

# Real-Time Measurement of Velocity Distribution of Water Flow

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## Abstract

This paper describes a system which enables a real-time measurement of 2-D water flow field. One distinctive feature of our system is that velocity vectors of water flow are obtained from the movement of tracer particles at video rate. In order to enable a fast measurement a real time video processor and two Digital Signal Processor(TMS320C25) are employed. The real-time video processor extracts contours of tracer particles in order to reduce the amount of image data to be processed. And two DSP(Digital Signal Processor) analyse the correlation of every tracer particle in the consecutive two images to obtain the velocity distribution of water flow.

## 1. Introduction

Recently, some system have been presented to obtain two-dimensional velocity distribution of water flow. While scanning of some velocity sensor is often used to obtain whole 2-D velocity distribution, scanning needs much time and some attentions. Whereas, one technique to use an image processor has some distinctive advantages. One advantage is that instantaneous 2-D velocity distribution can be obtained without any contact with flow field. When we use this technique, tracer particles are scattered into the water. And one TV camera observes the trace of particle motion. After that analysis of the consecutive two or more frames of image data gives 2-D velocity distribution of the water flow. But an important problem still remains to this technique. Even for the analysis of two frame images, more than thirty seconds are required.

Therefore, images of 2-D flow are once recorded into video recorder. After that those images are replayed and images are analysed spending a lot of time.

In this paper, we present a system which enables a real-time measurement of 2-D flow pattern. Using our system, velocity vectors are extracted from the particles images at video rate. Therefore, operators can be free from recording and playback task.

Our system consists of one TV camera, a real-time video processor and two Digital Signal Processor(TMS320C25). Water flow is visualized with paraffin particles and movements of these particles are observed by TV camera. After the images of particles are obtained by TV camera, the real-time video processor digitized the image signals to binary ones and detects the contour of the particles.

One distinctive feature of our system is that the real-time video processor extracts the important information from the video signals and reduce the amount of image data in order to enable a video rate processing.

Another feature of our system is the employment of two DSPs. Following the data processing with real-time video processor, a real-time image analysis is executed with two DSPs. Two DSPs perform data processing of consecutive two frames of data alternatively. One DSP process the 1st and 2nd frame data. And the other DSP process 2nd and 3rd frame data. Labeling program which runs on DSP analyses the connection of contours of tracer particles. And one-to-one correspondence of tracer images is analysed by DSP to obtain movements of traces. The employment of real-time image processor and two DSP enable a real time measurement of water flow. The velocity data is transferred to a personal computer and displayed on the monitor graphically.

## 2. Setup of measurement system

The setup of a measurement system developed here is shown in Fig.1. Paraffins are scattered on the water as tracer particles whose diameters are 1~2 mm. Since tracer particles flow with water, water flow can be obtained observing movements of tracer particles.

The TV camera samples images of tracer particles. The video signals of each pictures are converted into binary signals by a real-time video processor. In order to obtain the essential information, a real-time video processor detects the contour of the particles. The contour data of the particles are stored on a temporary memory. Receiving data about particles from the temporary memory, DSP calculates velocity vectors. After that, the data of velocity vector are transferred to a 16-bit computer, and this 16-bit computer displays results graphically. It is important to note that all these procedure are carried out on the real-time base within one scanning cycle.

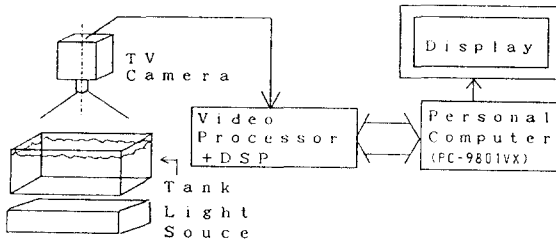


Fig. 1 Measuring System

## 3. Contour extraction

Our system developed employed a real-time video processor, which extract the important information from the video signal and reduce the amount of image data to be processed. Owing to this real-time video processor, fast sampling and effective usage of memory become possible. Block diagram is shown in Fig.2.

First, this real-time video processor digitize the video signal to one bit with 512\*256 pixel per a frame.

Next, from these images, contour extraction of tracer particles is performed.

A timing chart of the real-time video processor is shown in Fig.3, where the signals are shown during the period of the  $m$ -th horizontal scanning. When the rise of binary video signal is detected (at P1 in Fig.3), edge detector activates edge signal and the output  $n1$  in counter 1 is stored in the memory. Moreover, when the fall of binary video signal is detected (at p2 in Fig.3), edge detector activates edge signal and the data  $n2$  in counter 1 is stored in the memory. Since the data in counter 1 is stored when edges are detected, data in the memory

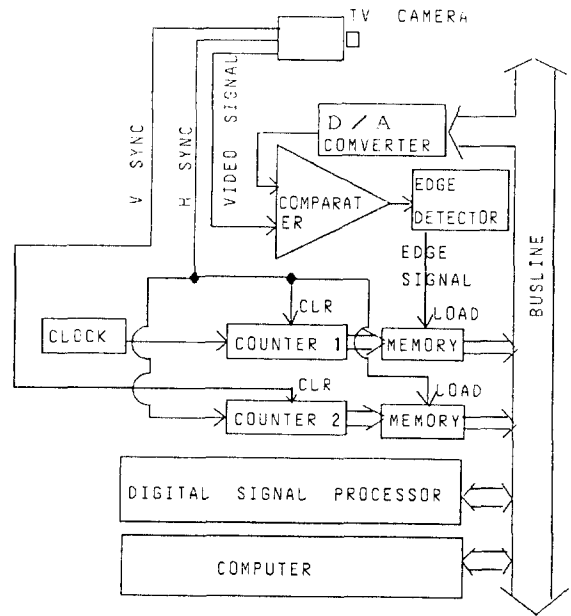


Fig. 2 Block diagram

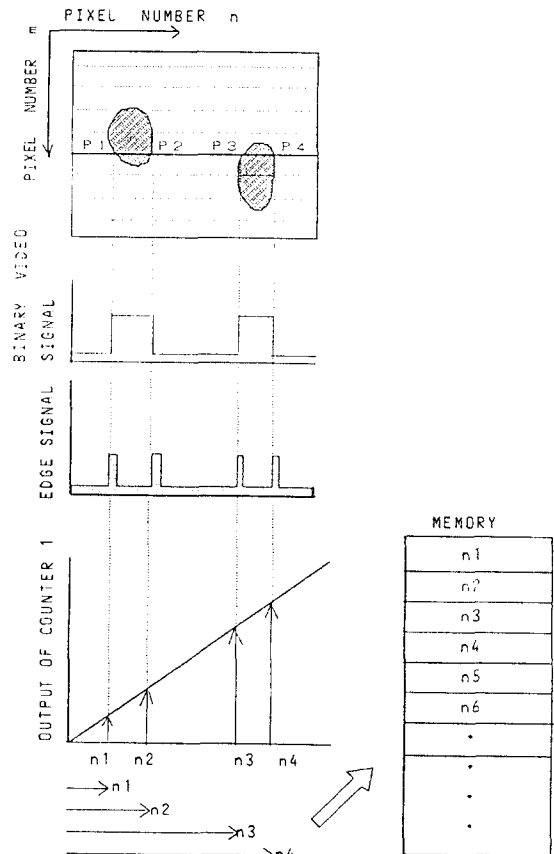


Fig. 3 Timing chart

corresponds to the contour of particles. Data  $m$  in counter 2 corresponds to the vertical coordinate.

Just after one vertical scanning on TV camera has finished, all data stored in the memory are transferred to DSP.

#### 4. Extraction of velocity vector

In our system, two DSPs are adopted in order to enable a real-time measurement. Fig.4 indicates the flow chart of DSP's task. Immediately after receiving the

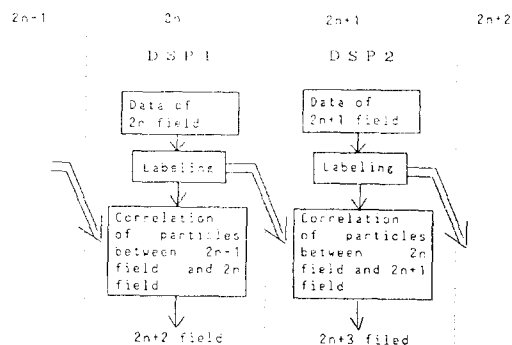


Fig. 4 Flow chart of measurement

contour data detected by real-time image processor, one DSP starts a wellknown labeling procedure to analyse the connection of contour data. The particles are ordered considering the position and shape. In addition, labeling procedure gives us projected area, gravity center, width and height of every tracer particle.

DSP also analyses one-to-one correspondence of tracer image in the consecutive two image data. Two types of methods to analyse one-to-one correspondence are adopted in our system. First method concerns the shapes of every tracer. Wherears, second method are concerns disposition, area and gravity center of every tracer.

The results of one-to-one correspondence are sent to a personal computer. This personal computer display the result graphically.

##### 4.1 Labeling

One labeling procedure is adopted in order to allocate label numbers to every tracer particle. Since fast data processing is desirable in our system, a relatively simple labeling procedure is adopted. To every image of the tracer, a

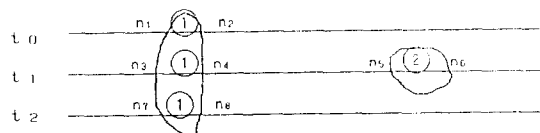
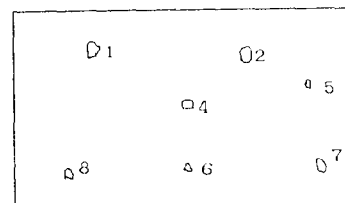


Fig. 5 Labeling procedure

label number is allocated as shown in Fig.5.

Our labeling algorithm can be briefly explained as follows. Consider that image data are obtained like Fig.5. At  $t_0$  DSP receives a pair of pixel number  $[n_1, n_2]$ . Then DSP allocate the label number 1 to this pair. At  $t_1$  DSP receives two pair of pixel number  $[n_3, n_4]$  and  $[n_5, n_6]$ . After examing the connection these pairs. DSP allocate label number 1 to the  $[n_3, n_4]$  and label number 2 to the  $[n_5, n_6]$ . At  $t_2$  DSP receives one pair of pixel number  $[n_7, n_8]$ . After examing the connection, DSP allocate label number 1 to this pair. And label number 2 is determined. Repeating the above procedure, label numbers are allocated to every particle images. And also, contour data of each particle is tabled onto the DSP memory. Furthermore, surrounding length, projected area width and height of every tracer particle are also tabled

##### 4.2 Analysis of one-to-one correspondence

In our system, two types of analysis of one-to-one correspondence are adopted. The first method concerns differences of the shape of every tracer. Therefore, the first method can be applied in a case where shapes of tracers are unequal and the total number of tracers are less than one hundred. Since an algorithm of the first method is relatively simple, a real-time measurement is possible. The second method concerns arrangements of neighbouring tracers, where geometrical shapes of tracers are not significant.

(method 1)

Fig.6 explains method 1. Sampling cycle of TV camera is 1/60 seconds. Therefore, we consider that movements of particles are so small that particle i in the first field can be found in the neighbouring region in the 2nd region. DSP check the neighboring particles a~e using the contour data in order to find the particle i in the second field. Differences of shapes of tracers can be evaluated by the following equation (see Fig.6).

$$E = \sum_{k=1}^{max(m, n)} |L_k - L'_k| \quad (1)$$

where  $L_k$  and  $L'_k$  are width of tracer particles.

(method 2)

We concern the case that deformations of the geometric arrangement of tracers are small between sampling period. In Fig.7 one typical example of such a case is shown. Here, we consider the case where particle i in the first field moved to particle j in the second field. Geometric arrangement of neighboring particles encircled in the first field and that of neighboring particles encircled in the second field are almost

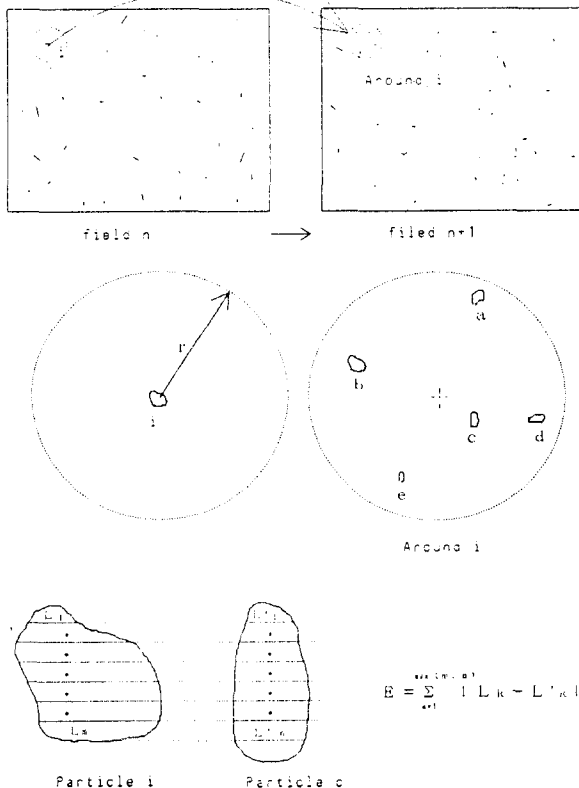


Fig. 6 Method 1

same. Therefore, movement of every tracers can be obtained by correlating the geometric arrangement of neighboring particles. In order to analyse one-to-one correspondence efficiently, we introduce some parameters as follows;

Gx(k),Gy(k):Coordinates of the gravity center of particle k.  
S(k) :Projected area of particle k  
W(k) :Width of particle k  
H(k) :Height of particle k  
M(k) :Number of neighboring particles of particle k  
MIN\_D(k) :Distance between the target particle and the most neighboring particle.  
MIN\_S(k) :Parameters to be evaluated by

$$MIN\_S(k) = \sum_{k=1}^{n(k)} (S(k) / r_k^2)$$

where  $r_k$  is the distance between target particle and the particle k.

DSP calculates and arranges these data on the table. DSP correlates these data of the consecutive two frame image.

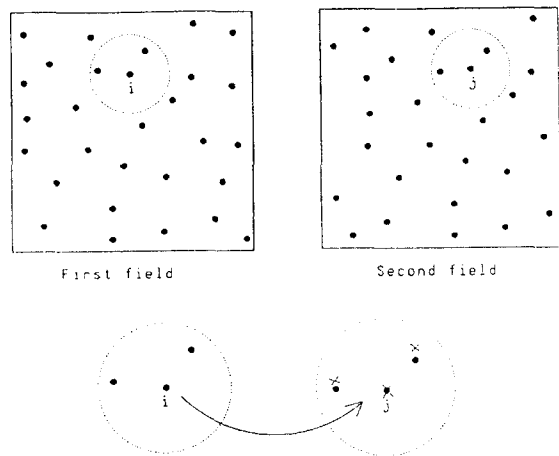


Fig. 7 Method 2

## 5. Experimental results

In order to show the applicability of our system, we built a test equipment in our laboratory. The size of the tank is 500\*500\*100 mm. The water flows clockwise by a motor settled at one corner. The flow velocity was about 0.2 m/s. Paraffin which has rectangular shape 1\*1\*1 mm are used as tracer particles.

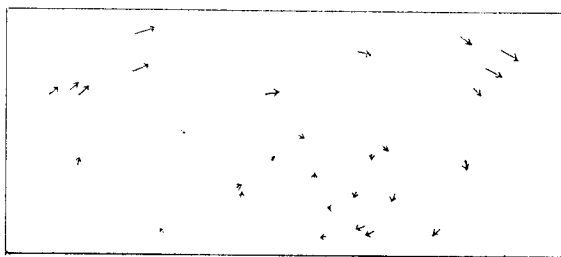


Fig. 8 (1) Instantaneous velocity vector

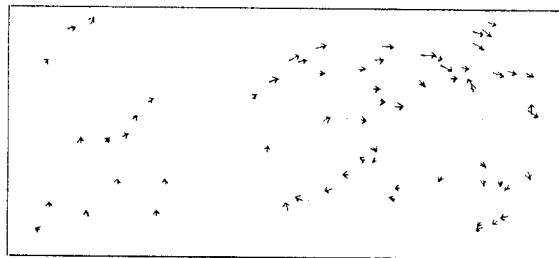


Fig. 8 (2) Instantaneous velocity vector

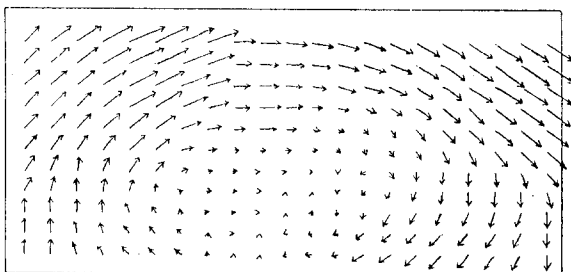


Fig. 9 (1) Estimated Velocity Distribution

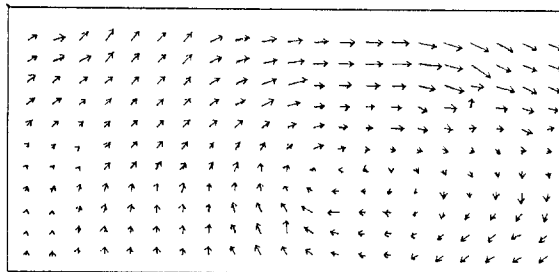


Fig. 9 (2) Estimated velocity distribution

Two experimental results are shown in Fig.8, where method 1 is used as one-to-one correspondence. Fig.8 (1) shows one example where 35 points of tracer are detected in 1/30 sec. Fig.8 (2) shows another example where 65 points of tracers are detected in 1/30 sec. While three velocity vectors are clearly erroneous in Fig.8 (2), the results are almost satisfactory. In order to know the whole velocity distribution in the field, the velocity  $V(x,y)$  at the node point  $n(x,y)$  is estimated as follows.

$$v(x,y) = \left\{ \sum_{i=1}^n v(x_i, y_i) (1/r_i^2) \right\} / \left\{ \sum_{i=1}^n (1/r_i^2) \right\}$$

$$r_i^2 = (x - x_i)^2 + (y - y_i)^2$$

where,  $x_i, y_i$  are coordinates of the  $i$ -th particles.

The results are shown in Fig.9 (1) and Fig.9 (2).

## 6. Conclusion

The authors developed a system which enables a real-time measurement of 2-D flow field. Experimental results show that the function of our system is satisfactory. One superior features of our system are that image processor and two DSPs enable a real-time measurement of a 2-D flow field.

## References

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