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Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 241-242
13-15 November, 2012

Error correction for 3D reconstruction of artificial blood vessel from ultrasound volume data

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1. Introduction

3D reconstruction of the blood vessel network (BVN) from ultrasound data has many therapeutic applications. The control of microbubbles *in vivo* by ultrasound is an actively researched topic which strongly depends on the BVN reconstruction [1, 2]. BVN reconstruction using CT and MRI data [3, 4] benefits from a higher resolution compared to ultrasound data. However, such modalities are unable to provide the flexibility offered by ultrasound: portability and real-time data are two examples. Because ultrasound data, and especially three-dimensional data, is of much lower quality than what can be obtained from CT or MRI, one can not use the conventional methods for BVN reconstruction from CT or MRI data.

A first three-dimensional BVN reconstruction method has been described in [5]. In this paper, we start by proposing several improvements to that conventional method. Then, we conduct a validating *in vitro* experiment using an artificial blood vessel with multibifurcations (capillary model). Unlike [5], we use a matrix array probe to acquire ultrasound volume data directly and thus increase the BVN reconstruction reliability. We present and discuss the BVN reconstruction results obtained under distinct experimental conditions, like flow velocity or echography gain.

2. Method

We describe in this section a method to reconstruct in three dimensions a blood vessel network. This reconstruction method is using Doppler volume data, either colour or power Doppler. We have enhanced the method described in [5] by significantly improving the noise filtering process and refining the reconstruction by post-processing.

First, we have extended the noise removal process by preceding morphological operations (erosions, dilations) with a linear mean filter, producing a monochrome (binarized) image. Three-dimensional thinning is then applied onto the image resulting from the noise removal process.

Then, it is important to note that a weak point of the method of [5] is the high rate of false positive bifurcations: many physically inexistent vessel bifurcations are detected. Thus, we have implemented as post-processing a false positive removal treatment. Concretely, this operation consists in measuring the lengths of detected vessels and in removing those whose length is less than a given threshold.

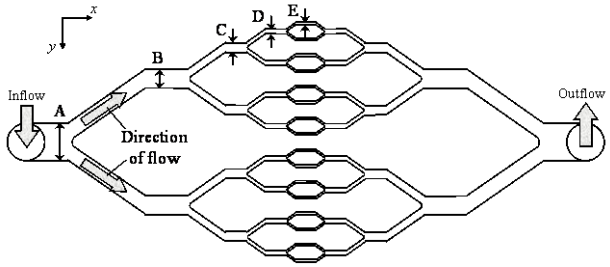

Figure 1: Construction of the multi-bifurcation artificial blood vessel (capillary model).

3. Results

We conducted an *in vitro* experiment aiming at performing a three-dimensional reconstruction of an artificial blood vessel made of poly(vinyl alcohol) built according to a capillary model by grayscale lithography (see **Figure 1** and **Table 1**).

Table 1: Diameters and section areas of the capillary as categorized in Figure 1.

	A	B	C	D	E
Diameter [mm]	2.0	1.4	1.0	0.7	0.5
Section area [mm^2]	3.14	1.56	0.79	0.4	0.2

Data acquisition was realized by a Philips xMATRIX iU22 echography equipped with a top-class matrix array probe X6-1 featuring high resolution three-dimensional imaging thanks to its 9200+ array elements. As mentioned in Section 2, ultrasound volume data was acquired in Doppler mode; power Doppler precisely.

We positioned the ultrasound probe as described in **Figure 2** and with the following parameters: $h = 40\text{mm}$, $\theta = 25\text{deg}$ and $\phi = 60\text{deg}$. Doppler liquid was flown inside the capillary to improve Doppler imaging quality. Volume data were captured with an echography gain value of 50% and an echography MI value of 0.3. Data were acquired under three different flow velocities: 5mm/s,

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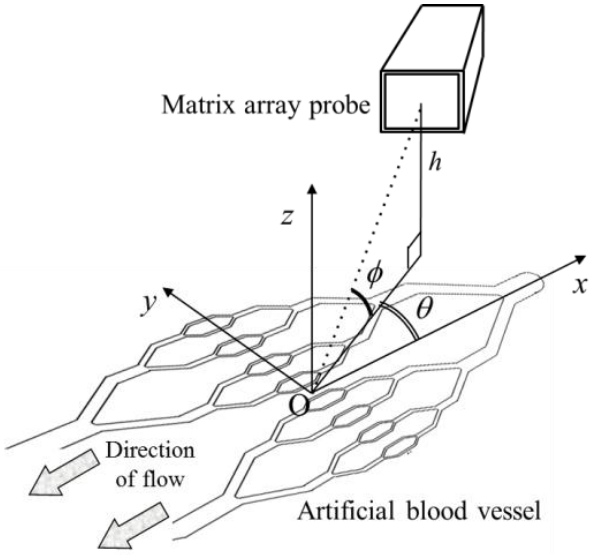

Figure 2: Experimental conditions: probe and capillary relative positions.

10mm/s and 20mm/s. The reconstruction results of the capillary under these specific conditions are presented in Figure 3.

Then, we acquired data on a larger scale: this time, the echography gain was set to 30%, 40% and 50%, and the MI value was set to 0.1, 0.3 and 0.5, and this for each of the three flow velocities. So in total we collected 27 data samples. We measured the amount of true positives as for vessels bifurcations detection. Results are given in **Figure 4**.

4. Discussion

We have conducted an *in vitro* experiment aiming at performing the reconstruction of artificial blood vessel according to a capillary model. We acquired

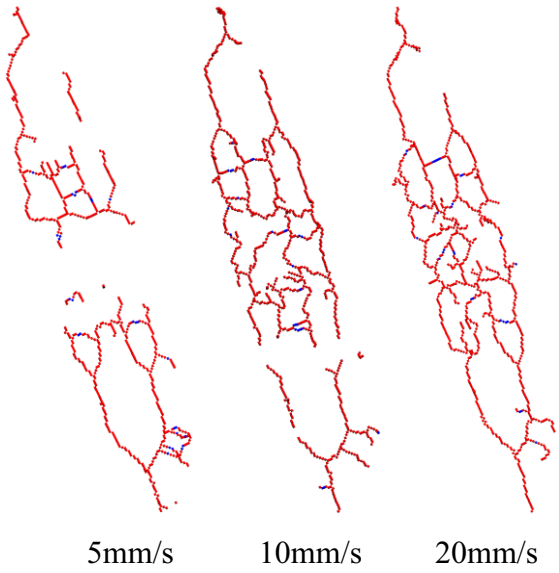

Figure 3: Reconstruction results in the case of an echography gain of 50% and an MI value of 0.3.

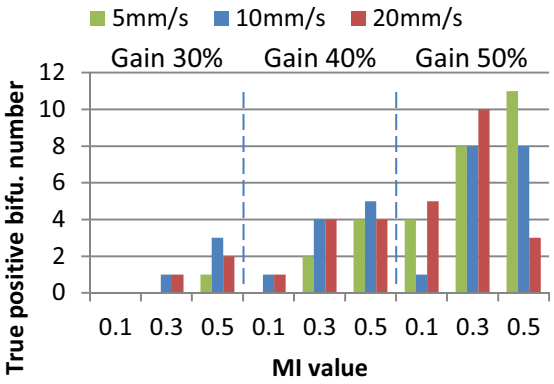

Figure 4: Amount of true positive detected bifurcations depending on flow velocity, echography gain and MI value.

volume data under different conditions so as to understand the effect of each parameter. Our results coherently confirmed that the higher the flow velocity, the better the reconstruction. As we can see in Figure 3, a flow velocity of 20mm/s produces a vessel reconstruction which is more accurate and less lacking than the reconstruction of the same vessel with a flow velocity of 5mm/s. Lastly, we were able to confirm the physical limitations of the ultrasound probe used in this experiment. Effectively, we can see that capillary sections of diameters less than or equal to 0.7mm were not properly detected.

Also, the influence of the echography gain and MI value was tentatively quantified in Figure 4; we obtained once again coherent results confirming that the combination of a high gain coupled with a high MI value enables the detection of more vessel bifurcations. For instance, in the case of an MI value of 0.3, a gain of 50% enabled the detection of 10 true positive vessel bifurcations whereas a gain of 30% in the same conditions enabled the detection of only 1 true positive vessel bifurcation. Regarding flow velocity, it is difficult to evaluate its impact on true positive detected bifurcations only. Effectively, the influence of the flow velocity is, as shown in Figure 3, more likely to result in missing vessel sections rather than missing vessel bifurcations.

Acknowledgment

This research is granted by the Japan Society for the Promotion of Science (JSPS) through the Funding Program for Next Generation World-Leading Researchers (NEXT Program).

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