XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

VELOCITY FIELD MEASUREMENT FROM IMAGE SEQUENCES

S. Ogata [1] ***and K. Saza*** [2]
[1] Kyushu Institute of Technology, Iizuka, Fukuoka 820-5802, Japan
[2] NTT Kyushu, Nagasaki, Japan

Abstract: We have improved a spatio-temporal correlation method to obtain velocity field from dynamic image. The new method can specify a certain image frame out of many sequential frames of a moving object and determine its 2-D velocity field on the basis of the specified frame. In addition, it enables us to avoid an edge effect of velocity field which appear at both ends of image row. The improvement has enhanced reliability and reduced computational time compared to other conventional methods.
Keywords: velocity vectors, dynamic image, spatio-temporal correlation

1 INTRODUCTION

The trajectory of moving objects has long been determined using two or three frames out of many image sequences as used in matching and gradient methods [1],[2]. Different from these methods, the spatio-temporal correlation method [3],[4] uses whole image sequences for motion analysis. It shows higher temporal resolution compared to other conventional methods in the case of a steadily whirling object with stationary illumination. Its application is however very limited due to its two defects, i.e., edge effect and prolonging of velocity vectors(optical flow) over the entire image frames, so that it is still in an early stage of the application.

In this paper, we improve the conventional statio-temporal method and demonstrate how to cancel edge effect and prolonging of velocity vectors, and then apply it to a non-steady motion and non-solid object with a little allowance.

2 SPATIO-TEMPORAL CORRELATION METHOD(STC)

2.1 Conventional spatio-temporal correlation method(CSTC)

Fig. 1 shows an image sequence consisting of M×N of frame size and L of frame number. In a frame, let take 3 [pixel] × 3 [pixel] of small segment out of M×N pixels of the frame as shown in the lower right of the figure with an arrow. Then, the velocity vector of the center pixel 0 is obtained by taking correlation between the 0^{th} pixel and other eight neighboring pixels (pixels k,k'; 1,2,3,4).

When a moving object passes through these eight neighboring pixels, the time series of the brightness values of the 0^{th} pixel and those of k and k', which are in a symmetrical direction to the 0^{th} pixel with respect to the moving object (e.g. forward: 4' → 0 → 4 or backward: 4 → 0 → 4'), show similar change in brightness values with a time lag needed for the movement of the object.

The moving direction is determined by calculating the cross-correlation between the time series of the brightness values of the 0^{th} pixel and those of the neighboring pixels and by finding the neighboring pixel with the highest correlation value and its sign (plus or minus)of the lag time.

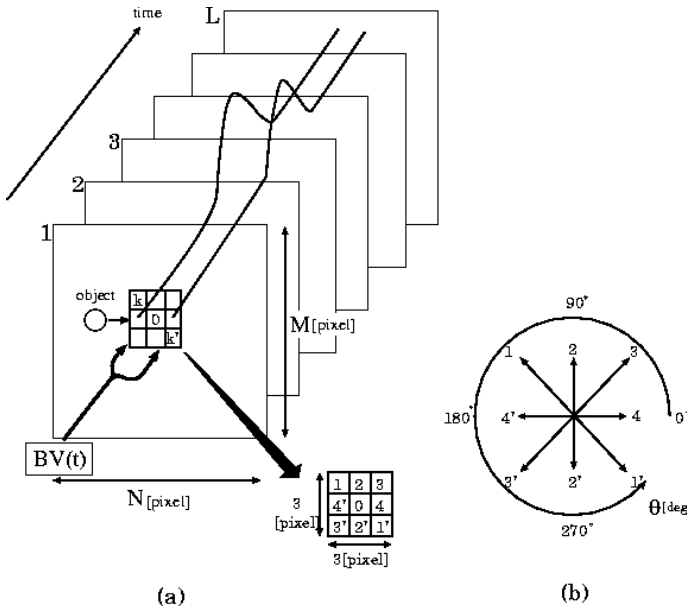


Figure 1. Basic idea of STC

When the maximum correlation occurs at k=4, e.g., the direction of the movement is forward 4' →0 →4 with a positive lag time and backward 4 → 0 → 4' with a negative lag time (refer to Fig. 2). The moving speed *V* is estimated by dividing the distance between the 0^{th} pixel and the pixel of the maximum correlation by the lag time.

$$V = \frac{d_k}{t_0}[pixel / Frame] \qquad (1)$$

In practice, the correlation function is defined by a product of the paired cross-correlation functions as follows:(notation of symbols used in the equations are listed below Section 5)

$$M_m(t) = \sum_{t=0}^{T'-1} | BV_0(t) - BV_k(t+t) | \qquad (2)$$

$$M_0{}^k(t) = \begin{cases} \dfrac{1}{M_m(t)} & (M_m(t) \neq 0) \\ 1 & (M(t) = 0) \end{cases} \qquad (3)$$

$$g_0{}^{k,k'} = \sqrt{M_0{}^k(t) \times M_0{}^{k'}(-t)} \qquad (4)$$

$$T' = T - 2 \times Maxt \qquad (5)$$

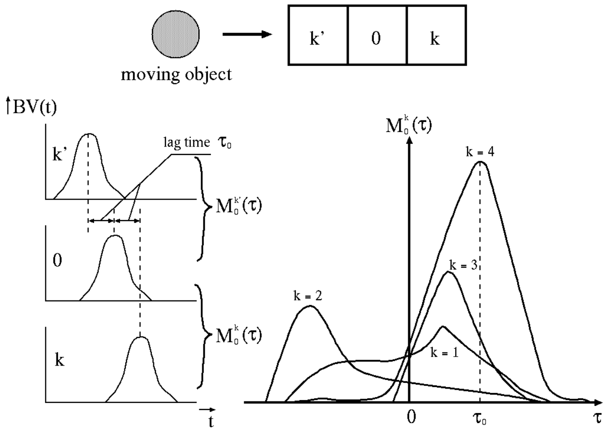


Figure 2. Cross correlation function in STC

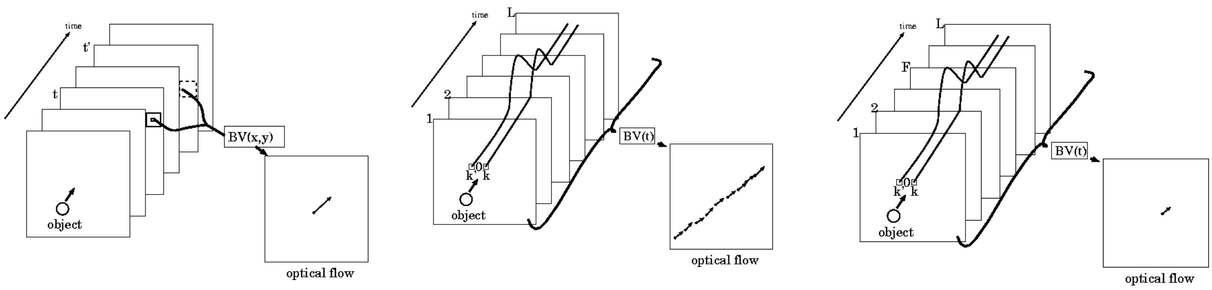
In this study, however, we choose 5 [pixel] x 5 [pixel] as a neighboring segment size considering the magnitude of the detectable speed of a moving object. It stretches speed to 2.0 [pixel/Frame] for horizontal and vertical movements, and twice that of 3 [pixel] x 3 [pixel].

2.2 Improved spatio-temporal correlation method (ISTC)

In CSTC, prolonging of velocity vectors is unavoidable owing to its analytical basis. For instance, Fig. 3(d) shows a prolonged velocity vectors obtained from the sequential image frames of a human object (including Fig. 3(a)-(c)). Different from CSTC, the present method (ICST) can specify an appropriate frame to visualize velocity vectors on that frame although the calculation uses whole frame sequences. (refer to Fig. 4(c)) With this improvement, we can avoid edge effect, prolonging of velocity vectors and even occlusion by others objects in a scene.

(a) 10th frame (b) 50th frame (c) 97th frame (d) prolonged flow

Figure 3. Image frames of human object and prolonged flow of velocity vectors (CSTC)



(a) Matching method (b) Conventional STC (c) Improved STC (this work)

Figure 4. Basic Ideas of matching method and two spatio-temporal correlation metods

3 MEASUREMENT AND CALCULATION

3.1 Detection of pixels connected with moving object in ISTC

In CSTC, the velocity vector of a pixel in focus is measured when a moving object passes through its neighboring pixels. A change appears in brightness-values time series of that pixel when the moving object passes on it, and the time series shows such a pattern as “background →moving object → background” as shown in Fig. 5.

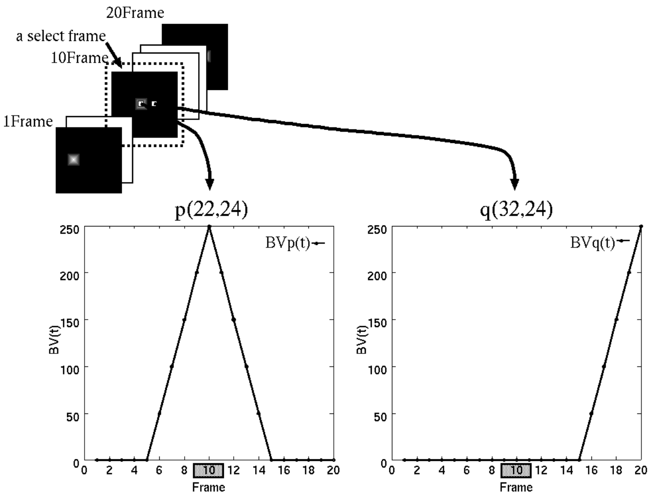


Figure 5. Recognition of moving pixel

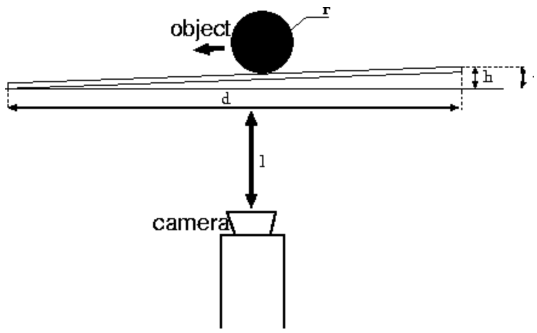


Figure 6. Experimental apparatus with Rotating cylinder and CCD camera

This means the time series takes either background or moving object. In the left figure of Fig. 5, e.g., the brightness values of the moving object appear from the 6th frame to 14th or else background. We can specify a frame except the first and last frames to avoid the edge effect. This enables us to observe the temporary change of the moving object using different specified frames.

3.2 Application to moving objects

As an attempt to ensure the present method's capability, we applied it to a non-steady motion with slightly increasing velocity from 3.33 [m/s] to 3.51 [m/s] for 2 [s] and a human object an example of non-solid object (refer to Fig. 3). Fig.6 shows the experimental apparatus with a rotating cylinder and video camera (r=50 [mm], h=5 [mm], l=2.0 [m], d=180.0 [cm], theta=0.16 [degree]).

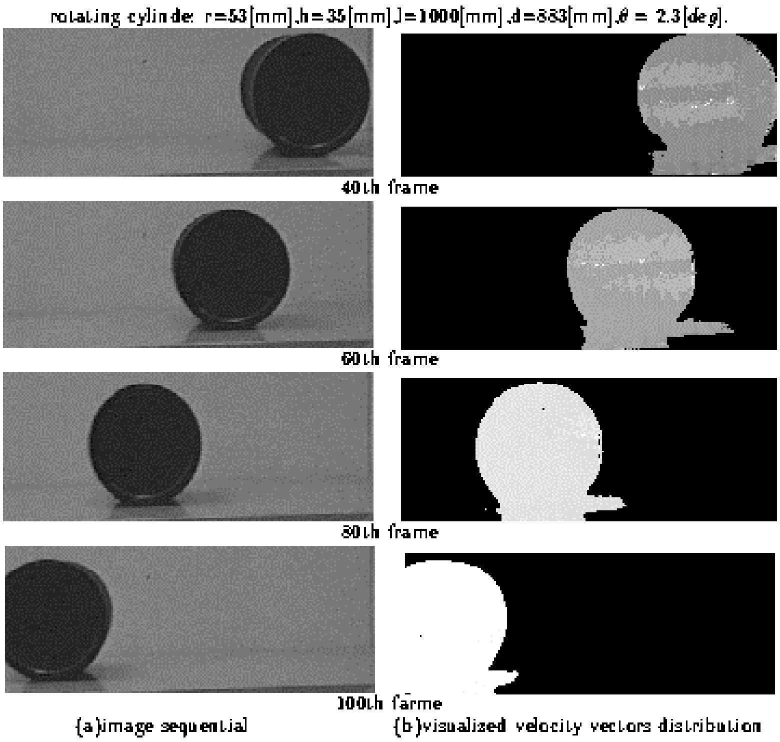


Figure 7. Results of motion analysis for image frames specified appropriately

As will be seen later, the cylinder begins to move with an initial velocity from right to left on a flat plate. Its actual motion is unsteady in a strict sense and being accelerating slightly although STC's theory is based on steady motion.

Fig. 7 shows the image sequences of the rotating cylinder(left column) and its velocities distributions (right column) visualized with 8 bits of gray levels in lateral direction. Actual motion accompanies with a rotation of the cylinder, and the cylinder is being accelerated including a part of shadows as seen in the figures. Although the object cylinder is moving laterally with rotating motion, its rotating effect isn't shown in the velocity distributions because no change of brightness values by rotation was observed here.

The result of the analysis for the rotating cylinder is shown in Table 1.

Table 1. Comparison between ISTC and other conventional methods for the image sequences of a moving cylinder.

Method	number of velocity vectors [pixel]	most probable direction [degree]	Most probable Velocity [pixel / frame]	cpu time [ratio]
ISTC	1036	180	1.00	15.5
CSTC	1338	180	1.00	15.7
Matching	2088	180	1.00	231.1
Gradient	3145	201	1.54	1.0

ISTC; Improved Spatio-temporal Correlation Method(present method)
CSTC; Conventional Spatio-temporal Correlation Method [1], [2]
cpu time is normalized by the gradient method

Fig. 8 shows an accelerating process of the rotating cylinder. The frames were chosen every 10 frame from the 40^{th} to 100^{th}. The velocity[m/s] was obtained through transformation of the magnitude of the flow[pixel/Frame], the actual size of the pixel (5.57×10^{-2} [m/pixel]) and 30 of the frame rate [Frame/s].

As shown in Figs. 7 and 8, the velocity vectors of the moving object with rotating and accelerating motions were detected successfully though ISTC which is based on a steady velocity around neighboring segment. This indicates that ISTC results in the reasonable velocity vectors from the image sequences of the moving object being slightly accelerated with a little allowance.

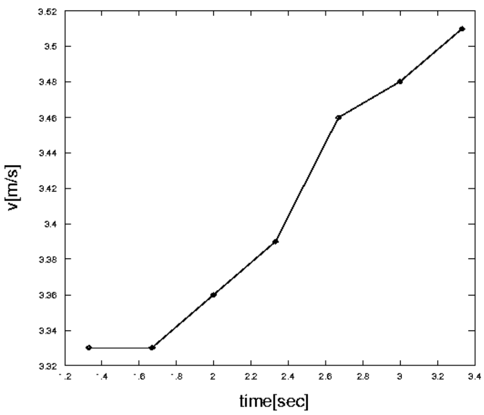


Figure 8. Change of cylinder's velocity

3.3 Consideration on noisy image sequences

Noise reduction is needed for image sequences because some kinds of noise are included in images through a CCD camera and AD converter when images are taken into a personal computer. If the brightness values of image sequences change moderately, spatio-temporal smoothing can be done using a filter with parameters m=n=p=3.

$$BV_{s(x,y,t)} = \frac{1}{mnp}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\sum_{k=0}^{p-1} BV_f(x+i, y+j, t+k) \qquad (3)$$

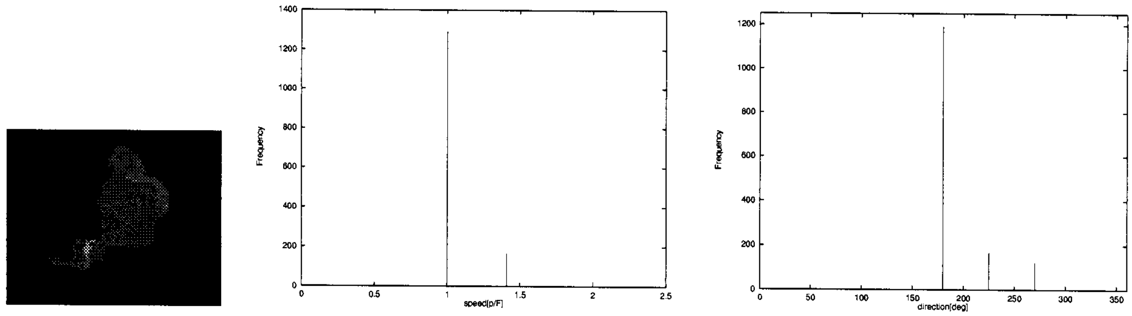
3.4 Image level compression for improving image pixel detection

In ISTC, the accuracy of velocity vectors detection depends on if the computer can recognize the moving pixels from others. It was found that an image level compression was very effective for ISTC and that the compression rate from 8 bits to 5 bits was sufficient to avoid mis-detection. If the brightness value BV(t) is within a range shown below, it is defined as the background pixel, i.e.,

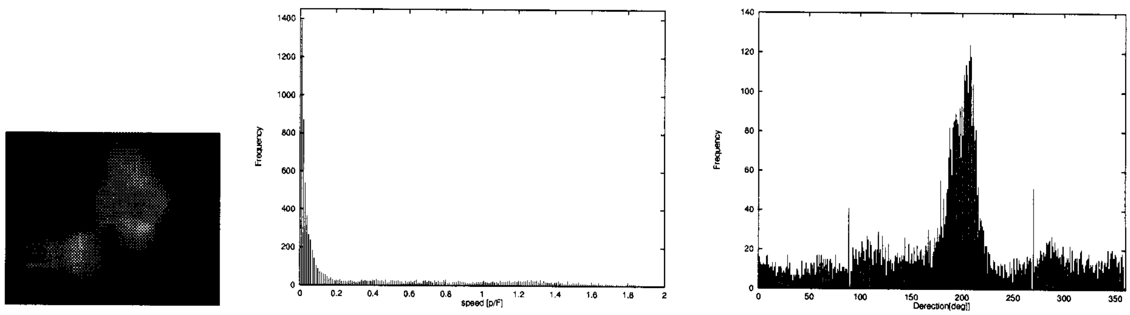
"brightness value in background – noise level "
< BV(t) <
"brightness value in background +noise level"

4 VELOCITY VECTORS DETECTION FOR HUMAN OBJECT

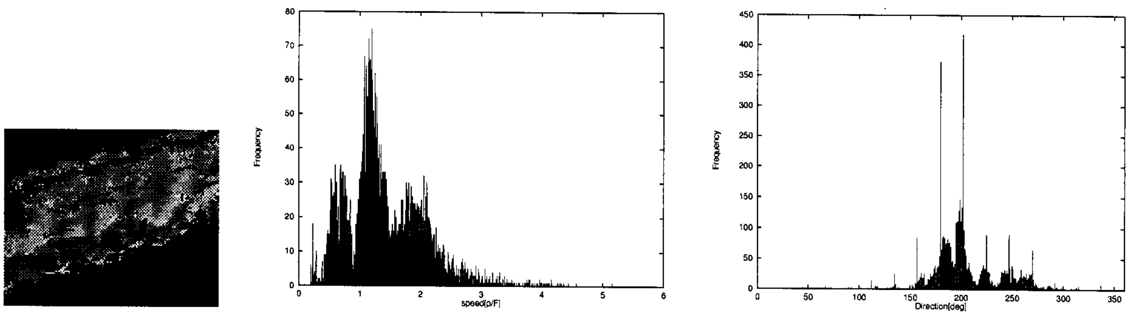
The accuracy of the velocity vectors detection of ISTC depends on the number of frames, frame rate and bits compression. To compare with other methods, we chose these parameters appropriately and obtained velocity vectors of the human object shown in Fig. 3. In the matching and gradient methods, velocity vectors were obtained using the 50th and 51st frames, while those of ISTC were done from whole the image frames. As velocity vectors distribute to some extent, we show the results using two kinds of histograms. To visualize the distribution of velocity vectors, we transformed its magnitude from 0 to 3.0 [pixel/Frame] into 0 to 255 of gray level.



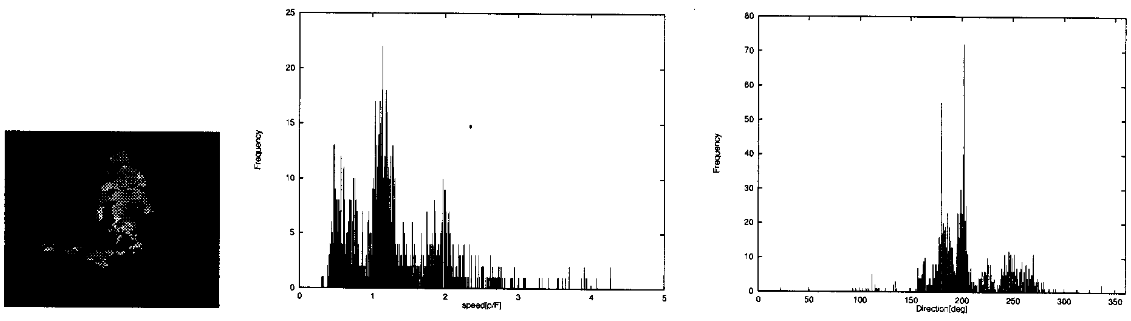
(a)Mathching method(15 × 15[block]detected)



(b)Gradient method(15 × 15[block]detected)



(c)CSTC(5x5, 16 neighbors used)



(d)ISTC(5x5, 16 neighbors used)

(a) Velocity distribution (b) Histograms of velocity (c) Histograms of direction(right)

Figure 9. Comparison of velocity vectors for four methods

The results are shown in Fig 9. Table 2 shows the comparison of the four methods. Here, cpu time was also normalized on the basis of gradient method. In the gradient method, the first peak in the velocity distributions appeared around 0 [Pixel/Frame], and the second peak around 1.3 [pixel/Frame]. We listed the figure of its second peak in table 2 because the first peak indicates zero velocity, and obviously doubtful. Except the gradient method, the main peak of the velocities distributes around 1 [pixel/Frame] in other three methods, while that of the direction concentrates all around 200[degree], i.e., a little larger than that of the experiment.

The walking speed of the human object in Fig. 3 can be estimated by assuming the height of the person as 1.7 [m] which corresponds to 56 [pixel] in the image. The estimation by ISTC resulted in 3.69 [km/hr] at 30 [F/s] of frame rate. This figure seems quite reasonable since ordinary people's walking speed is about 4 [km/hr], and other three methods also showed approximate figures. This indicates that ISTC can be applied to the motion analysis of non-solid objects with a little allowance.

Table 2. Velocity vectors of human object walking moderate speed

Method	Number of Detected vectors [pixel]	Speed in Frame [pixel/frame]	Speed [km/h]	direction [degree]	cpu time [ratio]
ISTC	1147	1.14	3.69	202	20.0
CSTC	5366	1.20	3.89	202	30.0
Matching	1481	1.00	3.24	180	1000.0
Gradient	3145	$1.32(2^{nd})$	$4.28(2^{nd})$	208	1.0

5. CONCLUSIONS

The present study is summarized as follows:

1. Problems of the edge effect and prolonging of velocity vectors of moving object can be eliminated by avoiding the top and end frames as a specified frame and using the change in pixel's brightness values in the specified frame.
2. The statio-temporal change of a moving object is visualized by obtaining velocity vectors of many image frames at different times.
3. The improved method can be extensively applied to non-steady objects and even non-steady, non-solid objects with a little allowance.

NOTATION OF SYMBOLES

$M_m(t)$: Similarity between different brightness value sequences.

$M_0{}^k(t)$: Cross-correlation function

$T' = T - Maxt$: Number of frames of moving image

$Maxt$: Maximum lag time specified by analyst

REFERENCES

[1] S.T. Barnard and W.B. Thomson, Disparity analysis of image, IEEE Trans. Pattern Anal. Mach. Intell., PAMI-2, **4**, (1980) p. 334-340.
[2] L. Dreschler and H.H. Nagel, Volumetric method and 3-D trajectory of a moving car derived from monocular TV frame sequences of a street scene, Comput. Graphics Image Process, **20**, (1982) p. 199-228.
[3] H. Miike, Y. Kurihara, K. Koga and H. Hashimoto, Velocity-field measurement of a vortex by dynamic image processing, Jpn. J. Appl. Phys., **25** (5), (1986) L409-L412.
[4] H. Miike, H. Hashimoto and K. Koga, Velocity-field measurement by pixel-based temporal multi-correlation analysis of dynamic image, Trans. IECE, **E69** (8), (1986) p. 877-882.

AUTHOR: Sumitoshi OGATA, Kyushu Institute of Technology, Iizuka, Fukuoka 820-5802, Japan, Phone int +81 948 29 7715, Fax +81 948 29 7709, E-mail: ogata@ces.kyutech.ac.jp