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Quantitative Velocity Estimation in Steady Flow by Image ProcessingTechnique

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Introduction

To estimate quantitative velocity in a fluid flow, various techniques of flow visualization are used to study VAD(Ventricular Assist Device) flow patterns. More quantitive investigations are performed with Laser Doppler Anemometer(LDA) and Hot-wire Anemometer and Image Processing Technique[1]. Velocity is one of the most commonly measured for flow characterization. However, measuring velocity parameters by LDA has great disadvantage that velocity can only be measured at one particular location at a time. Flow pattern images can be also used for the velocity measurement through correlation function, but its image processing is inefficient and expected to be improved.

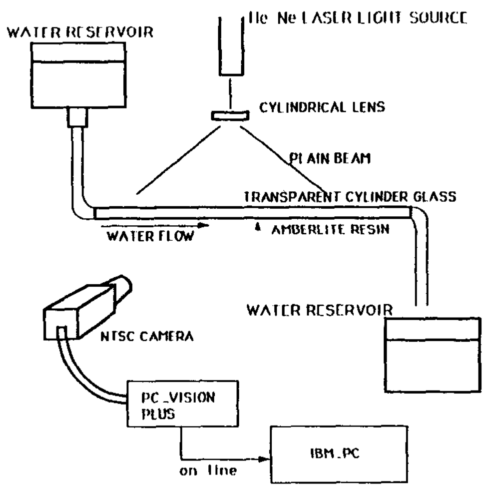
We simplified the ventricle to a simple glass tube model and calculated the velocity field of the two sequential images captured from a simple experimental system which causes steady fluid flow. The velocity distribution calculated by the image processing technique informs the relative velocities of small windows selected manually in order to investigate the optimal velocity distribution.

We obtained quantitative values of these velocities through comparing the velocities of the whole image with physical values of the velocities calculated by a simple fluid dynamics equation, and we evaluated the velocity distribution physically with the directional arrows and the calculated absolute values.

Methods

Flow Visualization

Experiments were performed with a steady fluid flow tester shown in figure1. In order to observe the flow patterns induced by the tester, polystylene particles (IRA 904, Amberite ion exchange resin, Rohm & HAss Co., Philadelphia, PA), less than 100 um, was suspended as scatterer, and through a cylindrical lens for the planar irradiation, He-Ne laser light source illuminates the transparent cylindrical glass tube which is the passway of the flow. Water is used as test flow.



<figure 1> Schematic diagram of the steady flow tester

The fluid flow was made with the tester in several conditions. We have experimented at the total height of the water reservoir, 40cm and 60 cm, and obtained the flow in two different speeds respectively. The physical velocities are calculated by the fluid dynamics equation with these conditions respectively.

The two sequential images were taken by an NTSC_type video camera (33 Hz) connected to an image grabber PC_VISION PLUS and stored into the IBM_PC with time interval of 1/33 second. These sequential images are transferred to VAX 11/750 to be processed by the Gould image processor IP8500.

Image Processing Technique

The boundary of flow tube is segmented through interactive process in order to find flow region. From two sequential images, optical flow is calculated by the Kalman filtering method with the motion constraint equation of brightness function f(x,y,t), which is known to have better performance than existing gradient-based algorithm[2,3,4].

With the equation

$$-\frac{\partial f}{\partial t} = \nabla f \cdot \mathbf{u}$$
$$f = f(x,y,t)$$
$$\mathbf{u} = (u,v) \quad \text{------------------ (1)}$$

a pixel velocity is estimated by combining the average velocity of neighboring pixels and the velocity observed at the pixel. **u** (u,v) is calculated iteratively with the Kalman filtering method and using the generalized least square error method (GLSE) in the observed part, the estimated part of the velocity approaches to more accurate values. Furthermore, improved gradient measurement techniques are adopted; the extrapolated frame difference (EFD) as temporal gradient instead of frame difference and the motion compensated interframe average for spatial gradient [5].

The combination of the above methods has been known to show fast convergence and small steady state error. These calculations are performed on VAX 11/750 and Gould image processor IP8500. The block diagram of the image processing technique is shown in figure2.

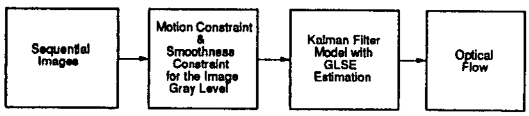
Physical Velocity Calculation

We have calculated the theoretical value of the velocity distribution for the experimental condition with the fluid dynamics equation [6];

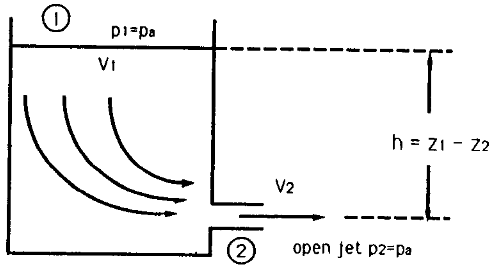
$$\frac{p_1}{\rho} + \frac{1}{2}V_1^2 + gz_1 = \frac{p_2}{\rho} + \frac{1}{2}V_2^2 + gz_2$$

where $g = 9.8 m/sec^2$ ———— (2)

We assume that the pressures p_1 and p_2 have atmospheric value, or $p_1 = p_2 = p_a$, that the cross-sectional area of the water reservoir is much greater than the area of the glass tube of the water, and that the flow is under steady frictionless condition. And we conclude that the velocity of the water can be calculated by the equation,



<figure 2> Block diagram of Image processing technique



<figure 3> A simplified model for calculation of steady flow velocity

$$V_{cal} = \sqrt{(2gh)} \qquad \text{-----------------} (3)$$

where h is the total height of the water from the center line of the cylindrical glass tube. Figure 3 shows the schematic model of the tester for the calculation of velocity.

Results and Discussion

We obtained the flow pattern in the cylindrical glass tube of water grabbed in the steady state of the flow with a video camera. And from the equation (3), we obtained the fluid average velocity absolute values, 10 cm per 1/33 second with the height of the water reservoir 60 cm, and 8.5 cm per 1/33 second with the height 40 cm.

From comparison of the velocity field distribution arrows and calculated physical velocity, the absolute values of the velocity arrows can be taken. In the case of high speed, calculated optical flow may be meaningless because two sequential images have no correlation and the motion constraint is violated. Therefore, comparison of the calculated velocity field with the measured data by other method such as LDA and Hot-wire Anemometer and also high speed video camera system are needed.

In this paper, the feasibility of the physical relation between the calculated velocity from the fluid dynamics equation and the measured one is tested.

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