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Irrigation canal discharge measurement by using commercial digital video camera

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ABSTRACT

This study present the image measurement techniques on the surface velocity field and water stage. The images of free surface and stage gauge are obtained from commercial digital video camera. Time series of surface velocity and stage had been collected simultaneously. Knowledge of flow filed in a irrigation canal was essential for computing discharge. Large scale particle image velocimetry（LSPIV）was used to determine surface velocities in the irrigation canal. LSPIV proceeds by using the bubbles float on the water surface as the tracer particles, and making cross-correlation analysis between two continuous images. Thus, it can calculate the speed and direction of tracer particles. The whole surface velocity distribution in a irrigation canal can be obtained. The water stage of canal obtains from the digital video camera images by making use of image segment to separate stage gauge and background. Discharge computed by using the surface velocities and water stage via open channel velocity distribution theory. Comparing the image techniques measured discharge with Parshall flume data shows the differences are to be less then 5%. The results suggest that the developed image measurement techniques can be used in the applications to estimate irrigation canal discharge effectively.

Keywords: Surface velocity, Water stage, Tracer particles, Cross-correlation analysis

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1. INTRODUCTION

Traditional irrigation canal discharge measurement equipments were weir and water level gauge, and by used of weir formula or stage-discharge rating curve to calculate the canal discharge. There were some factors may cause error during measure process, while with both of above methods to measure canal discharge in the field. For example: backwater effect, transverse velocities, the variation in water stage and approach velocities will affect the measure results. In order to keep the measurement of canal discharge correctly, the discharge station must maintained and corrected frequently. It must paid extraneous expenses in each discharge station. Therefore, it was difficult to set up many discharge stations along the irrigation canal, so it can't control the discharge distribution in the whole irrigation canal. With the rapid development of modern optical techniques and digital image processing techniques, whole-field optical diagnostics, such as particle image velocimetry(PIV), had become available in fluid mechanics. The surface velocities and water stage of irrigation canal were measured by local image remote sensing system. Furthermore, the new measurement provided non-intrusive whole flow field velocity measurement, and it was more effectively than traditional methods [Dabiri et al., 1991].

2. Experimental setting and measurement

In this study, a video camera was used to capture images of tracer particles on the surface of the irrigation canal. The camera was a 811×508 pixel video camera that can record up to 30 frames per second. The video camera can be controlled remotely by a computer, and images can be directly downloaded. The cost of video camera compared to traditional velocimetery, the PIV method had a relatively low cost.

The location of the irrigation canal was in the Fongyuan City (Figure1). The video camera was mounted above the irrigation canal, and the video camera was perpendicular to the plane of the water surface (Figure2). The cross-section of the irrigation canal was rectangular, and was constructed by concrete walls. A discharge measurement structure Parshall flume was installed downstream of the measurement cross-section. So, the advantages of the measurement cross-section were fixed cross-section and the results of measurement can be compared with Parshall flume.

3. Image processing and analysis

3.1 Image enhance

The images captured from video camera were often destroyed by environment and video camera. Therefore, image pre-process should be done before image analysis. The image pre-processing procedure was divided into two stages: (1) image enhance; (2) image restoration. The purposes of image pre-processing were to advance image quality and improve important signal.

The image enhance can be achieved using two different approaches: spatial domain processing and frequency domain processing. Spatial domain processing enhance images signal by the mask that through adjusted pixels to enhance the important parts of the images. Assuming that f was the input image and T was the mask, and the expression of spatial domain processing can be expressed by the following:

$$g = T \cdot [f] \tag{1}$$

where g is the output image.

The second one method was frequency domain processing that used Fourier transform and convolution to enhance images. Through Fourier transform that the edge or the obvious variation in images the Fourier coefficients will show in high frequency, on the other hand the smooth portion in images the Fourier coefficients will show in low frequency. Thus, image enhance can be achieved by adjusted the Fourier coefficients.

3.2 Image restoration

As it appeared in Figure 3, the original image was distorted because of the oblique viewing angle of the camera. The original images should be restored before used the PIV method to calculate the surface velocities. A transformation was needed to map the image coordinates onto physical space coordinates. The transformation parameters can be determined using a set of ground reference points and numerically optimizes the physical and image coordinates [Kinoshita et al., 1990]. The general expression of the projective transformation was the following:

$$\begin{bmatrix} xw \\ yw \\ w \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \\ a_5 & a_6 & a_7 & a_8 \\ a_9 & a_{10} & a_{11} & a_{12} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{2}$$

where (X, Y, Z) were ground reference points, (x, y) were image coordinates, a_{12} was scale parameter, and w was a parameter. Assuming a_{12} and w equal to one, then the eq. 2 can be expressed as:

$$\begin{bmatrix} X & Y & Z & 1 & 0 & 0 & 0 & 0 & -xX & -xY & -xZ \\ 0 & 0 & 0 & 0 & X & Y & Z & 1 & -yX & -yY & -yZ \end{bmatrix} [a] = \begin{bmatrix} x \\ y \end{bmatrix} \tag{3}$$

where $a = [a_1 \quad a_2 \quad a_3 \quad a_4 \quad a_5 \quad a_6 \quad a_7 \quad a_8 \quad a_9 \quad a_{10} \quad a_{11}]^T$ were the transformation parameters.

3.3 Water surface images analyze

In this study, the PIV method was applied to obtain flow patterns in the irrigation canal. The core of the PIV method was the image analysis algorithm used to extract velocity vectors of the surface tracers from the recorded images [Fujita et al., 1994]. First split the images into multiple interrogation area (IA). Secondly, for each pair of corresponding IA, calculate the 2D fast Fourier transforms (FFT) of both IA, compute the cross product of the first interrogation area FFT and the second interrogation area FFT conjugate, determine the inverse fast Fourier transforms of the result. Then find the location of the maximum in the correlation plane to compute the displacement and velocity of flow [Willert and Gharib 1991]. It was accomplished through the use of discrete cross-correlation function, the integral formulation can be described as:

$$f_{II'}(x,y)=\sum_{m=1}^{M}\sum_{n=1}^{N} I(m,n)I'(m+x,n+y) \tag{4}$$

where the f_{II} was the cross-correlation coefficient, I and I' were the intensity value of the image pair [Utami et al., 1991; Westerweel et al., 1997; Gui et al., 2001; Wereley et al., 2003]. Figure 4 was the concept of the PIV method.

An important advantage of the cross-correlation method was that the method removed the directional ambiguity. Furthermore, the PIV analysis was dependent on some parameters that must be selected based on the nature of flow and the tracers used in the experiments. But the most important was the size of the IA. On one hand, the IA must be small enough to preserve the scale of interest in the flow. On the other hand, the IA size must be large enough to include recognizable tracers patterns. Consequently, in the study the size of IA was selected to be 32×32 pixels and 64×64 pixels.

4. Discharge computation method

After the surface velocities were calculated, the method used for computation of the discharge was the velocity-area method. Discharge was computed at the cross-section which located within the PIV measurements area. The canal cross-section was divided into several sub-section, and the vertical velocity profile of the each sub-section can be assumed either parabolic or logarithmic. Average velocity was then calculated for each sub-section from the PIV measurements. The average velocity of each sub-section V_i can be computed as:

$$V_i = Au_i \tag{5}$$

where A was the coefficient relating surface velocity and the depth-averaged velocity of the sub-section, and the value u_i was the surface velocity of each sub-section. In this study the coefficient A was equal to 0.9, so the average velocity of each sub-section was computed as 0.9 of the surface velocity. Therefore the discharge for each sub-section was computed as:

$$q_i = \frac{V_i + V_{i+1}}{2}\cdot\frac{h_i + h_{i+1}}{2}\cdot D \tag{6}$$

where h_i was the depth of sub-section, and D was the width of sub-section. For the sub-section near the bank, the discharge of the first and the last sub-section were computed as:

$$q_1 = \frac{2}{3}V_2\cdot\frac{h_1 + h_2}{2}\cdot D \tag{7}$$

$$q_{n-1} = \frac{2}{3}V_{n-1}\cdot\frac{h_{n-1} + h_n}{2}\cdot D \tag{8}$$

the canal discharge Q was obtained as the sum of the sub-sections:

$$Q = \sum_{i=1}^{n-1} q_i \tag{9}$$

4.1 Image measure results

The procedures of PIV method was showed in Figure 5. By used of the physics reference points and the transformation parameters through eq. 3 the image project transformation can be achieved. Figure 6 was the original water gauge image, and by used of image segmentation and geometric transformation, the correct water gauge image (Figure 7) can be obtained. Through image segmentation and edge detection, the water level was 0.518 m.

The correct water surface images can be obtained by used of image projection transform, and used the PIV method to measure the surface velocities. The time step between the image pairs was 1/15 second, and the canal discharge were calculated with two different IA sizes. In the study, the sizes of IA were 32×32 pixels and 64×64 pixels. Figure 8 and Figure 9 were the surface velocity field of two different IA. The surface velocity profile of the cross-section also calculated with two IA sizes: 32×32 pixels and 64×64 pixels, Figure 10 and Figure 11 were the results, respectively.

4.2 Comparisons of discharge measurement results

In order to verify the measurement results, the discharges measured by PIV method were compared with the results measured by Parshall flume. The discharges measured in irrigation canal by PIV method with two different interrogation area sizes: 32×32 pixels and 64×64 pixels. The results of above two different interrogation area sizes were 3.52 cms and 3.83 cms, respectively. The discharge measured by Parshall flume was 3.655 cms. The discharge differences between PIV method and Parshall flume were 3.70% and 5.61%. The results showed that used small IA was better than big IA, because the IA must be small enough to preserve the scale of interest in the flow since the flow scales smaller than the size of IA are lost through the processing.

Besides, the velocity distribution computed with the PIV method can be compared with current meter. The average velocity of each sub-section at the cross-section was measured by current meter. In Fig. 12 velocity measurement with the PIV method and current meter were compared, and the results were quite well.

5. Conclusions and suggestion

With the rapid development of modern optical techniques and digital image processing techniques, digital image processing had been used in many field. In the study, the local image remote sensing system was built to capture the water surface and stage gauge images, and provided a no-intrusive method to measure whole flow field velocity and water level. The PIV method was used to measure surface velocities in the irrigation canal, and surface velocities were converted to depth-averaged velocity by log-law curve fit.

The irrigation canal discharge measurements were taken with the PIV method and Parshall flume, and the differences were within 5%. Furthermore, the local image remote sensing system utilized simple, low-cost equipment, making it affordable and easy to set up for discharge measurement. Though the PIV method had above advantages, but the image quality will affect the results. Reflections and shadows made it difficult to detect motion in some circumstances, so the influence of spatial filters and the light distribution of images must be considered further more.

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Figure 1 The photo of the irrigation canal.

Figure 2 The local image remote sensing system.

Figure 3 The original image of water surface.

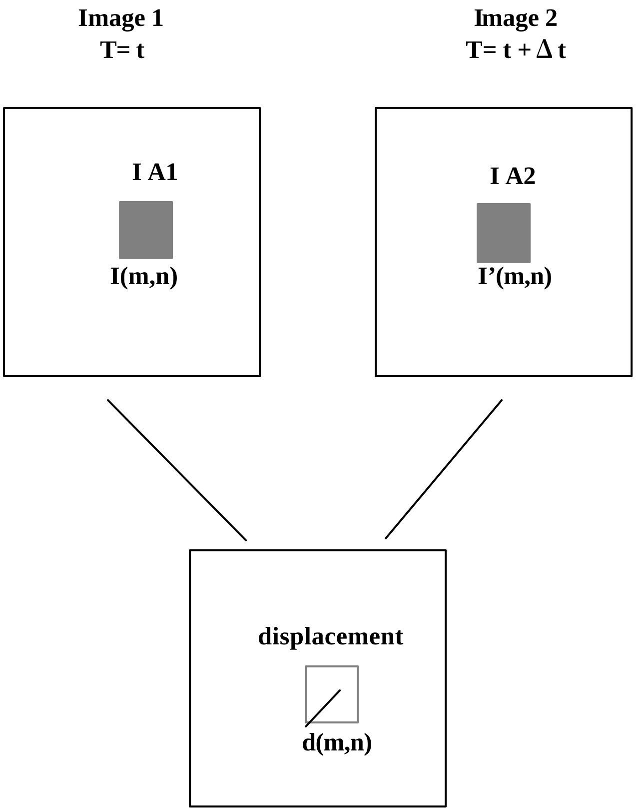

Figure 4 The concept of the PIV method.

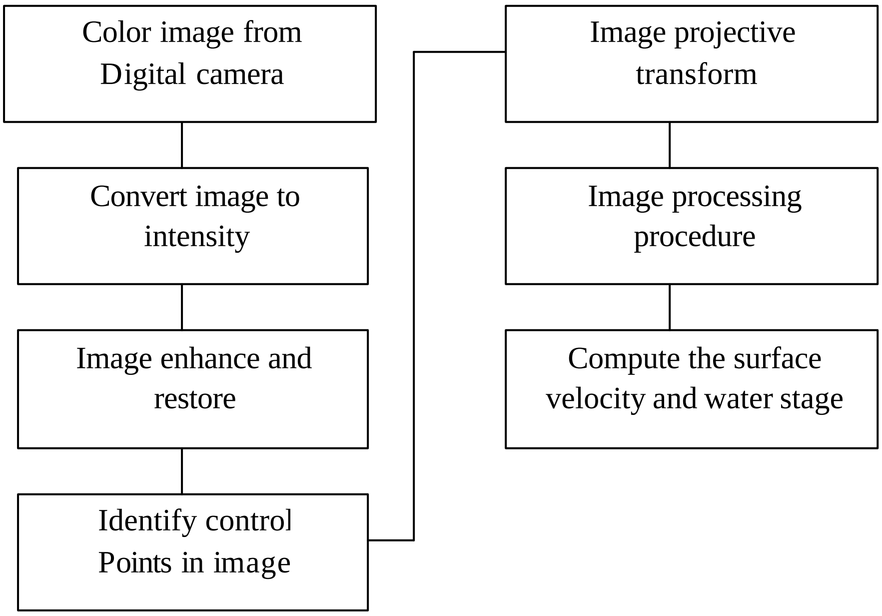

Figure 5 The procedure of the PIV method.

Figure 6 The original image of water gauge.

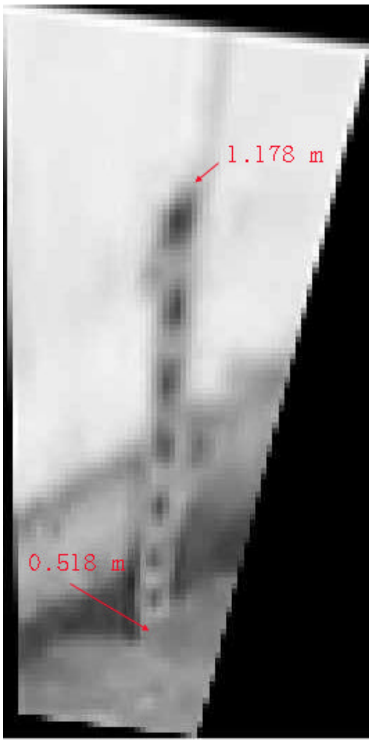

Figure 7 The water gauge image after image transform.

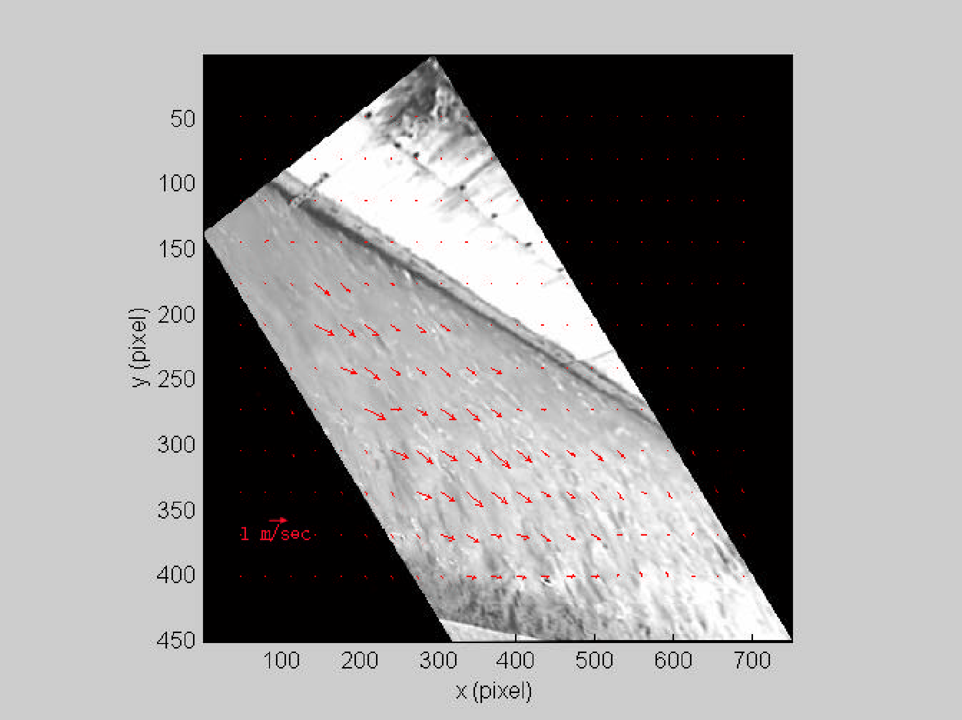

Figure 8 The surface velocity field of canal (32x32 pixels).

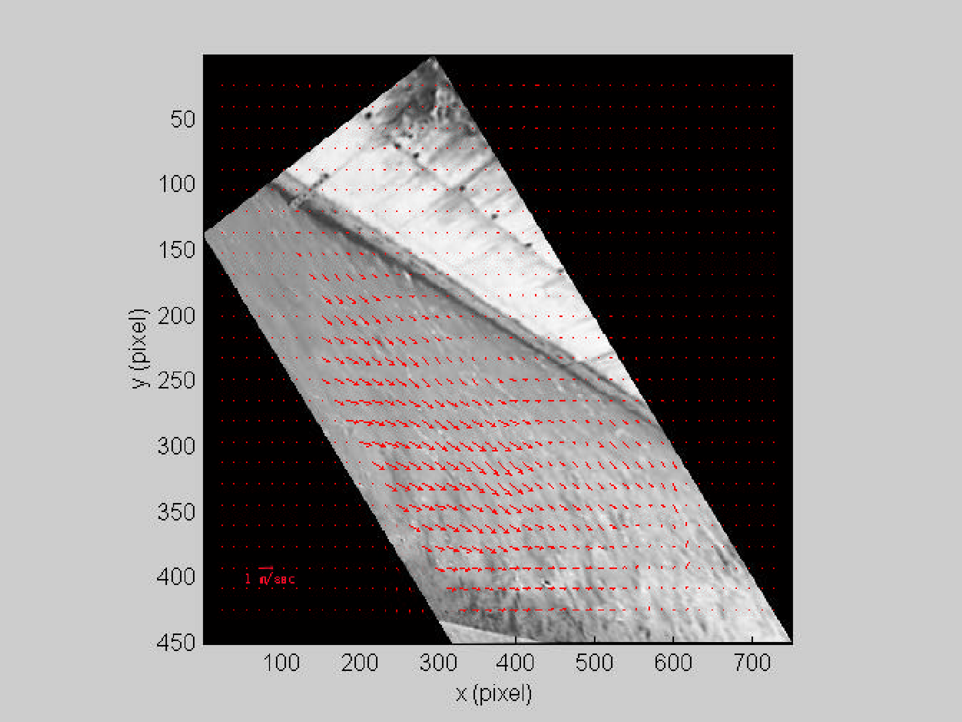

Figure 9 The surface velocity field of canal (64x64 pixels).

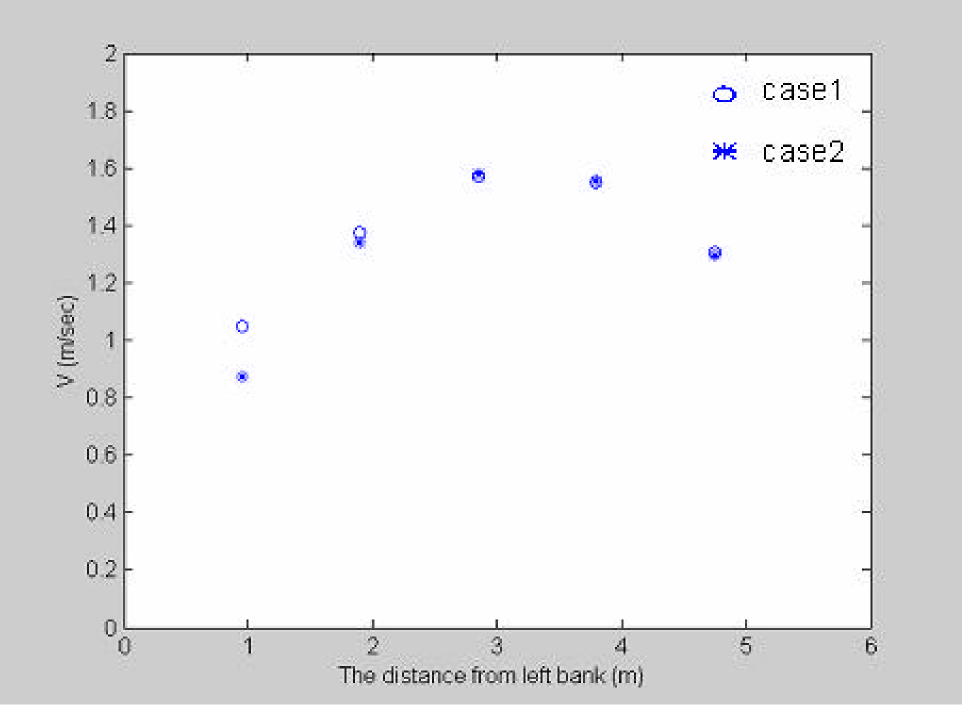

Figure 10 The cross-section surface velocity profile of canal (32x32 pixels).

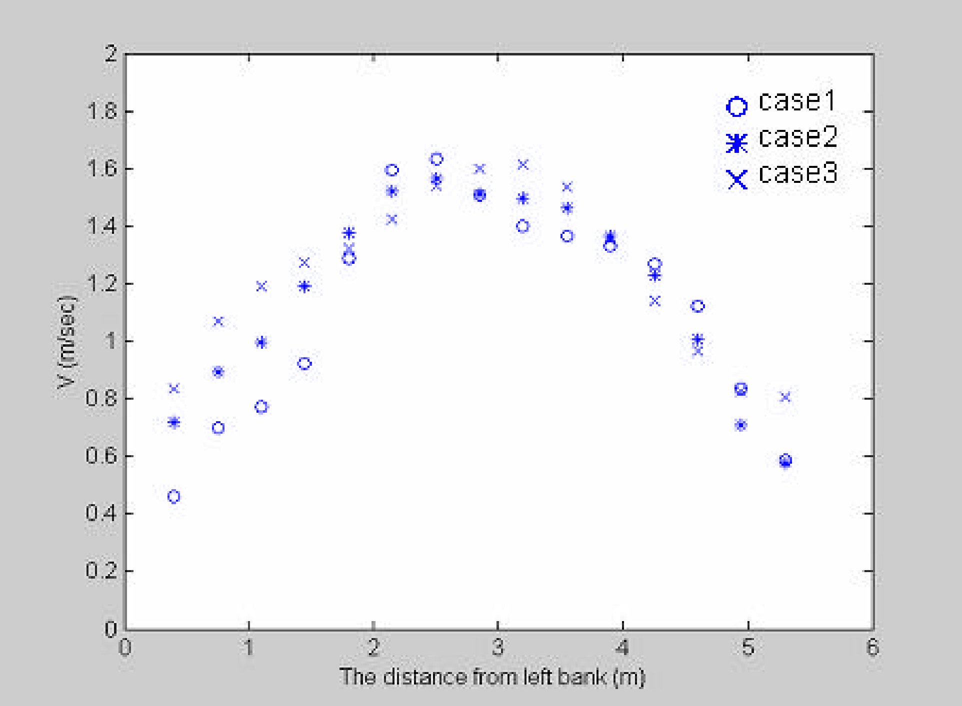

Figure 11 The cross-section velocity profile of canal (64x64 pixels).

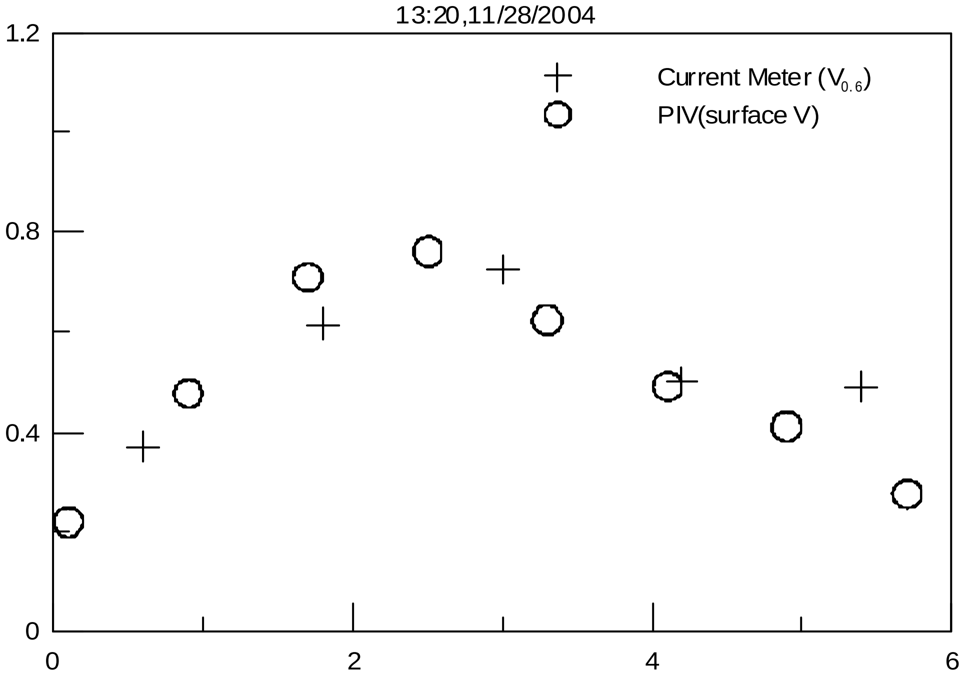

Figure 12 Comparison of velocities measured by PIV and current meter.