인간 망막의 in-vivo 광단층 촬영을 위한 신호 대 잡음비 향상에 관한 연구

SNR improvement of spectral-domain optical coherence tomography for in-vivo human retinal imaging

Jang-Woo You*, Teresa C. Chen**, Mircea Mujat***, B. Hyle Park***, Johannes F. de Boer***

*한국과학기술원, **Massachusetts Eye and Ear Infirmary and Harvard Medical School, Wellman Center for Photomedicine, ***Massachusetts General Hospital, Harvard Medical School

deboer@helix.mgh.harvard.edu

OCT has emerged as a promising technology [1] for *in-vivo* imaging in a wide range of medical applications. The evolution from time-domain to spectral-domain and optical frequency domain imaging (OFDI), [2,3] has made simultaneous improvement in sensitivity, high speed, and axial resolution feasible in many applications, such as retinal imaging. [4]

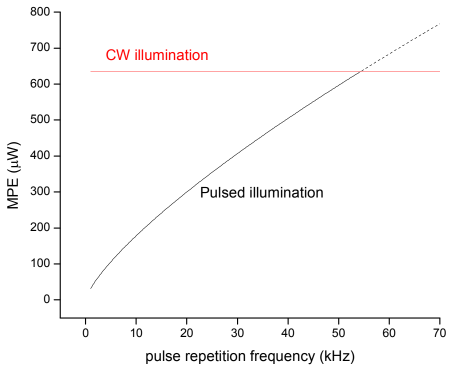
Yun *et al.* theoretically investigated axial and lateral motion artifacts in CW SD-OCT and swept-source OFDI, and experimentally demonstrated reduced axial and lateral motion artifacts using a pulsed source and a swept source in endoscopic imaging of biological tissue. [2,3] In ophthalmic applications of SD-OCT, SNR reduction caused by high speed lateral scanning of the beam over the retina may be dominant over axial patient motion. Using pulsed illumination can reduce lateral motion artifacts. We analyzed the SNR benefit of pulsed-illumination over CW SD-OCT, demonstrating that pulsed illumination provides a better SNR for in-vivo high speed human retinal imaging.

Yun *et al.* [2] derived the equations for the SNR decrease due to lateral motion in CW SD-OCT. For a CW source, the SNR decrease is given by,

$$SNR\ decrease \cong -5\log_{10}\left(1+0.5\frac{\Delta x^2}{w_o^{\,2}}\right), \tag{1}$$

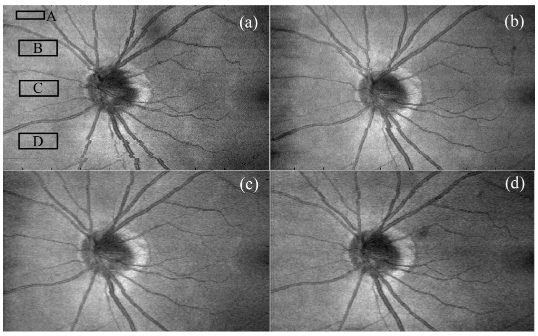
where Δx is the scanning distance during the camera integration time and w_o denotes full-width-half-maximum (FWHM) of the beam profile.The normalized displacement is defined as $\Delta x/w_o$. For pulsed illumination, Δx is replaced by $(\tau_{pulse}/\tau_{camera})\cdot\Delta x$, where τ_{pulse} is the pulse width in time and τ_{camera} is the integration time of the camera for a single A-line.

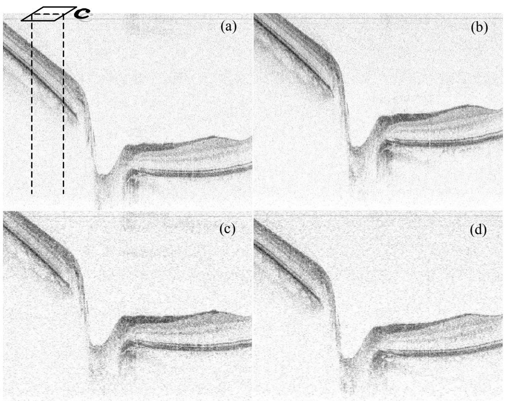
We applied, for the first time to our knowledge, pulsed illumination to human retinal imaging and we compared SNR with CW illumination. The pulse width was 8 μs and the pulse repetition rate was 29.3 KHz,



synchronized with the integration time of the high-speed line scan camera. According to the ANSI standard for safe use of lasers, the maximum permissible exposure expressed as the average power of a pulse train increases with the pulse repetition rateup to a frequency of 55 kHz, where the limit to continuous wave exposure is reached. [5]

As shown below, integrated reflectance images of the retina of a healthy volunteer at two different lateral scanning speeds characterized by 1000 and 500 A-lines per image for CW and pulsed illumination were measured. We can see some discontinuities in the 1000 A-line images because of the two times longer measurement time relative to the 500 A-line images.





The SNR in each measurement was calculated and analyzed by selecting 4 regions of interest based on the integrated reflectance image as shown above to compare the SNR in the same region of the retina for CW and pulsed illumination. The sample arm power after the slit lamp of CW and pulsed illumination was set to 600 μW and 385 μW respectively. The 385 μW average power for pulsed illumination will cause a 1.9 dB smaller SNR compared to the 600 μW for CW. This has been accounted for in the SNR analysis comparing pulsed and CW illumination. The ONH is in axially different locations (right figure) so the SNR was compared after correcting for the depth dependent sensitivity decrease.

1. D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J. G. Fujimoto, "Optical Coherence Tomography," Science, **254**, 1178-1181, (1991)
2. S. H. Yun, G. J. Tearney, J. F. de Boer, and B. E. Bouma, "Motion artifacts in optical coherence tomography with frequency-domain ranging," Opt. Express, **12**, 2977-2998, (2004)
3. S. H. Yun, G. J. Tearney, J. F. de Boer, and B. E. Bouma, "Pulsed-source and swept-source spectral-domain optical coherence tomography with reduced motion artifacts," Opt. Express, **12**, 5614-5624, (2004)
4. J. You, T.C. Chen, M. Mujat, B. H. Park, and J.F. de Boer, "Pulsed illumination spectral-domain optical coherence tomography for human retinal imaging" (Submitted)
5. American National Standards Institute, *American National Standard for Safe Use of Lasers Z136.1*. 2000: Orlando.