea. His current research interests include the dual path spectral domain OCT for 850 nm.

Nam Hyun Cho, received the B.Sc. and M.S. Degrees in 2007 and 2011 respectively in Electrical and Electronics Engineering from Kyungpook National University, Daegu, South Korea. He is currently working toward Ph.D. degree in the department of Electronics Engineering at Kyunpook National University,Daegu, South Korea. His current research interests include the signal processing and spectral domain OCT for Opthalmology applications.

Ruchire Eranga Henry Wijesinghe, received the B. Sc. degree in the year 2012 in Electrical Engineering from Kyungpook National University, Daegu, South Korea. He is currently working toward M.S. degree in the department of Electronics Engineering at Kyunpook National University, Daegu, South Korea. His current research interests include the human retinal imaging by using spectral domain OCT for medical applications.

Jeehyun Kim, received the B. Sc. degree in the year 1995 in Electronic Engineering from Kyungpook National University, Daegu, South Korea. He joined as a researcher in Daewoo precision industry in the year1995~1998. He obtained the M.S. and Ph.D. degrees in 2000 and 2004 respectively in Biomedical Engineering from University of Texas at Austin.He joined as a postdoctoral researcher in University of California, Irvine,Beckman Laser Institute in the year 2004~2007. He joined as an assistant professor in the Electronics Engineering Department of Kyungpook National University in 2007 and currently he holds post of associate professor.His current research interests include Bio medical imaging, Nueroscience, Photo-Acoustic Imaging and Sensors.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.