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NON-INVASIVE FLOW CONTRAST IMAGING OF BLOOD VESSELS IN HUMAN RETINA

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INTRODUCTION

Structural images of the retina acquired with Fourier Domain Optical Coherence Tomography (FDOCT) have revolutionized clinical ophthalmic diagnosis, providing exquisite structural volumetric images of the retina and optic nerve head non-invasively in real-time [1]. However, the functional behavior of the retina cannot be extracted from these images. Consequently, the development of techniques for non-invasive blood flow contrast imaging in the retina is a rapidly evolving field of ophthalmic research. The conventional way to visualize blood vessels is to use a contrast agent in combination with cSLO or fundus camera. The limitations of these techniques are the need for an extrinsic contrast agent (which has a common side effect in patients including severe nausea and allergic reactions), and short imaging window (bolus of contrast flows to the eye within seconds of injection). Recently, several implementations of flow contrast for FD OCT have been reported in the literature, OMAG [2], phase variance OCT [3], Doppler OCT [4] and speckle variance (sv) OCT [5]. For an overview of these techniques, please review article [6].

In this report we demonstrated a real-time flow contrast imaging platform using speckle variance OCT for retinal vasculature imaging in human. A high speed OCT acquisition system and GPU accelerated processing platform are used to acquire and process *en-face* flow contrast images in real time. These results represent an important step forward from other reports in the literature that present real time flow imaging in cross sectional images only [7], and the addition of functional imaging to real time volumetric structural imaging with GPUs [8].

METHODS

Hardware and Software components

In this study, a custom-built 1060nm Swept Source (SS) OCT system was used for human imaging at the Eye Care Center (ECC) at the Vancouver General Hospital (VGH) with consent obtained from all subjects before participation and with ethics review board approval from Simon Fraser University (SFU). The system was operating at a line rate of 100 kHz using an external k-clock provided by the Axsun source. More details of this system have been previously reported [9]. The acquisition and processing engine was consisted of dual Xeon E5-2620 CPUs, 64 GB of RAM, and a NVIDIA GTX Titan GPU. For software development, we used Microsoft Visual C++ 2008 and CUDA Toolkit version 5.5 for programming the GPU. For profiling and optimization purposes, we use NVIDIA's Visual profiler software.

Processing

The implementation of the GPU-based speckle variance OCT is built upon our previous work presented described in [10]. For speckle variance calculation, multiple repeated measurements were acquired at each B-scan location. A term "BM-scan" is used to indicate these multiple B-scans. The term speckle is used to describe the OCT intensity signal caused by the partially coherent backscattered light from biological tissues [11]. The speckle pattern acquired from moving particles would vary temporally, such as in blood flow, and would remain constant for structural components such as tissue and vessel membranes. By calculating the variance of the speckle pattern within a BM-scan, the increased contrast generated from blood flow

can emphasize vasculature networks, including capillaries, within the retina.

In this work, each volume contains 1024-points per A-scan, 300 A-scans per B-scan, 3 B-scans per BM-scan, and 300 BM-scans in the entire volume. For batch processing, we selected a batch size of 30 B-scans and transferred the data to the GPU to perform in real-time the FDOCT processing pipeline, calculate the speckle variance, execute motion registration, generate intensity and sv en face projections, notch filtering and visualize results simultaneously with the acquisition.

Figure 1 is a GPU profiler image demonstrating a single batch processing iteration in the GPU software. In this figure, we demonstrate the implementation of the Swept-Source based svOCT for each processing step. Step 1 consists of DC subtraction, zero-padding, FFT, and post-FFT operations. Step 2 contains the kernel for generating the en face projection, where we used the parallel reduction algorithm implemented in [10]. Step 3 is the speckle variance calculation executed using the batch-processing method described in [10]. Lastly, step 4 demonstrates the rendering of three user selected en face images. The idle time presented after step 4 represents the time required for sending the images from the GPU to the monitor for display, which occupies nearly half of the entire GPU execution timeline.

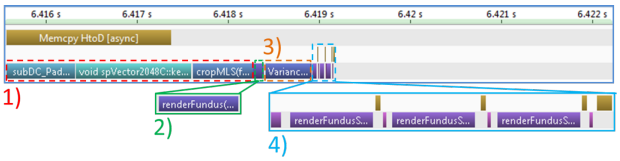

Figure 1. CUDA processing pipeline captured using the NVIDIA Visual Profiler.

Additional processing steps such as motion registration and notch filtering can be applied to improve the image results; however, it increases the processing time. In general, the standard processing steps 1-4 are sufficient for imaging a stable patient with a relatively small field of view (2x2mm^2).

RESULTS AND DISCUSSION

Retinal images at the foveal region were acquired from human volunteers at ECC. Figure 2 presents the comparison of a single B-scan as well as the *en-face* projection between the intensity OCT and the svOCT. The total acquisition time for an entire volume (1024x300x900) required ~2.7 seconds, and the overall standard speckle variance processing and display times took ~270 milliseconds. In the case of imaging a larger field of view, the added registration and filtering increased the overall processing and display times to ~645 milliseconds which is still beyond the acquisition speed of most conventional OCT systems. Figure 3 is a demonstration of three *en-face* projections generated with corresponding selected region indicated by red (b), green (c), and blue (d), and super-impose these three regions to generate a colour-mapped image (e).

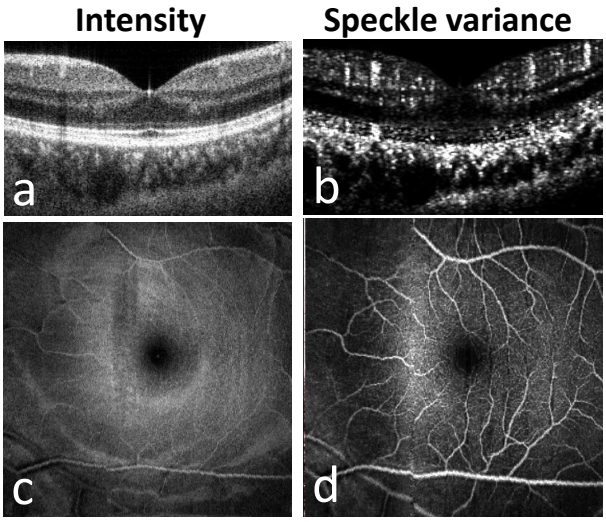

Figure 2. Comparison of (a) an intensity B-scan and (b) a svOCT B-scan. Comparison of (c) the intensity *en-face* view and (d) svOCT *en-face* projection.

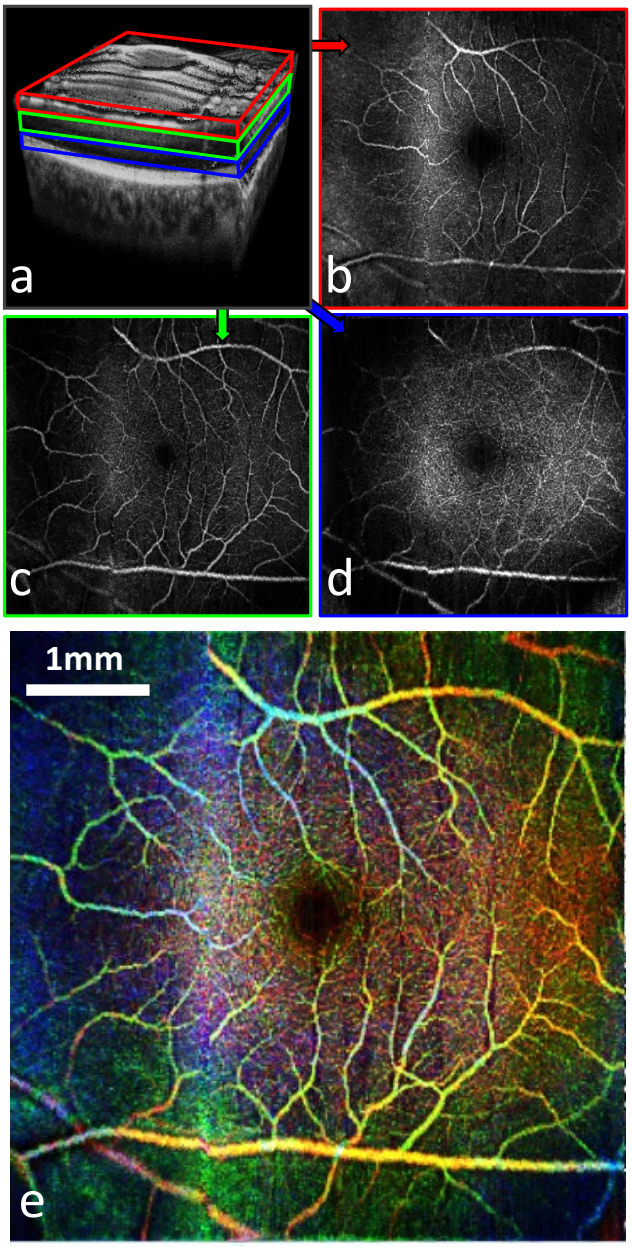

Figure 3: A representative volume view (a) with three user-selected depth layers indicated. The corresponding *en-face* views of each selected region in red (b), green (c), blue (d). A super-imposed image of all three regions into a single colour-mapped image (e).

More representative flow contrast images acquired at foveal region (a, b) and optic nerve head (c, d) are presented in Figure 4.

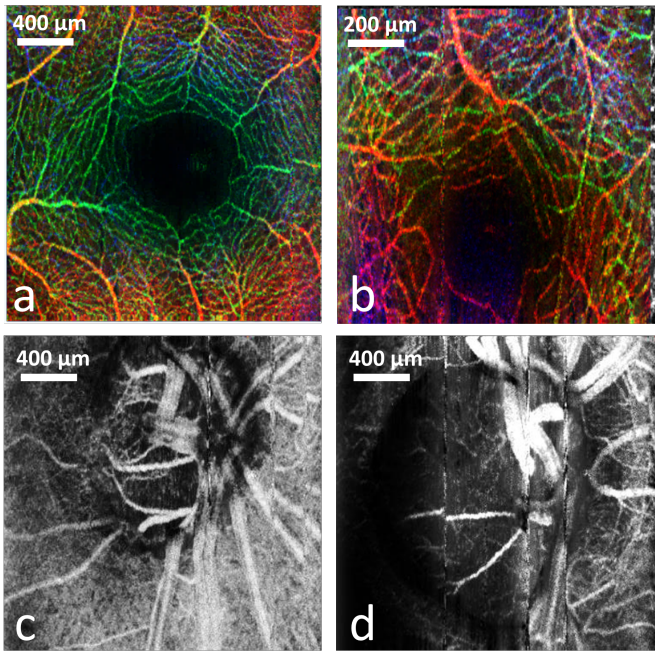

Figure 4: Representative colour-mapped sv *en-face* at foveal region with the field of view of (a) 2x2 mm^2, and (b) 1x1 mm^2. Flow contrast *en-face* projection at the optic nerve head acquired from a healthy volunteer (c), and a glaucoma patient (d).

CONCLUSION

In conclusion, this report has demonstrated an approach to use GPU to accelerate the image processing for real-time blood flow contrast detection with FD OCT system. This can be used as an important imaging tool to monitor the blood vessels in longitudinal studies, study various diseases that affect the retinal vasculature such as diabetic retinopathy, and also provide another imaging option other than fluorescein angiography.

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