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Volumetric Imaging of Superficial Micro-vasculature using High-frequency Array Transducer: Phantom Study

Anam Bhatti[1‡], Takuro Ishii[1,2], and Yoshifumi Saijo[1]
([1]Grad. School of Biomed. Eng., Tohoku Univ.; [2]Frontier Research Inst. for Interdisciplinary Sciences, Tohoku Univ.)

1. Introduction

The advent of ultrafast acquisition techniques in conjuction of spatiotemporal clutter filter based on singular value decompostion (SVD) has sigificantly enhanced the sensitivity of Doppler ultrasound in visualization of micro-vessels. This combined approach provides new diagnostic markers for numerous preclinical and clinical applications[1)]. The advancements realized in 2D ultrasound imaging can also be extended to 3D volumetric ultrasound imaging, enabling a comprehensive evaluation of micro-vasculatures in disease diagnosis and its progression.

3D Doppler volumetric imaging has been previously reported for brain functional imaging, via step-by-step scanning approach to observe the tumor vasculature[1)]. However, this iterative translation approach leads to prolonged acquisition time and is mainly applicable to stationary objects such as small animal scanning. Recently, a continuous translation approach for 3D volumetric imaging has been introduced by Chen et al[2)]. This involves the continuous translation of a 1D transducer at a constant speed to generate stacks of B-mode images. However, the former approach encountered challenges in terms of image quality attributed to interference noises caused by the translation of probe, ultimately affects the visibility of micro-vessels.

In this study, we observed the feasibility of 3D volumetric imaging via continuous mechanical translation, specifically aimed to visualize superficial micro-vasculatures. To overcome the limitation of interference noises we introduced a non-local means (NLM) filter[3)] to effectively eliminate the noises and improves the sensitivity and visibility of micro-vasculatures.

2. Method

Fig.1 illustrates the workflow of the proposed approach of 3D volumetric imaging using 1D high-frequency ultrasound (HFUS) transducer that mechanically translate continuously at a constant speed of 1 mm/s and 2 mm/s.

2.1 Imaging System:

A research purpose ultrasound imaging

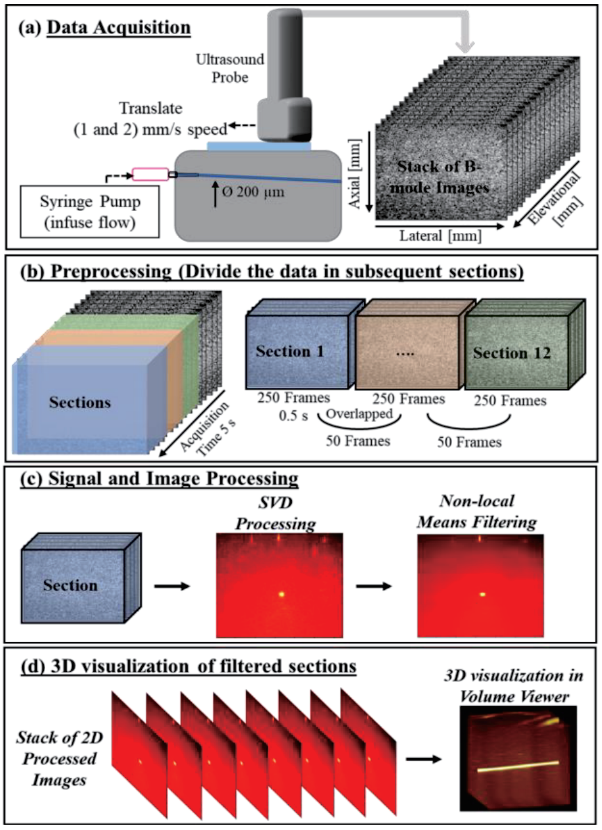

Fig. 1. Flow chart of 3D volumetric imaging for visualization of superficial micro-structures.

system (Vantage 256, Verasonics Inc., Kirkland, WA, USA) equipped with L38-22v CMUT (KOLO silicon, USA) linear array transducer was used for transmission and reception of ultrasonic signal. 2500 compound frames were obtained at pulse repetition frequency of 5 kHz. Each frame was compounded by 10 steered plane waves. The start of the acquisition was synchronized with the triggering of the vantage and motorized translation stage. A straight tube micro-phantom (200-micron) at the depth of 4 mm was fabricated to mimic the superficial microvasculature. To enable the flow within the micro-tract, a flow circuit assembly comprised on syringe pump and tubing was connected with micro-phantom. This assembly facilitated the infusion of flow at a rate of 10 mm/s. To translate the transducer in elevational direction (distance 5 mm and 10 mm), the probe was mounted via 3D printed probe holder

E-mail: ‡anam.bhatti.q8@dc.tohoku.ac.jp

with 2D stage (OSMS(CS)20-35, Sigmakoki Co.), which was controlled by controller (SHOT-302GS, Sigmakoki Co.) to translate the transducer continuously with a constant speed of (1 mm/s and 2 mm/s).

2.2 Processing:

Acquired volumetric data was preprocessed by dividing into subsequent sections to extract the desired flow signal efficiently via singular value decomposition (SVD) based clutter filtering. Preprocessing of data illustrated in **Fig. 1** shows that the 12 sections (250 frames = 0.5 s) were created based on the acquisition time (2500 frames = 5 s) with overlap of (50 frames = 0.05 s). Each frame was then processed with SVD as shown in **Fig.1**. Later, an established NLM filter[4)] was implemented on each section to remove the interference noises. Once all the sections were processed with combined algorithm of SVD and NLM, a 3D matrix were created to visualize the obtained flow structures in MATLAB built-in application of volume viewer.

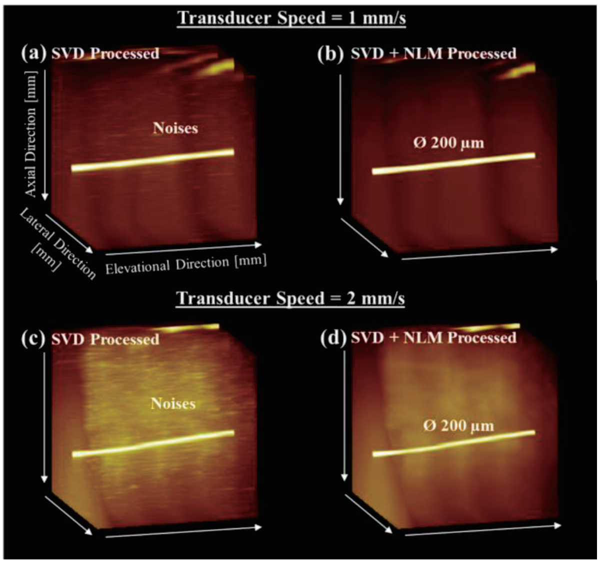

Fig. 2. 3D rendered volumetric images of 200-micron flow tract. (a – b) 3D images obtained with transducer speed of 1 mm/s, (c-d) 3D images obtained with transducer speed of 2 mm/s.

3. Results

3D realization of superficial volumetric imaging of micro-structures through continuous mechanical translation, as depicted in **Fig.2**, reveals that the higher transducer motion speed leads to increased interference noises. Furthermore, the power Doppler image of each section, processed using SVD clutter filter and SVD + NLM filter presented in **Fig.1(c),** indicates that the application of the NLM filter effectively mitigates the interference noises resulting from the probe translation. Notably, these noises exhibit a dependency on the transducer speed, as evidenced by the volumetric images in **Fig.2.** Volumetric data acquired at a transducer speed of 1 mm/s **Fig.2(a-b)** comprised fewer noises compared to that obtained at 2 mm/s **Fig.2(c-d).** In both instances, the NLM filter effectively eliminates interference noises leading to a twofold enhancement in image contrast compared to the images without NLM processing as shown in **Fig.3**.

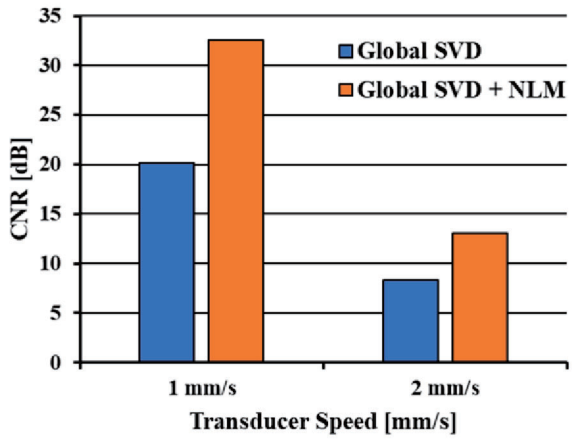

Fig. 3. Quantitative comparison of contrast-to-noise ratio among SVD and SVD + NLM under two conditions of transducer speed (1 mm/s and 2 mm/s).

4. Conclusion

This study demonstrates the feasibility of 3D volumetric imaging of superficial micro-vasculatures using continuous mechanical translation. The integration of the NLM filter into this approach substantially improves the image contrast, evident both in the qualitative assessment in **Fig.2** and in the quantitative results shown in **Fig. 3**. Based on these findings, the proposed approach can be utilized in the 3D volumetric visualization of superficial microvasculature to observe the comprehensive vascular structures in the diagnosis and prognosis of diseases.

References

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