Visualization of a blood flow with Two-Dimensional Moving Target Indication

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1 Introduction

Since the appearance of a sonar in World War I, ultrasonic devices are widely spread and applied for various fields; non-destructive evaluations for industrial field, fish finders for fishery, active sonars for military use and diagnostic devices for clinical use. An ultrasonic diagnostic device has been a powerful tool to observe organs such as heart, liver, and so on and fetus with scanning an ultrasonic beam for the last two decades.

A current ultrasonic diagnostic device has the function not only to observe the morphology of organs but also to visualize a blood flow based on Doppler effect at the same time. However, owing to the disadvantage of Doppler effect, only the component parallel to an ultrasonic beam can be detected. Therefore, the detailed observation of the blood flow is not performed, especially, in the neighborhood of valves of a heart.

In order to measure a blood velocity vector, the Doppler frequency shift must be detected from three different directions. Chihara et al.[1] and Fox et al.[2] developed three-probe ultrasonic Doppler systems to measure the blood velocity vector at one point. However, the three-probe systems can not measure a blood velocity profiles at many points, because it is difficult to scan and to focus three beams in a human heart. Otsuki et al.[3] presented a method, based on the assumption that a flow direction is restricted to a 2-D plane, for estimating 2-D blood velocity vectors in a human heart by using the conventional color Doppler system and Euler's equation in flow dynamics. Furthermore, Chihara et al.[4] proposed a similar method using an equation of continuity in place of Euler's equation. Since the blood flow is not restricted to the 2-D plane, however, these estimation methods can not obtain the exact projection of the three-dimensional blood velocity vector on the 2-D plane.

As a new method to measure the blood flow instead of ultrasonic Doppler method overcoming problems as described above, we proposed High-speed Digital Subtraction Echography(High-speed DSE) and Two-Dimensional Moving Target Indication(2D-MTI) method [5]-[8] to visualize the blood flow and successed in extracting particles. The DSE method has existed from long ago and not been used for ultrasonic images. It was unsuitable for extraction of moving targets, because old type of the ultrasonic diagnostic device could be taken in only row frame rates.

Hence, we performed experiments using one particle flowing in the straight tube, some particles in the straight tube and some particles in the bump tube, for the purpose of visualizing the flow with various velocities. This paper reports principle of 2D-MTI method, experimental results and discussion. The conclusions contain a summary of key results.

2 Principle of 2D-MTI Method

Process of High-speed DSE is the image subtraction between successive B-mode echograms measured with high frame rate, where the current frame is called as live image and the last frame as mask image. High-speed DSE extracts moving targets and cancels fixed structures in a scanning area. The principle of 2D-MTI method is shown in Fig.1.

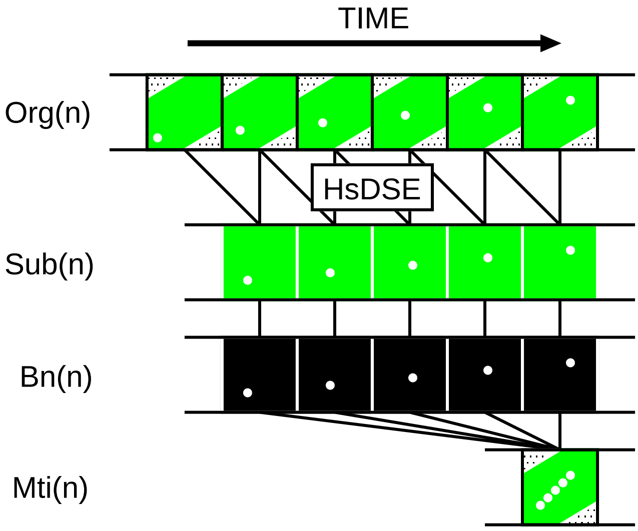


Figure 1: Principle of 2D-MTI method using High-speed DSE system. B-mode image $Org(n)$ on the first row lines up successively, where n is discrete frame number 0, 1, 2, $\cdots$. High-speed DSE image $Sub(n)$ on the second row is generated by subtraction $Sub(n) - Sub(n-1)$ between $Org(n)$. The moving targets on $Sub(n)$ is one of $Org(n)$ as negative intensity is made nothing. $Bn(n)$ on the third row is binary image of $Sub(n)$. Finally, 2D-MTI image $Mti(n)$ on the last row is generated by superimposing $Bn(n) + Bn(n-1) + \cdots$ accumulation of $Bn(n)$ on $Org(n)$.

$Org(n)$ on the first row is an original B-mode image, where n is discrete frame number 0, 1, 2, $\cdots$. Firstly, $Sub(n)$ on the second row is generated by applying High-speed DSE for $Org(n)$. The negative components resulting from the subtraction were compelled to be zero in order that only the particle of the live image appears on $Sub(n)$. The 3x3 median filter is used three times for $Sub(n)$ to remove speckle noise. $Bn(n)$ on the third row is a binary image of $Sub(n)$. The threshold level is set to extract only particles. 2D-MTI image $Mti(n)$ on the last row can be generated by superimposing the accumulation of $Bn(n)$, $Bn(n) + Bn(n-1) + \cdots$, on $Org(n)$ described in eq.(1),

$$Mti(n) = Org(n) + \sum_{i=0}^{k} Bn(n-i)w_i \tag{1}$$

where w_i is a weight to make gradation in particles and k is the discrete frame number of superimposed $Bn(n)$. We call a trace of a moving target as "worm". The worms on the $Mti(n)$ are given added weight by coloring as follows. The particles on the live image $Bn(n)$ was colored to red and the color of the particles on the previous image, $Bn(n-1), Bn(n-2), \cdots$ was changed gradually from green to yellow. A length and direction of the worm indicate the speed and direction of a particle, respectively. The number of k is in inverse proportion to the number of worms. The animation presentation of a series of 2D-MTI image $Mti(n)$ demonstrates the blood flow and fixed structures.

3 Experiments

Figure 2 shows an experimental arrangement,

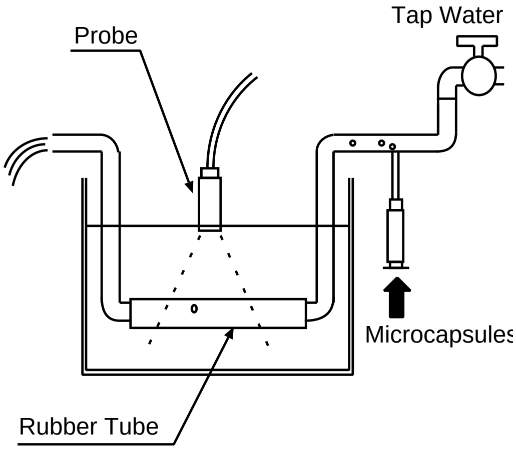


Figure 2: Schema of the flow phantom. Water and microcapsules flow through a straight or bump shaped tube with a thickness of 1mm. The micro capsule, which includes innocuous gas, is made of VCl_2-AN and has a diameter of 10-70μm. Ultrasonic B-mode images were taken with a convex type probe with a resonant frequency of 3.5MHz connected to an ultrasonic diagnostic device (Hitach Medical Corp EUB-565A).

where water and micro capsules flow at the constant speed of 500mm/sec through a straight or bump shaped rubber tube with a thickness of 1mm. The micro capsule, which includes innocuous gas, is made of VCl_2-AN and has a diameter of 10-70μm. Ultrasonic B-mode images were taken with a convex type probe with a resonant frequency of 3.5 MHz connected to an ultrasonic diagnostic device(Hitach Medical Corp. EUB-565A). In the following experiments, five particles was used to construct the worm.

Firstly, the experiment was performed using a straight tube with a diameter of 13mm, where only one particle flows through the tube for the purpose of extracting a particle and selecting the adequate frame rate for a flow speed. B-mode images were taken with a frame rate of 60, 116, 164 and 303frame/sec. Secondly, the experiment was carried out using the straight tube with a diameter of 12mm, where some particles flow through the tube to discriminate the worms. B-mode images were taken at 116 frame/sec. Finally, the experiment was carried out using a bump tube with a diameter of 40mm, where some particles flow in the tube for the purpose of discriminating the worms and visualizing of a turbulent flow. B-mode images were taken at 116 frame/sec.

4 Results and Discussion

Figure 3(a)-(d) are the subtracted images $Sub(n)$ in the case of one particle flowing in the straight tube for a frame rate 60, 116, 164 and 303frame/sec, respectively. Figure 3 is a three-dimensional expression of $Sub(n)$, where XY-plane corresponds to an image plane and Z-axis to the grey level of a pixel.

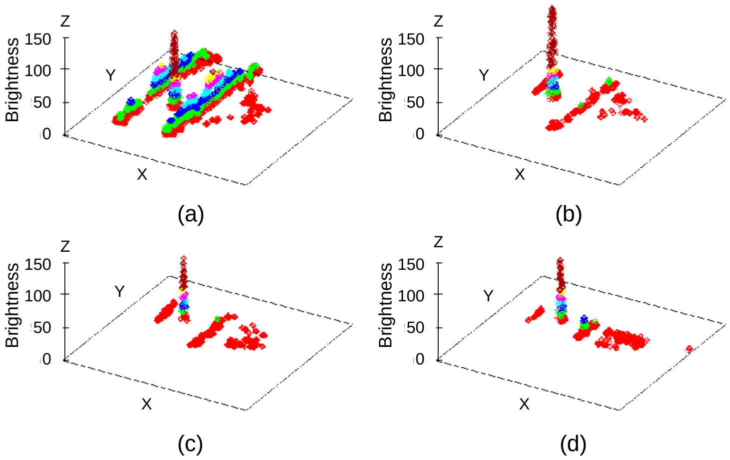


Figure 3: 3-Dimensional High-speed DSE image $Sub(n)$ for a frame rate (a)60, (b)116, (c)164, (d)303frame/sec. XY-plane corresponds to an image plane and Z-axis to the grey level of a pixel. In the high frame rate more than 100frame/sec((b)-(d)), fixed structures are cancelled in the case of the flow speed of 500mm/sec.

Figure 4(a)-(d) show the 2D-MTI images $Mti(n)$ for a frame rate of 60, 116, 164 and 303frame/sec, respectively.

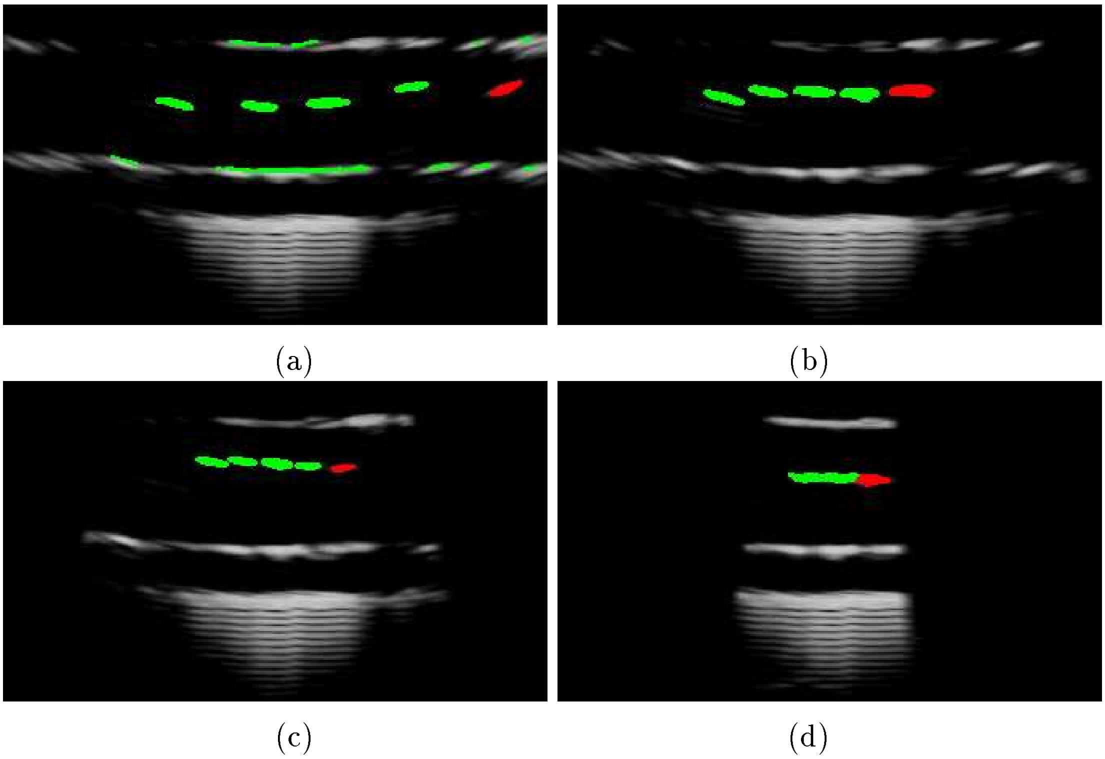

(a) (b) (c) (d)

Figure 4: 2D-MTI image $Mti(n)$ for a frame rate (a)60, (b)116, (c)164, (d)303frame/sec. If the flow speed is so fast for frame rate, e.g. (a), a scale of particle is large, however, it is difficult to recognize the worm. In this experiment, most suitable frame rate is (b).

Figure 3 indicates that this method requires the high frame rate more than 100 frame/sec to cancel fixed structures in the case of the flow speed of 500mm/sec. On the other hand, Fig.4 demonstrates that the particle size and the distance between particles becomes smaller as frame rate getting higher. The reason is that the particles between frames cancel each other when the flow speed is too slow for frame rate. Therefore, it is necessary to select the suitable frame rate.

We propose the formula between the flow speed and frame rate as described in eq.(2).

$$f = \frac{v}{p} \tag{2}$$

where v is the flow speed, p is the length of particle on B-mode images in the direction of movement and f is frame rate. When the flow speed is 500mm/sec and the length of particle is 4.5mm, the suitable frame rate is about 110 frame/sec by eq.(2). We can conclude that most suitable frame rate to extract a particle and cancel fixed structures is 116frame/sec (Fig.3(b) and Fig.4(b)). Following experiments were performed at frame rate 116frame/sec.

Figure 5 shows the 2D-MTI image in the case of some particles in the straight tube, which indicates that four worms can be distinguished and that their speed and direction can be identified. Furthermore, the coloring helps to discriminate the worms.

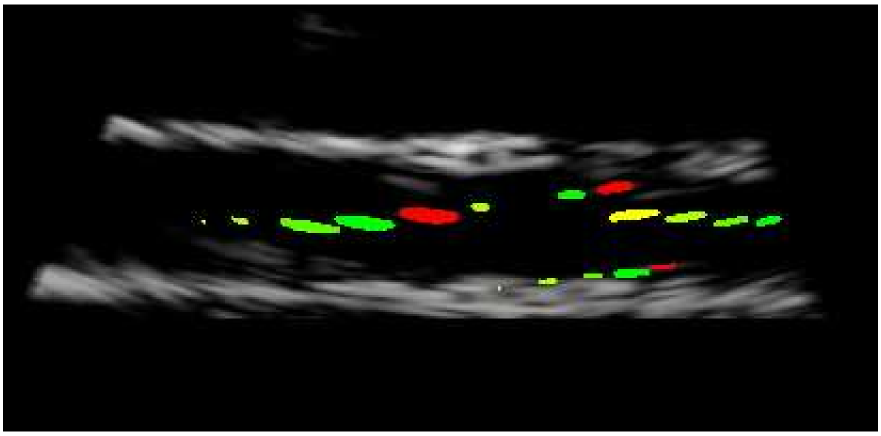
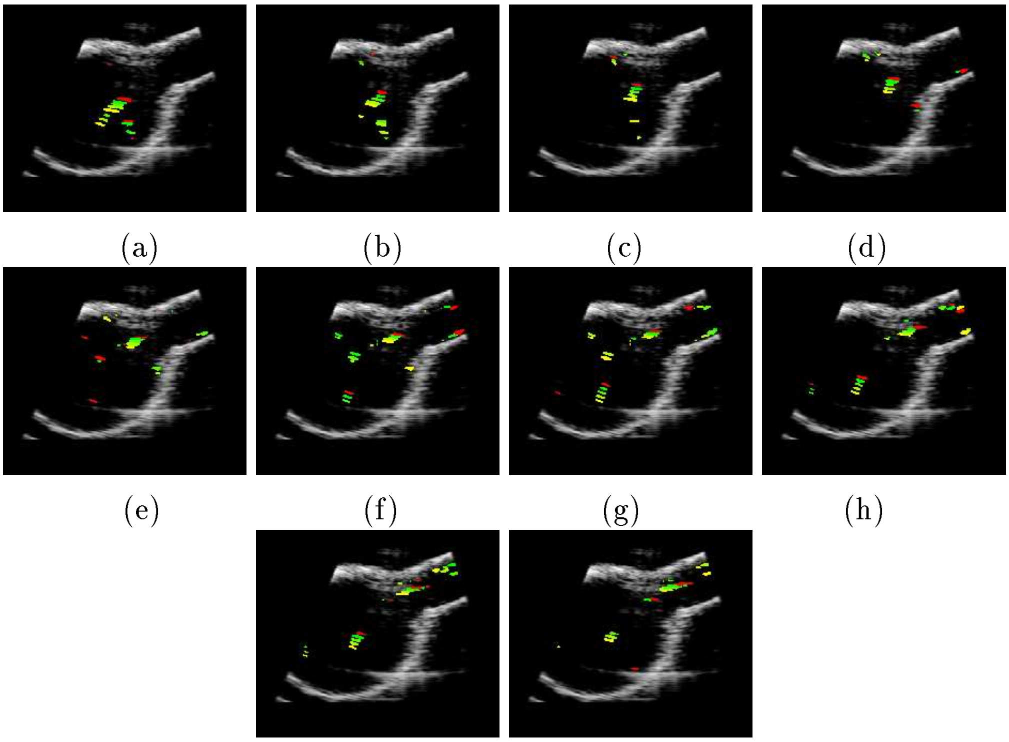


Figure 5: 2D-MTI image in the case of some particles in the straight tube, which indicates that four worms can be distinguished and that their speed and direction can be identified. Furthermore, the coloring helps to discriminate the worms.

Figure 6(a)-(j) show the series of 2D-MTI images in the case of some particles in the bump tube. The time interval of the image is 17msec. The result shows that this method effects on visualizing the motion of worms with various directions in the turbulent flow. Some worms do not have five particles, which means that the worms cross the scanning plane, i.e. they have the flow component normal to the plane.


(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j)

Figure 6: The series of 2D-MTI images in the case of some particles in the bump tube. The time interval of the image is 17msec. The result shows that this method effects on visualizing the motion of worms with various directions and the turbulent flow. Some worms do not have 5 particles, which means that the worms cross the scanning plane, i.e. they have the flow component normal to the plane.

From the above results, the Color Doppler method can not be visualized the flow at the region where the ultrasonic beam crosses to the flow vector at right angles, while the 2D-MTI method can be visualized the flow regardless of the angle between the flow and the beam.

5 Conclusions

We proposed the 2D-MTI method to visualize the blood flow and performed basic experiments using a rubber tube to evaluate this method. The experimental results show that this method enables to extract particles and visualize the steady flow or the turbulent flow. Consequently, we successed to discriminate the worms on the 2D-MTI image more clearly and to visualize the flow regardless of the measurement angles.

The 2D-MTI method using High-speed DSE system, which solves the problem of the ultrasonic Doppler method such as dependence on measurement angle, has the potential to visualize the two-dimensional the blood flow in heart and the blood vessel.

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