34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Noninvasive Internal Bleeding Detection Method by Measuring Blood Flow under Ultrasound Cross-Section Image

Keiichiro Ito, Koichi Tsuruta, Shigeki Sugano, *Fellow IEEE*, and Hiroyasu Iwata, *Member, IEEE*

***Abstract*—The purpose of this paper is to propose noninvasive internal bleeding detection method by using ultrasound (US) image processing under US cross-section image. In this study, we have developed a robotic system for detecting internal bleeding based on the blood flow measured by using a noninvasive modality like an US imaging device. Some problems related to the measurement error, however, still need to be addressed.**

In this paper, we focused on US image processing under US cross-section image, and constructed blood flow measurement algorithm under US cross-section image for internal bleeding detection. We conducted preliminary blood flow measurement experiments using a phantom containing artery model and a manipulator equipped with a US probe (BASIS-1). The results present the experimental validation of the proposed method.

I. Introduction

Internal bleeding detection is very important so that the necessary courses of treatment can be quickly made in order to save patients who have internal bleeding in the abdominal area [1]. Therefore, many researches have focused on the problem of detecting the position of a bleeding source using some modalities [2], [3]. However, these methods specialize only on identifying the position of the bleeding source, and need a contrast agent because they depend on the doctor's vision. A medical doctor is not able to use the method with the contrast agent on a patient with a contrast agent allergy or a high severity of symptoms.

Therefore, we aim to develop a robotic system to detect a bleeding source based on the blood flow measured by using a noninvasive modality like an ultrasound (US) imaging device. We have developed a wearable manipulator equipped with a US probe (BASIS-1), and have also reported some algorithms to measure the cross-section area of a blood vessel under cross-section image and blood speed under longitudinal section image for calculating blood flow [4].

However, we could not have measured the blood speed accurately under longitudinal section image by using US Doppler. The blood vessels get lost on the US image due to displacement of the blood vessel.

Blood speed should be measured, therefore, under cross-section image, because the blood vessel, which is measurement object, cannot be easily lost on the US image even if displacement occurs. In order to measure the blood speed under cross-section image by using the US Doppler, the measurement point has to be maintained because of reducing Doppler noise. Also, the angle between US Doppler beam and blood vessel should be measured to correct the measured blood speed by US Doppler. This means that methods to track the blood vessel and detect the angle for measuring blood speed under US cross-section image are key technologies needing establishment for internal bleeding detection.

Many measurement systems related to US imaging processing and visual servoing for internal objects have recently been developed [5], [6]. However, methods for detecting internal bleeding and measuring blood flow by using US imaging device has yet to be introduced.

In this paper, therefore, we focused on US image processing under US cross-section image, and constructed blood flow measurement algorithm under US cross-section image for internal bleeding detection.

Keiichiro Ito, Hiroyasu Iwata, and Shigeki Sugano are with the Department of Creative Science and Engineering, School of Modern Mechanical Engineering, Waseda University, 17 Kikui-cho, Shinjuku-ku, Tokyo, 162-0044, Japan. Phone: +81-3-3203-4457, Fax: +81-3-3203-4457, Email:{itokei-1985,jubi, sugano}@sugano.mech.waseda.ac.jp. Hiroyasu Iwata is also with the Waseda Institute for Advanced Study (WIAS)

II. Internal Bleeding Detection System

A. System Overview

The blood flow measurement robotic system. The system is composed of a US imaging device, BASIS-1 and a PC for robot control and image processing. An output image from the US imaging device is processed and send to the PC in order to control the position and posture of the probe. The US imaging device (MicroMaxx (SonoSite Inc., Micro-convex probe (1-5 MHz)) outputs the image signal, then captured by video grabber Epiphan's DVI2USB Solo into a PC (Core2Duo 2.0GHz). The image processing is implemented by Intel's OpenCV. The BASIS-1 has 5-DOF (Pitching (1DOF), Rolling (1DOF), Positioning (2DOF), and Contacting (1DOF)).

B. Flow for Internal Bleeding Detection

It is important for the flow volume of the upside, downside, and the branched blood vessel in a segment to be measured for detecting bleeding. In addition, the priority of the diagnosis of the abdominal aorta is very high, and that of the medium artery (branched vessel) is next highest. Therefore, meeting this priority for detecting bleeding is logical. For example, when there is a bleeding source in segment A as shown in Fig.1, doctor could predict that internal organs and tissues that are below the bleeding source would become ischemia easily.

R. W. Gill reported on a method to calculate the blood flow [7]. The parameters for calculating the blood flow are the cross-section area ($S(t)$ cm^2) changed by the pulse amplitude

978-1-4577-1787-1/12/$26.00 ©2012 IEEE

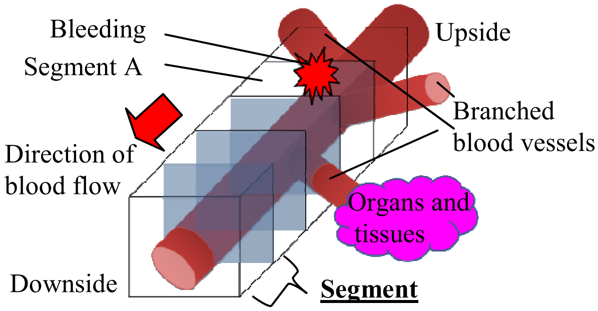

Fig.1 Segment (divided the blood vessel within a certain range)

and the blood speed changed by the pulse amplitude (V(t) cm/s). Based on the blood flow distribution, V(t) is not the maximum speed but the average speed in the cross-section of the blood vessel. In addition, the blood flow is usually defined as the stroke volume in the medical field. Based on the report, we calculated the average blood flow Q ml/stroke, (1)

$$Q=\frac{1}{T}\int_{0}^{T} S(t)\cdot V(t)dt \qquad (1)$$

The following functions are required in order to propose measurement algorithms that are accurately suitable and automated for measuring the blood flow. We focused on, in this paper, functions 3) and 4).

1) Extracting cross-section image of a blood vessel:
   Since the blood pressure in an artery is uniformly in the radial direction compared to that in a vein, an optimal cross-section image of an artery can be approximated as a circle. In addition, a ratio of the major and minor axes a circle approaches one. We control US probe so that the ratio of the major and minor axes approaches one to extract an optimal arterial cross-section.
2) Measurement of the cross-section area:
   Measuring alteration of a cross-section area from moment to moment
3) Tracking the center of the blood vessel:
   In order to accurately measure the blood speed, the center of a blood vessel on the US image has to be maintained when the speed is measured using the US Doppler. Therefore, the US probe has to track the blood vessel which moves with breathing under cross-section image.
4) Measurement of the blood speed:
   In order to accurate blood speed on cross-section image by using US Doppler, we have to detect the angle between US Doppler beam and blood vessel, and correct the measured blood speed.
5) Calculating blood flow:
   Calculating the blood flow of one heartbeat based on (1)

III. Blood Flow Measurement Algorithm

Fig.2 shows the overview of the blood flow measurement algorithm.

A. Tracking the Center of a Blood Vessel

In order to track the center of a blood vessel on the US image, we constructed a visual feedback control algorithm as shown in Fig. 3.

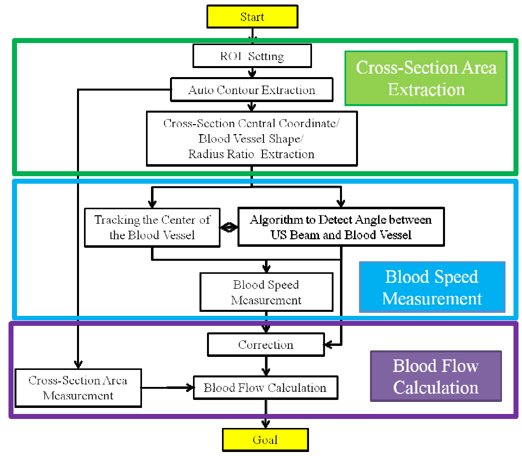

Fig.2 overview of the blood flow measurement algorithm

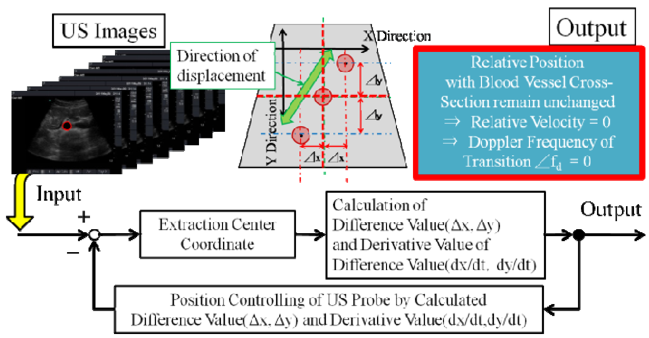

Fig.3 Visual feedback control algorithm for tracking blood vessel

The US probe could be controlled to correspond the center of a blood vessel with the center of the US image based on difference value of center of a blood vessel of inter-frame, $(\Delta x, \Delta y)$ and derivative value of the difference value, $(dx/dt, dy/dt)$. This means that Doppler noise could be removed by relative speed between US probe and blood vessel approaching zero.

B. Measurement of a Blood Speed

In order to measure blood speed accurately, there are two phases to correct the measured blood speed; Detecting angle between US beam and blood vessel, Correcting the blood flow based on the angle.

First, US probe is controlled to corresponding X-axial plane (Direction of blood flow) with y-z plane of US image, as shown in Fig.4.

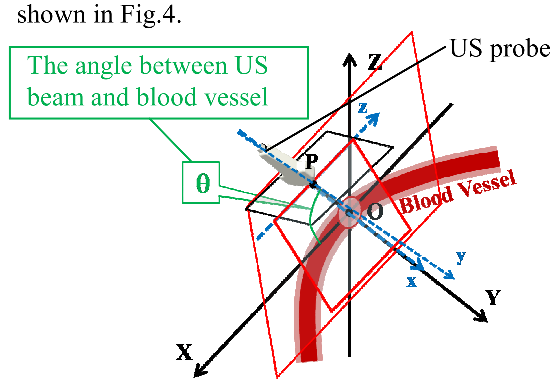

Fig.4 Relations between coordinate of US probe and blood vessel

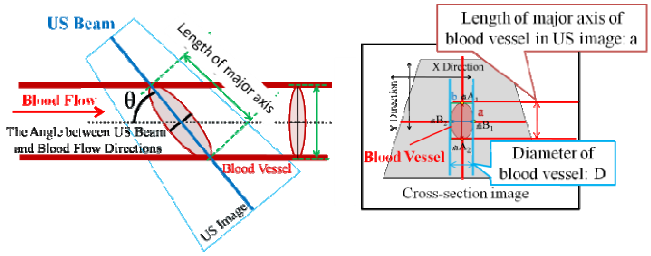

Fig.5 The angle between US beam and blood vessel

The angle between US beam and blood vessel could be calculated geometrically, as shown in Fig.5 and as in (2)

$$\theta = \frac{\pi}{2} - \cos^{-1}\left(\frac{D}{a}\right) \tag{2}$$

D: Diameter of blood vessel
a: Length of major axis of blood vessel in US image

Next, a medical doctor compensates the Doppler cursor corresponding to the centerline of the vessel. V(t) is obtained by using the function measuring Time Average Mean, (TAM). After extracting the TAM of the cycle, the Q is obtained based on the cross-section area, S (t), V(t) and θ, as in (3).

$$Q = \frac{1}{T}\int_0^T S(t) \cdot V(t) \cdot \tan\theta \, dt \tag{3}$$

IV. Experiments and Results

In order to quantitatively verify the effectiveness of the proposed method, we performed preliminary experiments using an ultrasound phantom containing an arterial model in which the pulsation and displacement occur and BASIS-1.

A. Experiment of Tracking the Center of the Blood Vessel

1) Purpose: The purpose of this experiment is to evaluate the proposed algorithm for tracking the center of the blood vessel.

2) Methods: We used a model for evaluating the pulse amplitude and displacement of an artery. The model consists of a mock body cavity model made of an agar phantom, stimulant blood vessel models made of silicon, a pulsative blood flow pump (Harvard Inc., stroke volume 15-100 ml, beating rate 10-100, flow volume 150-10,000 ml/min) and Coriolis flow sensor (Keyence, FD-SS20A, Resolution 10 ml/min). The agar phantom is often used in ultrasonic diagnosis experiments because the acoustic coefficient is similar to that in the human body [8]. In order to displace the vessel model, we recreate the displacement by direct acting actuator that has a piston motion in a cycle. Table I lists each parameter based on average of human body [9].

We performed tracking the center of the blood vessel and measured gap between the center of the vessel and the center of the US image. The initial position was set to within 5 mm from the center of the blood vessel model.

3) Results: Fig.6 shows the gap between the center of the vessel and the center of the US image in axis y.

Table I Parameters of the experimental model

Beating rate 1/min	Stroke volume ml	The cross-section area cm^2	Depth of the vessel model mm
60	40	1.32	50

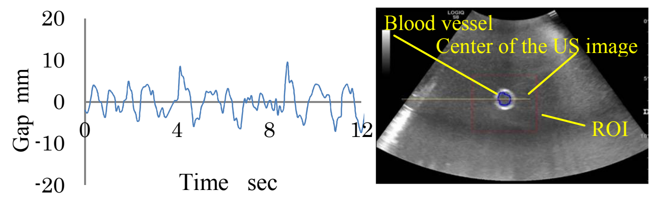

Fig.6 The gap between the center of the vessel and the center of the US image in axis y

We confirmed that the average tracking errors were 3.11mm (x direction) and 1.63mm (y direction).

B. Flow Volume Measurement Experiment

1) Purpose: The purpose of this experiment is to evaluate the blood flow measured corrected by proposed algorithm.

2) Methods: In this experiment, we also used the model mentioned in above Section A. We implemented the proposed algorithm to measure the blood flow in each angle between US beam and blood vessel ($\theta = 15, 20, 30$ deg). Also, the flow calculated based on the cross-section area and flow speed measured by using proposed methods was compared to the flow not corrected by the angle and the true value.

3) Results: As shown in Fig.7, measurement error of the blood flow by proposed method decreased 83.3% compared to that of not corrected at the angle of 15 deg. Also, proposed method could reduce the measurement error in each angle, as shown in Table II. We confirmed the effectiveness of detecting angle between US beam and blood vessel and correcting the blood flow based on the angle to measure the blood flow accurately.

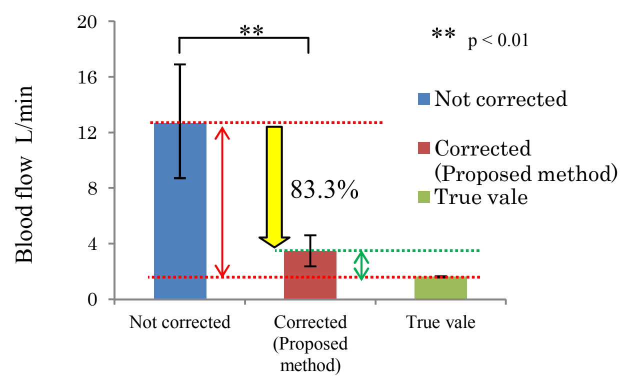

Fig.7 Result of the flow volume measurement (θ = 15)

Table II Measured blood flow in each angle

Angle θ[deg]	Not corrected L/min	Proposed method L/min	True value L/min
15	12.6	3.45	1.62
20	14.5	4.36	1.99
30	6.91	2.37	2.01

C. Experiment of Internal Bleeding Detection

1) Purpose: The purpose of this experiment is to evaluate the internal bleeding detection method based on measured blood flow by proposed algorithm.

2) Methods: In this experiment, we used a model with internal bleeding, as shown in Fig.8. First, the flow volume of the upside, downside are measured by proposed algorithm. Next, difference between the flow of the upside and downside (Measured internal bleeding) is calculated. Finally, existence and volume of the internal bleeding is detected based on the difference.

3) Results: Table III shows the detected volume of the internal bleeding by proposed method and algorithm. We confirmed that the proposed method could detect existence of the internal bleeding based on difference of flow volume between upside and downside. Also, we confirmed that the system could detect volume of internal bleeding within the average error of 2.41 L/min.

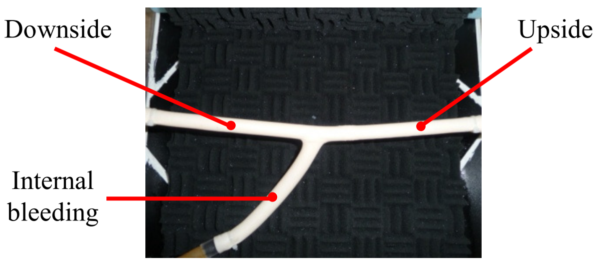

Fig.8 A model with internal bleeding

Table III Detected volume of the internal bleeding by proposed method (N=20)

Angle θ[deg]	True value L/min	Measured internal bleeding L/min	Error L/min
15	1.05	5.08	4.13
20	0.98	2.22	1.31
30	1.07	2.87	1.80

V. Discussion

The proposed method could improve the measurement accuracy compared to that from a manual measurement, as shown in Fig.7. Also, we confirmed that the method could detect the internal bleeding noninvasively by using blood flow measured US imaging device. From those points of view, the proposed algorithms would be effective as a platform of internal bleeding detection.

In emergency medical care, however, the target volume of internal bleeding should be within approximately 0.6-1 L/min. We considered two chief error factors of volume of internal bleeding: Image processing, Blood flow measurement.

As shown in Fig.6, the gap between the center of the vessel and the center of the US image in each axis was 3.11mm (x direction) and 1.63mm (y direction). The contour detection using a binarized image in this paper has to have the threshold level set to high to get a clear-cut outline of the contour. As this result, the contour was thicker compared to the true contour, and the threshold level misaligns the true center of the vessel and the measured center.

As shown in Table II, the average error of blood flow measurement was 85.7%. We considered the blood flow measurement error rate affected the error of volume of internal bleeding. In order to measure a flow volume and detect internal bleeding more adequately, we confirmed that the system needs accurate contour detection method, automated method adjusting controlling gain for tracking the center of the vessel and advanced correcting algorithm of measured blood flow.

VI. Conclusion

We proposed noninvasive internal bleeding detection method by using image processing under US cross-section image. We confirmed that the proposed methods could reduce the blood flow measurement error variation than manual measurement under cross-section image.

In clinical settings, however, the target volume of internal bleeding should be measured accurately. Therefore, the proposed algorithms need to be extended. As future work, the contour detection method and advanced correcting algorithm of measured blood flow have to be constructed. Then, we will extend the algorithms for real motion of an artery and perform experiments in clinical settings.

Acknowledgment

This research was supported in part by Waseda Institute for Advanced Study (WIAS), and Yokohama City University Medical Center in Japan and Nagoya University School of Medicine.

References

[1] S. Iwai, "Japan advanced trauma evaluation and care guideline," The Japanese association for the surgery of trauma, 2008, pp. 43–114.
[2] J K. Willmann, "Multidetector CT: Detection of Active Hemorrhage in Patients with Blunt Abdominal Trauma," American Roentgen Ray Society, 2002, pp. 179:437-444.
[3] FH. Miller, "An initial experience: Using helical CT imaging to detect obscure gastrointestinal bleeding," Clinical Imaging, Volume 28, Issue 4, 2004, pp. 245-251.
[4] K. Ito, et al., "Development of Adaptable RT Echo-Device Detecting Bleeding Source: BASIS-1", Society of System Integration, 2010, pp. 1153-1154.
[5] R. Chan, "A Variational Energy Approach for Estimating Vascular Structure and Deformation B-mode Ultrasound Imagery", Proc. of International Conference on Image Processing, 2000, Vol.1, pp. 160-163.
[6] A. Takemura, "Segmentation of Ultrasonic Images by Using Locally Adaptive Filter and Wavelet Analysis-Detection of Superficial Peripheral Vein by a High-Frequency Ultrasonic Equipment-", Journal of the institute of electronics, information and communication engineers, 2001, pp. 1452-1460.
[7] R. W. Gill, "Measurement of Blood Flow by Ultrasound : Accuracy and Sources of Error", Ultrasound in Med and Biol,1985, No.4, pp. 625-641.
[8] M. Fujii, "Noncontact Measurement of Internal Temperature Distribution using Ultrasonic Computed Tomography : The 2nd Report: Numerical Simulation and Experimental Measurement", 1994, pp 131-139.
[9] S. Gondo, "Bio-engineering", 1984, pp 56-57.