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3D Vector Flow Imaging using a 2D Matrix Array Transducer by Synthesizing and Rotating Sub-apertures

2次元アレイの分割送受信と回転操作による3次元血流ベクトルイメージング

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1. Introduction

3D vector flow imaging (VFI) gathers much attention as it is capable of visualizing comprehensive complex flow dynamics, such as twisting and vortex features[1,2]. A solution to achieve volumetric 3D VFI is using a 2D matrix array transducer and transmitting seteered unfocused ultrasound pulses to use the principle of a multi-angle vector flow estimation[3,4]. In practice, a 2D matrix array transducer (>1000 elements) can be used when it is connected to a single 256-ch US scanner through a multiplexer, which allows the system to devide the 2D matrix elements into sub-apertures (groups of 256 ch) and sequentially select a sub-aperture to be activated[5]. Yet, it is challenging to acquire desired 3D VFI because the possible sub-aperture patterns in the multiplexer are limited by its electrical connections. For example, the multiplexer can devide the elements only along its elevational axis and hence transmission pulses can be steered only along the lateral direction.

To overcome the problem, this study devise a novel scheme to acquire sufficient data for the volumetric 3D VFI by synthesizing sub-apertures and rotating the transducer.

2. Materials and Methods

2.1 Experimental setup

Fig. 1 shows the schematic of experimental setup. The 2D matrix array transducer (Vermon) consisted of 1024 (32x32) elements (fc: 3.5 MHz; element pitch: 0.3 mm). The transducer was connected to a programable ultrasound scanner (Vantage 256 system, Verasonics) via a 4-to-1 multiplexer (UTA 1024-MUX Adapter, Verasonics). The multiplexer had predefined sub-aperture groups, which were four 32×8 elements divided along the elevational direction of the transducer. Measurements of 3D vector flow were carried out using a straight tube polyvinyl alcohol (PVA) phantom. The phantom was made of an aqueous solution of 68 wt% dimethyl sulfoxide (DMSO) and 15 wt% PVA, and a 7 mm straight flow tract (tube) was created in the phantom. The tube was filled with blood mimicking fluid (BMF) made of an aqueous solution of 10 wt% glycerol and 0.1 wt% ultrasound scatterer (Godd Ball, Suzukiyushi Industrial Corp.). The BMF was circulated in the tube phantom with a steady flow pump (Thermo Fisher Scientific K. K Variable Flow Chemical Pump) at an average speed of 20 cm/s.

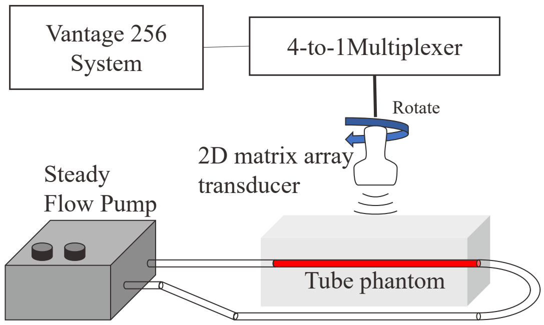

Fig. 1 Schematic of imaging system and experimental setup.

First, the RF data of a B-mode image was acquired. The ultrasound beam was transmitted at a pulse repetition frequency (PRF) of 5 kHz as a plane wave pulse of a center frequency of 3.5 MHz and one wavelength pulse duration. After the B-mode signal acquisition, the RF data of a color Doppler was acquired. In order to reconstruct 2D vector flow, the

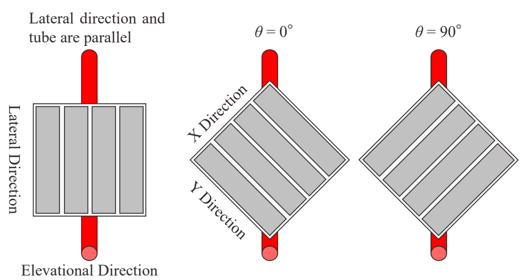

Fig. 2 Schematic of rotations of the 2D matrix array transducer

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plane wave pulses were transmitted at angles of ±8 degrees with a center frequency of 3.5 MHz and a pulse length of three wavelengths. To estimate one Doppler velocity, thirty-six pulses were transmitted and received sequentially for each 32x8 elements. The PRF was 2 kHz (1 kHz for each transmission angle). 32×8 elements were activated sequentially to acquire full volume data. Obtained RF data of B-mode and color Doppler was reconstructed with the beamformer of the Vantage 256 system.

2.2 3D Flow Estimation

Fig. 2 shows the schematic of the method of rotating the transducer to estimate the 3D VFI. The transducer was rotated by angles of 0 and 90 degrees in the axial direction. **Fig. 3** shows the schematic of 3D vector flow estimation. 1D flow velocities v_1 and v_2 were estimated using multi-angle vector Doppler techniques at transmission angles $\pm\theta$. After rotating the transducer by angle ϕ, 1D flow velocities v_3 and v_4 were estimated at transmission angles $\pm\theta$. Using the multi-angle Doppler technique[3,4], each component of 3D flow vectors was estimated by following equations:

$$v_x = \frac{v_1 - v_2}{2\sin\theta}, \quad (1)$$

$$v_y = \frac{(-v_1 + v_2)\cot\phi + (v_3 - v_4)\csc\phi}{2\sin\theta}, \quad (2)$$

$$v_z = \frac{v_1 + v_2 + v_3 + v_4}{4\cos\theta}, \quad (3)$$

where v_x, v_y and v_z were x, y and z (axial direction) velocity components, respectively. x and y directions were shown in **Fig. 2**. In our experiment, θ was 8 degrees and ϕ was 90 degrees.

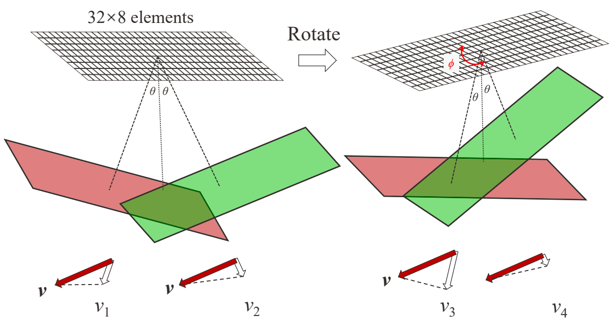

Fig. 3 3D vector flow imaging method

3. Results and Discussions

Fig. 4 (a) and **4 (b)** respectively show the speed of 3D vector flow in the long-axis plane and the short-axis plane. The velocity profile was faster in the center of the tube phantom. **Fig. 4 (c)** shows the 2D vector flow in the plane through the center of the tube phantom. The direction of the estimated 3D flow vectors was from the lower right to the upper left of the figure, indicating the flow along the tube. This result shows that 3D VFI estimation in this method is achieved.

4. Conclusion

In this paper, a novel scheme of 3D vector flow imaging using a 2D matrix array probe connected with a single ultrasound platform was devised by synthesizing and rotating sub-apertures. The experiment indicated that the proposed method can estimate desirable 3D flow vectors in a straight flow tube.

Acknowledgment

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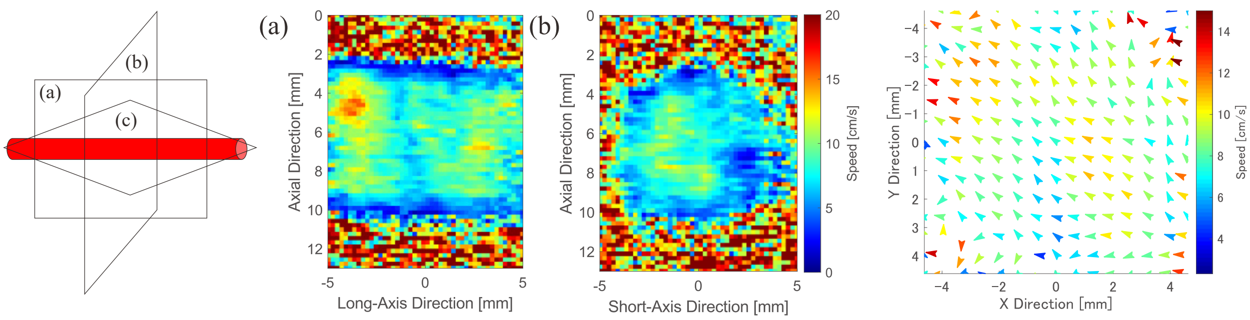

Fig. 4 (a) 3D vector flow speed in the long axis plane (b) 3D vector flow speed in the short axis plane (c) 2D vector flow in the plane perpendicular to the axial direction