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Three-dimensional detection of tip position of catheter in ultrasound volume through time-series analysis of microbubble dispersion

超音波ボリューム中の微小気泡拡散の時系列解析によるカテーテル先端の3次元位置検出

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1. Introduction

In a conventional catheter therapy, the catheter position is monitored through X-ray image to induce the tip in blood vessel network, where there is a limitation of radiation exposure for patient and physician. Because an X-ray equipment is generally huge and expensive, if ultrasound can be replaced to X-ray, the size and cost for therapy become lower without any concern in radiation exposure. Our laboratory has researched therapeutic application using ultrasound with small object, which is a thin catheter or microbubbles, mainly for drug delivery. The tip of the thin catheter is bent by local acoustic radiation force [1,2] at the bifurcation of the blood vessel. Also, drug-containing microbubbles are released from the tip of the catheter to be induced to the target path or trapped on vessel wall [3]. Furthermore, three-dimensional (3D) blood vessel network obtained ultrasound image was reconstructed [4]. At present, the most fundamental problem is visualization of catheter on ultrasound image because of not only the size and material of the catheter but also its 3D shape curved in blood vessel. Therefore, a method to monitor the tip position of catheter is necessary to realize active drug delivery using catheter to the desired path in blood vessel network. In this study, we propose a method to detect the tip position of catheter in ultrasound volume by time-series analysis of spatial dispersion of microbubbles, which were released from the tip of the catheter as contrast enhancement in blood flow.

2. Proposed Algorithm

Fig.1 shows the transition of ultrasound image to explain the principle to detect the tip of the catheter, where the catheter itself is undetectable by ultrasound. When a suspension of microbubbles was injected into the catheter, a stream of microbubbles would spread from the tip of the catheter. Meanwhile, dispersion of microbubbles must be detected by ultrasound image, where the origin of the spatial dispersion should indicate the tip of the catheter. Therefore, 3D position estimation of the tip position of the catheter should be possible through temporal variation of 3D brightness distribution. To address this issue, we tried to divide the acquired ultrasound volume into small volumes to compare between them temporally and to narrow down to the most possible small volume containing the tip of catheter.

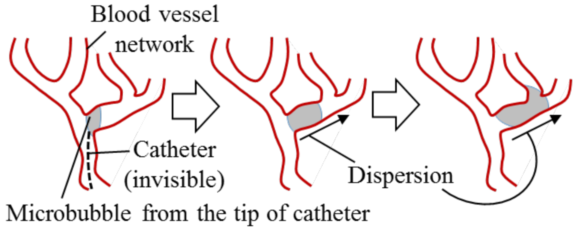

Fig.1 Dispersion of microbubbles from the tip of the catheter to detect its position.

Fig.2 shows the flowchart of the algorithm proposed in this study. First, the original ultrasound volume V, which includes time variation information, was spatially divided into N x N x N small volumes (F3) to be analyzed the temporal variation of the spatial average brightness in each small volume (F5). Here we established a parameter of instantaneous peak of brightness, which is presumed to indicate the dispersion of microbubbles. Through all small volumes, the number of instantaneous peak, which is adjusted with a threshold value, is counted (F6). When the number was 1, the tip of the catheter is included in the identical small volume. When the number was more than $N^3/2$, the algorithm determines it is the limitation of division due to too many candidate small volumes. Otherwise, when the number was between 2 and $N^3/2$, there should be a competition among the candidate small volumes based on the amplitude of brightness and temporally integrated value of mean brightness. If there are high

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correlation and phase difference among the brightness variations of the candidate small volumes, the small volume which has the earliest phase is selected as the objective volume (F7). Also if the chosen volume is possible to be divided again, it is substituted to V and return to F3 (F9).

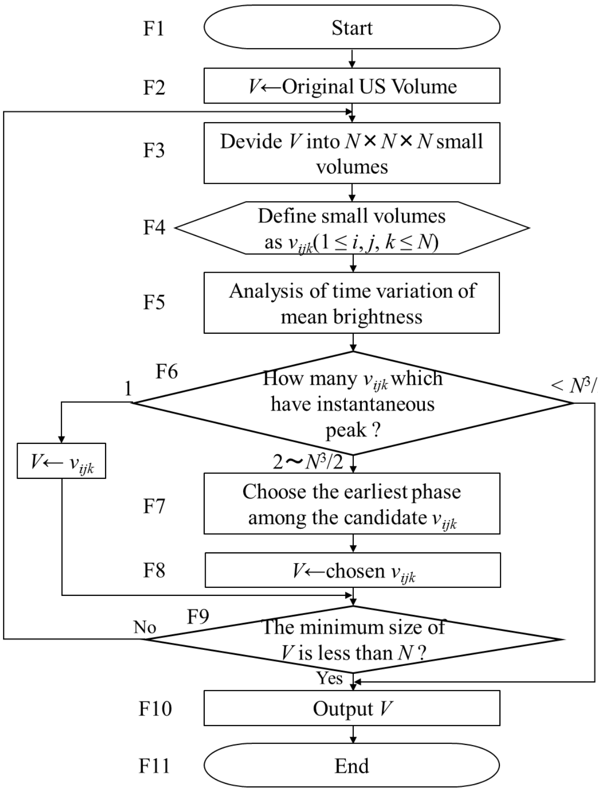


Fig.2 Flowchart of the tip position of catheter detection.

3. Experiment and result

We have fabricated an artificial blood vessel as shown in Fig.3 using a 3D printer from a CT data of a porcine liver blood vessel. On the bottom of the water tank filled with degassed water (40℃), it was placed to be inserted a conventional catheter, which has outer diameter of 1.1 mm, and inject microbubbles [3] with flow rate of 1.0 mL/s and concentration of 1.0 ng lipid/mL. Also, artificial flow was produced with a flow velocity of 130 mm/s. Using an echography iU22 (Philips Co., Ltd.) with a 3D probe X6-1, the original ultrasound volume was recorded with 5 volumes/s, gain of 10%, mechanical index of 0.9, and depth of 60 mm.

We established $N = 3$ to proceed the algorithm to an original volume with 160 x 242 x 177 voxels. After experiencing the loop in Fig.2 for three times, the algorithm succeeded to narrow down to the most candidate volume of 6 x 9 x 7 voxels, which is equivalent to $3.9 \times 2.4 \times 3.8\ \mathrm{mm}^3$. Fig.4 shows two pairs of cross sections of the original volume before and at the moment of microbubbles injection, where the candidate volume was designated as red rectangle. We confirmed the possibility of validity using the above algorithm from the results of qualitative experiment.

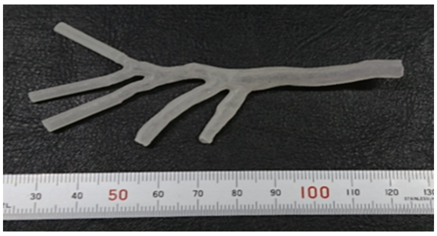
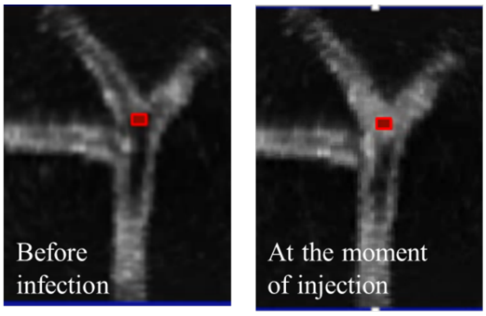
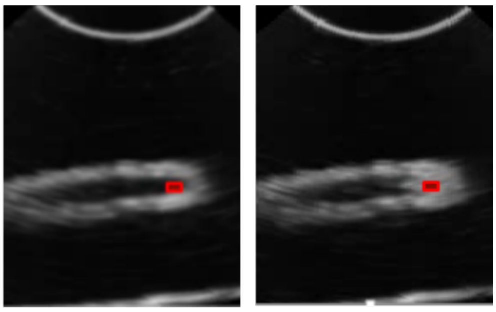


Fig.3 Outlook of artificial blood vessel.



(a) Horizontal plane



(b) Vertical plane

Fig.4 Cross sections of the original volume before and at the moment of microbubbles injection.

4. Conclusion

In this study, we proposed a method to detect the tip position of catheter in ultrasound volume by time-series analysis using spatial dispersion of microbubbles. Also, we confirmed the effectiveness of the algorithm through a qualitative experiment, where the candidate volume was determined with the accuracy of several mm. We are going to improve this method by adjusting experimental parameters to be able to apply to an *in vivo* experiment.

References

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