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Tempo-spatial analysis of ultrasound volumes to estimate tip position of thin catheter in blood vessel

生体内での極細カテーテル先端位置推定のための超音波ボリュームの時空間解析

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1. Introduction

In a conventional medical technique using a catheter, such as angiography or PTA (percutaneous transluminal angioplasty), the tip position of the catheter was monitored through X-ray images to induce the catheter through blood vessel network (BVN). Because there is a limitation of radiation exposure for a patient, and a conventinal equipment as X-ray imaging is generally huge and expensive, there is a requirement to replace with ultrasound, which has a potential to monitor the status of the catheter. However, it is difficult to confirm the position of catheter in blood vessel on ultrasound image. To monitor the tip position of thin catheter, a preceding study has reported [2], which detects Doppler shift produced by a vibration element mounted on the tip of a catheter tip. However, because of the size of the element, there is a limitation in the size of blood vessel to be inserted. Because our group has already developed the method to bend thin catheter using acoustic radiation force [1], which aimed an arbitrary control through blood vessel network, there is a possibility that both monitoring and controlling are realized by ultrasound alone. Therefore, we have aimed to estimate the position of the tip of the catheter by processing ultrasound volumes, which contain time-series variation of microbubbles dispersion [3]. However, because the method used only the subtraction between volumes, the accuracy was insufficient. Therefore, we have newly introduced an optical flow method, which considers the gradient of brightness, to determine the tip of catheter in blood vessel.

2. Methods

The experimental setup is shown in **Fig.1**. A thin catheter, which has an inner and outer diameter of 0.6 mm and 1.1 mm respectively, was inserted into an artificial blood vessel and placed below 4 mm from the water surface in a water tank. The artificial blood vessel has inner diameter from 2.2 to 4.0 mm produced with rubber by mimicking a porcine portal vein. In the water surface, an ultrasound transducer X6-1 (Philips), which connected to an echography iU22 (Philips), was set to acquire ultrasound volume with a convex angle of 45 deg, a gain of 20 %, and a volume rate of 9 Hz. In addition, an optical position sensor (Polaris Spectra, NDI) was installed above the water tank to obtain the position of the ultrasound probe. Using the above setup, while an artificial flow was produced with 50 mm/s, microbubbles suspension, which has a concentration of 2 μg/ml, was injected through the catheter with an injection rate of 0.3 ml/s and spread from the tip of the catheter.

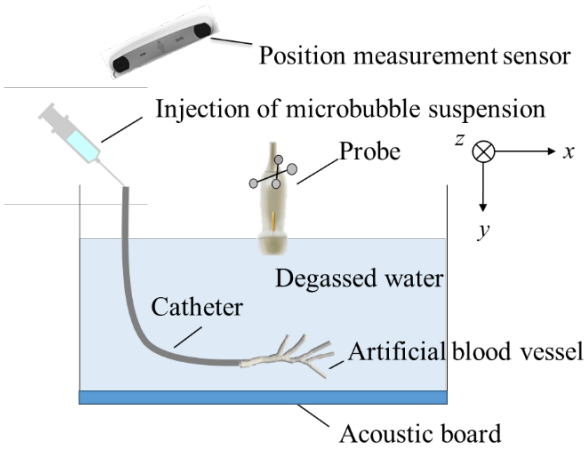

Fig.1 Experimental setup for observation of spread of microbubbles from the tip of the catheter.

To analyze the spread of microbubbles, we introduced Lucas-Kanade method [4] as an option of optical flow analysis. Defining time-series ultrasound volumes as V_m (m = 0, 1, 2,…, N-1), those were subtracted from the initial volume as $S_m = V_m - V_0$. In the time-series S_m, the region of blood vessel was extracted to reduce the calculation cost. After the distribution of optical flow vectors were obtained, shorter flows were regarded as noise and eliminated by clustering process of K-means method [5]. Considering the obtained distribution of flow originated microbubbles, the average direction of the vectors and the center of gravity in the distribution were calculated to determine the tip position.

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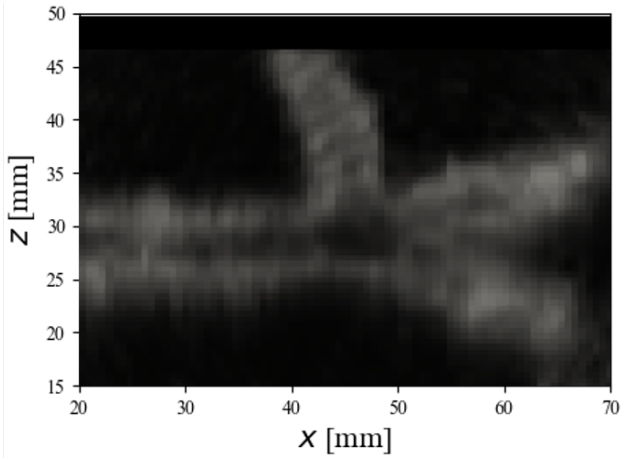
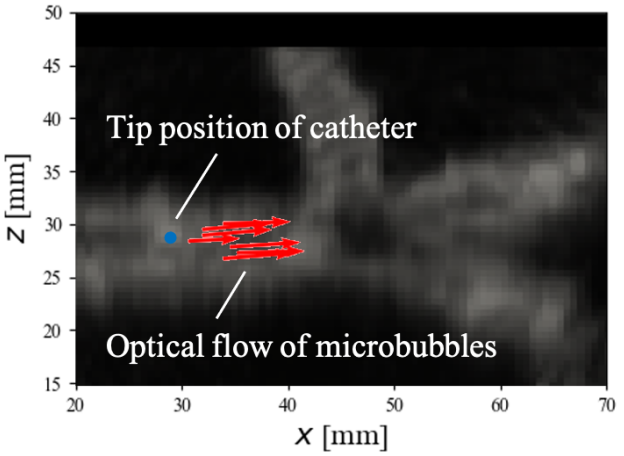
3. Results

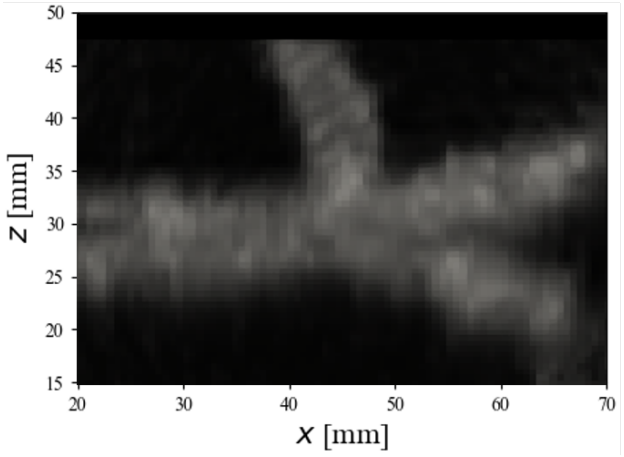
Using the experimental system shown in Fig.1, the dispersion of microbubbles injected from the catheter tip was analyzed. **Fig.2** shows the extracted images in *x*-*z* plane of the ultrasound volumes, where (a), (b) and (c) indicate V_{16}, V_{21} and V_{25}, respectively. Fig. 2 (a) is the original B-mode image before the injection of microbubbles. Fig. 2 (b) and (c) shows the calculated flow vectors superimposed on the original B-mode images. It is possible to confirm the diffusion of microbubbles. The blue dots are the true position of the tip of the catheter, which were measured before the examination using the optical position sensor. The red arrows represent the detected flows, where the direction and the origin of flows were confirmed to correspond to the experimental setup.



(a) Original B-mode (V_{16}) before injection of microbubbles



(b) Calculated flow vectors superimposed on B-mode (V_{21}) after injection of microbubbles



(c) Original B-mode (V_{25}) after injection of microbubbles

Fig.2 Variation of calculated flow vectors caused by microbubbles dispersion

Fig. 3 shows the estimated position error between the calculated and actual tip position, which was less than 1.0 mm in the *y*- and *z*-directions. On the other hand, the error more than 2.5 mm was detected in the *x*-direction, which corresponded to the axis of the catheter. Because the beam width of the acoustic radiation force distribution of the 2D array transducer is about 5 mm, the system has a potential to adopt the position error. However, it should solve the insufficiency by further analysis of the position estimation.

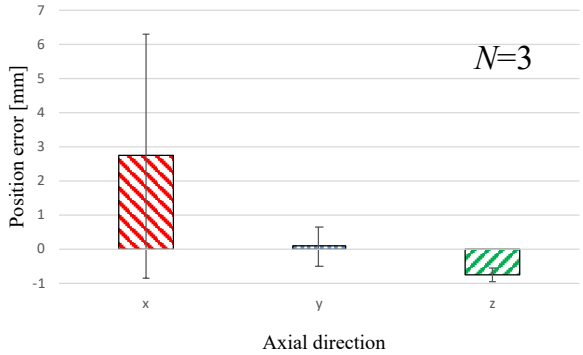


Fig.3 Comparison of the tip position calculated by the proposed method and actual one.

4. Conclusions

We developed a method to detect the tip position of the catheter by processing optical flow method with time-series ultrasound volumes during the dispersion of microbubbles in an artificial blood vessel. Then we confirmed the accuracy of the detected tip position. We are going to improve the method to enhance the accuracy for not only artificial blood vessel experiment but also in vivo experiments.

References

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