

BLOOD FLOW VISUALIZATION IN IMMERSIVE ENVIRONMENT BASED ON COLOR DOPPLER IMAGES

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Abstract— An accurate grasp of blood flow patterns in a human heart is important to evaluate cardiac diseases of patients. Doppler ultrasound method is widely used to visualize blood flow patterns and has obtained excellent results in diagnosis. However, the output from Doppler ultrasound method is usually represented as a two-dimensional image, though blood flow patterns have three-dimensional complex structure and change dynamically. Therefore, improvement of both data acquisition and data visualization techniques is indispensable to diagnosis of cardiac faculty. It is worth mentioning that visualization also dominates the level of understanding as data acquisition, because poor visualization ruins the value of the most accurate result of measurement as if it were nothing. The authors construct an interactive visualization system suitable for three-dimensional blood flow, utilizing the immersive projection display. With the developed visualization system, which possesses interactivity and a wide field of view, users can easily understand the state of entire flow, such as the occurrence of turbulence, and the patterns of blood flow.

Keywords— Heart, Blood Flow, Immersive Environment, Visualization, Color Doppler Image

I. INTRODUCTION

An accurate grasp of blood flow patterns in a human heart is important to evaluate cardiac disease of patients. At present, Doppler ultrasound method, which measures a velocity distribution of moving objects from a Doppler shift between a transmitted ultrasound wave and the reflected wave, is widely used to visualize blood flow patterns [1].

However, the output from Doppler ultrasound method is usually represented as a two-dimensional image on one cross section of a heart, though blood flow patterns in a human heart have three-dimensional complex structure and change dynamically. Therefore, to understand important features that reflect a sign of cardiac diseases, such as the region of mitral regurgitant jets[2], medical doctors are compelled to reconstruct a three-dimensional flow pattern from a number of two-dimensional color Doppler images in their minds. Added to this, because the reconstructed pattern is based on each doctor's subjectivity, a common recognition about a disease is difficult to be established between doctors. This fact disturbs smooth communication and discussion between doctors.

To overcome these inconveniences mentioned above, the authors consider that two problems have to be solved. The first is the method of data acquisition, and the second is the method of data visualization. For data acquisition, numerous attempts have been made till today. For example,

- Scanning a three-dimensional region[3]
- Knowing three components of velocity[4]

On the other hand, the importance of visualization is inclined to be overlooked. However, visualization also dom-

inates the level of understanding as data acquisition, because poor visualization ruins the value of the most accurate result of measurement as if it were nothing. The authors consider that the visualization methods must fulfill these demands: (1) stereo (three-dimensional), (2) interactive, and (3) wide, but not overcrowding.

An immersive projection display (e.g.[5]), which has been developed with virtual reality technology, is suitable for constructing the visualization environment mentioned above[6]. In immersive environment, a wide field of vision is provided to users. And immersion brings the sense of three-dimensional arrangement of visualized objects.

In this paper, the authors present development of the visualization system suitable for blood flow patterns, which are complex and time varying, in the immersive environment.

II. MEASUREMENT

The authors made a phantom model which imitates a blood vessel and a valve and measured pulsatile flow in the model, as a blood flow in a human heart, with Doppler ultrasound method[7].

The model is made of Plexiglas and consists of a cylindrical chamber (diameter = 50mm, length = 150mm) and an artificial valve. At the entrance of the chamber, 16 orifices (diameter = 4mm) are arranged in a radial pattern. These orifices generate uniformly distributed inflow into the chamber. The artificial valve is a porcine mitral valve (diameter = 31mm) and attached to a tapered adapter to absorb differences in diameter between the chamber and the valve. Fig. 1 shows the arrangement of the phantom model. Fig. 2 and 3 are photographs of the apparatus.

The process of the measurement is as follows:

1. Place an ultrasound sector-scan type probe at the top of Fig. 1.
2. Send cornstarch water periodically with a pulsed pump along the direction of arrows in Fig. 1. Systolic/diastolic time ratio is 1:2.
3. Scan the region of interest (ROI; dotted region in Fig. 1) and acquire a color Doppler image.
4. Rotate the probe around its long axis by some constant degree each and repeat processes 3-4.

Table I shows properties of the data acquisition environment.

The structure of the acquired data is described in polar coordinates. Each measured point is addressed by r, θ, ϕ , shown in Fig. 4.

According to the data acquisition method mentioned above, a velocity distribution on only one plane can be

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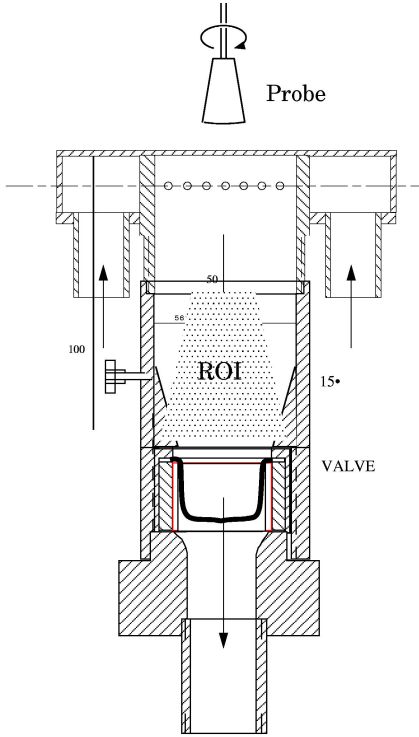


Fig. 1. Phantom model

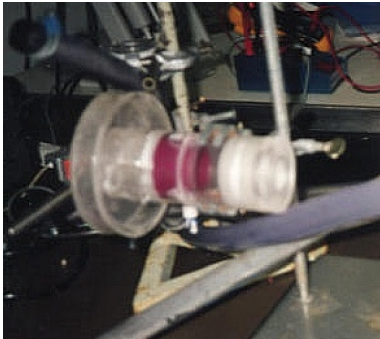


Fig. 2. Appearance of phantom model



Fig. 3. Artificial valve (left) and reservoir of water (right)

TABLE I

PROPERTIES OF DATA ACQUISITION ENVIRONMENT

Flow volume	16.3 (ml/s)
Center frequency of ultrasound	6.18 (MHz)
Number of frames/sec	26.6 (fps)
Total number of frames	53
Angle step of probe rotation	3 (deg)
Resolution of velocity	0.0268 (m/s)
Number of beams/plane	30
Number of samples/beam	164
Resolution of beam angle	0.66 (deg)
Interval of sampling points	0.308 (mm)
Maximum diameter of measured area	36 (mm)
Length of measured area	50 (mm)

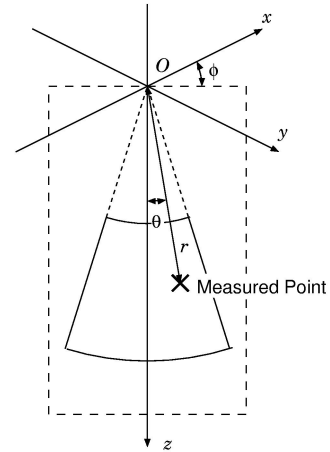


Fig. 4. Coordinates in measurement

obtained at one time. On the assumption that the flow is periodic, the authors treated the flow data acquired at the same phase of a cardiac cycle as the data acquired at the same time.

In this way, the velocity distribution of blood flow in three-dimensional space was acquired.

III. VISUALIZATION

A. Resampling

The acquired data are represented in polar coordinates, while a general graphic system uses Cartesian coordinates. Therefore, the authors resampled the acquired data at regularly spaced intervals along three orthogonal axes and obtained isotropic volume data. The size of the volume data is $32 \times 32 \times 48$.

B. Visualization Method

The authors propose several methods for indicating velocity of flow.

B.1 Given Structure

The confirmation that the data were acquired properly is important before applying other visualization methods. Therefore, the authors provide the visualization method that preserves the structure of raw data (Fig. 5). Each point is colored in the same manner as the representation

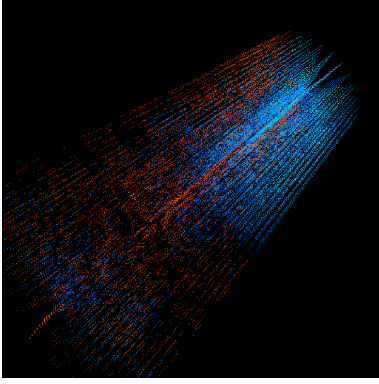


Fig. 5. Method 1: given structure

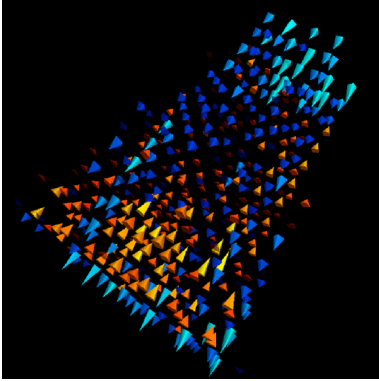


Fig. 6. Method 2: arrow

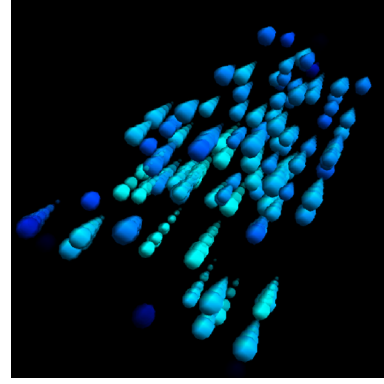


Fig. 7. Method 3: particle tracking

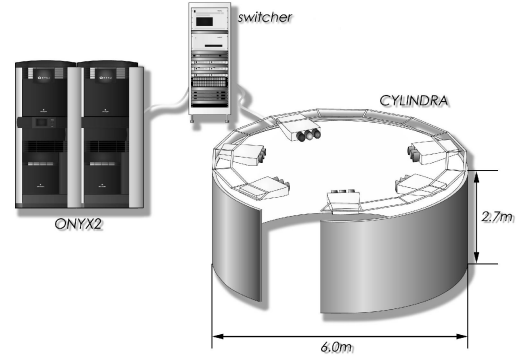


Fig. 8. Cylindrical immersive projection display: CYLINDRA

of traditional two-dimensional color Doppler images, that is, the manner that a velocity component toward or away from a probe is represented as color hue.

B.2 Arrow

To grasp three-dimensional blood flow patterns, users must change viewpoint, and thereupon the traditional one-to-one mapping between color hue and direction of flow cannot be established. Therefore the authors adopt an arrow symbol to indicate velocity of flow. The direction of arrow represents the direction of flow and the length represents the speed of flow, as in Fig. 6. Users can understand the flow direction intuitively because the direction of flow is directly visualized.

B.3 Particle Tracking

In this method, instead of drawing velocity of each position, a trajectory of an imaginary particle is drawn, as in Fig. 7. Users can observe the movement of a fluid element, which reflects the dynamics of flow more directly than the velocity vector field.

The movement of the particle i is calculated by the following equation:

$$\vec{x}_i(t) = \vec{x}_{i0} + \int_0^t \vec{v}(\vec{x}_i(t'), t') dt' \quad (1)$$

where $\vec{x}_i(t)$ is the position of the particle i at time t , \vec{x}_{i0}

is the initial position of the particle i , and $\vec{v}(\vec{x}, t)$ is the velocity of flowing fluid at position \vec{x} , time t .

C. Immersive Projection Display: CYLINDRA

For visualization, the authors use a cylindrical immersive projection display (Fig. 8) at Nara Institute of Science and Technology (Nara, Japan). The display system, named CYLINDRA, consists of 330 degrees cylindrical screen (diameter = 6.0m, height = 2.7m) and 6 front projection-type projectors [8]. Projected image is generated and controlled by SGI Onyx2 (CPU: R10000[250MHz] \times 8, Memory: 1.5GB, Graphics: InfiniteReality2 \times 2). Wearing liquid crystal shutter glasses, users are surrounded by a stereo image and can feel deep immersion into the virtual world.

D. User Interface

One of the advantages of immersive environment is to allow users to move freely in the virtual world. In order not to dismiss this advantage, the user interface suitable for immersive environment must be one without restriction, for example, cordless one. Therefore the authors use an infrared remote controller to transmit users' requests to the visualization system. With the infrared remote controller, users can translate, rotate and scale the visualized image and change the method of visualization without training.



Fig. 9. Panoramic view in cYLINDRA (constructed from six photographs)

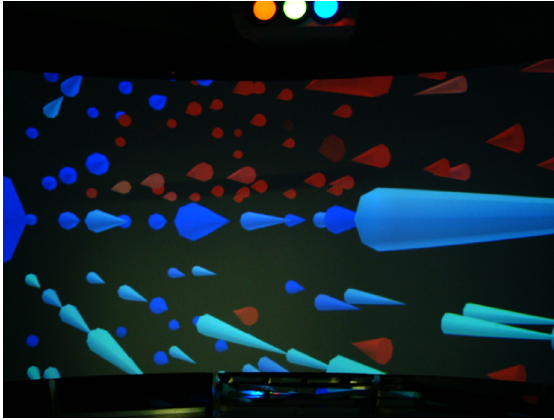


Fig. 10. Visualization in immersive environment: arrow

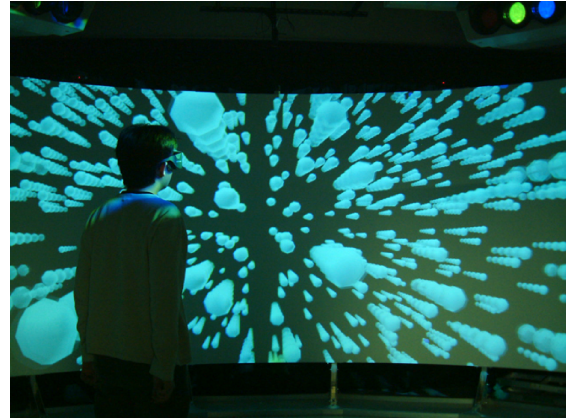


Fig. 11. Visualization in immersive environment: particle tracking

IV. RESULTS AND DISCUSSION

Fig. 9 shows the panorama image in the immersive environment. And Fig. 10 and 11 are scenes of visualizing and investigating the acquired data.

Using the immersive projection display, users could grasp the three-dimensional state of the entire flow, such as the occurrence of backward flow or turbulence, at a glance. In comparison with the flow visualization on monitor, the visualization in the immersive environment makes it easy to grasp the structure of blood flow patterns with a help of a sense of distance.

However, to observe the details of flow patterns, the density of information increases even if immersive projection display is used. Thereupon users cannot observe the internal flow because of the strong occlusion. To solve this problem, the visualization needs to provide users with the function to eliminate surroundings of the region of interest, or to obtain a cross sectional image. To fulfill these demands, the authors have to develop an intuitive user interface that allows users to indicate a region or a plane in three-dimensional space.

And the interactive change of a viewpoint sometimes makes users lose a sense of direction. To offer an overlook figure helps users understand the configuration of the flow more clearly without losing a sense of direction.

V. CONCLUSION

In this paper, the authors presented the development of the visualization system suitable for blood flow patterns in

the immersive environment. The state of entire flow, such as the occurrence of turbulence, and the patterns of blood flow can be understood easily with the developed visualization system. In the meantime, some new problems, especially concerned with a man-machine interface, occurred. The future task is to find solutions to these problems and to enable to grasp the detail of complex three-dimensional flow in immersive environment.

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