Parallel processing of OCT data for monitoring of restoration procedures

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Optical Coherence Tomography (OCT) is a method of non-contact and non-invasive imaging of the internal structure of objects. It originates from medicine, but now it is also routinely used in many non medical examinations.[1] OCT allows for analyzing with micrometer-level axial resolution of the internal structure of the works of art, especially easel paintings.[2,3] Additionally, the OCT may be used for real-time monitoring of technological processes. As examples taken from the cultural heritage filed may serve some conservation treatments[4] including laser ablation of varnish.[5]

In Spectral OCT systems utilizing CPU for data processing the main limitation for real-time imaging lays in the time of data processing, which usually takes more time than the acquisition. Utilizing a General-Purpose computing on Graphics Processing Units (GPGPU) for massively parallel processing of the OCT data gives a solution this problem – it allows to overcome the limitation of processing time and to visualize cross sectional images faster than to acquire data.

The presented results were obtained with a computer workstation equipped with Intel® Core™ i7 920 (2.67 GHz) CPU, 6 GB RAM memory and low cost, game-designed graphic card: NVIDIA® GeForce® GTX 580 with 3 GB device memory, featuring the Fermi architecture. It controls a laboratory-made, high resolution Spectral domain OCT system, which is equipped with a Superlum Broadlighter Q870 with central wavelength λ_c = 870 nm and full spectral width at half maximum $\Delta\lambda$ = 200 nm. This source provides axial resolution Δz = 3 μm.

The software for instrument control and parallel data processing was developed under Microsoft® Windows™ 7 Professional x64 operating system and written in C++ programming language. All procedures for parallel processing in GPU were compiled with NVIDIA® CUDA™ compiler version 4.0. The OpenGL® 4.0 Library was used for 2D/3D visualization of the results.

The developed software is capable of processing about 1 000 000 spectra (2048 points each) per second (Fig. 1). The processing and visualization is faster than acquisition, therefore the same data is reprocessed several times until a new data occurs. It allows for on-line adjustments of data processing (e.g. dispersion compensation) and display (e.g. rotation angle, zoom) parameters. The frame rate of reprocessing (with rendering) and the total frame rate when new data is transferred to the GPU are presented in Table 1.

The developed software may be utilized for real-time monitoring of various, dynamic processes. One of them is laser ablation of varnish (Fig. 2). The effectiveness of the process depends strongly on the properties of the ablated layer and the thickness of removing varnish. Since the thickness of an ablated layer changes rapidly form point to point, safe removing of varnish without any control is almost impossible. This drawback may be overcome by real-time monitoring of this process with high-resolution, fast OCT system.

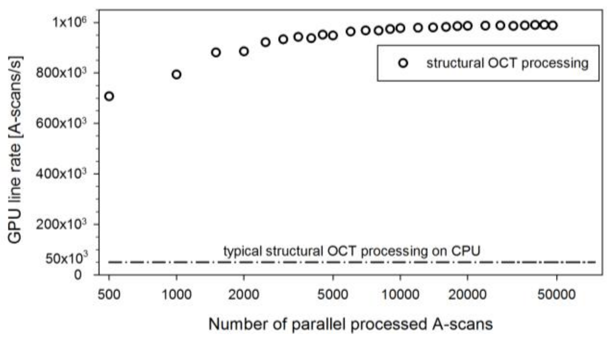

Fig. 1. GPU line rate for structural OCT imaging as a function of the number of A-Scans

Table 1. Frame rate of processing and visualization of the OCT data (with and without transfer of new data)

Protocol	No. of A-scans	Frame rate of reprocessing and visualization	Total frame rate (data transfer, processing and visualization)
Cross 2x2000	4 000	120 fps*	45 fps
Cross 2x4000	8 000	87 fps	22 fps
4 slices 4x2000	8 000	87 fps	22 fps
4 slices 4x3000	12 000	62 fps	15 fps
3D 100x100	10 000	21 fps	13 fps
3D 140x140	19 600	13 fps	6 fps

*Limited by screen

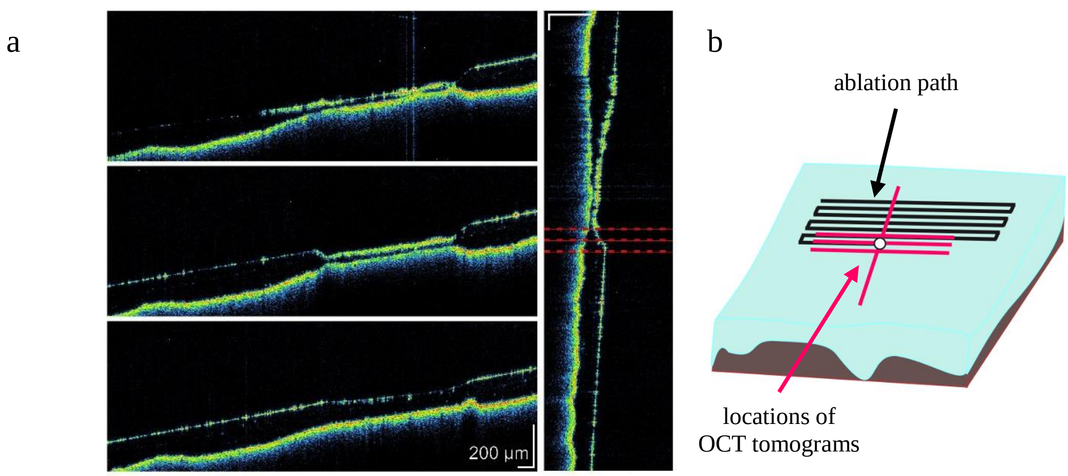

Fig. 2 a: A screen shot registered during real-time OCT imaging of varnish ablation process
b: locations of OCT tomograms (red lines) and ablation path (black lines)

The ascendancy of the processing speed over acquisition of the data allows for processing of the same data set several times in order to optimize parameters of numerical analysis and/or visualization conditions in a real-time. Alternatively, to avoid reprocessing of the data and to better utilize the computational power of the graphic card, the GPU processing opens a gate for implementation time-consumed algorithms previously executed in post-processing only. Now, some of them may work in real-time, and may create a new applications of the OCT technique, especially if the development of GPU technology continues to be as rapid as at present.

REFERENCES

1. D. Stifter, "Beyond biomedicine: a review of alternative applications and developments for optical coherence tomography," Applied Physics B Lasers and Optics, 88(3), 337-357 (2007).

2. P. Targowski, M. Iwanicka, L. Tyminska-Widmer et al., "Structural Examination of Easel Paintings with Optical Coherence Tomography," Acc Chem Res, 43(6), 826-836 (2009).

3. H. Liang, M. Cid, R. Cucu et al., "En-face optical coherence tomography–a novel application of non-invasive imaging to art conservation," Optics Express, 13(16), 6133-6144 (2005).

4. M. Iwanicka, E. A. Kwiatkowska, M. Sylwestrzak et al., "Application of optical coherence tomography (OCT) for real time monitoring of consolidation of the paint layer in Hinterglasmalerei objects," Proc. SPIE, 8084, 80840G (2011).

5. P. Targowski, J. Marczak, K. E.A. et al., "Optical coherence tomography for high-resolution real time varnish ablation monitoring," Lasers in the Conservation of Artworks (LACONA IX), in press