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Unseeded and Seeded PIV Measurements of River Flows Videotaped from a Helicopter

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Abstract : A new PIV method for measuring river surface flows using videotaped images taken from a helicopter has heen developed. In this method, shifting of background images while videotaping was effectively corrected using the known coordinates of fixed points on the image. In low flow conditions, river surface flows were visualized using rice crackers, while in flood flow conditions surface ripples generated by the effects of near-surface turbulence and pressure fluctuation were used as natural unseeded tracers. The performance of the presented method was verified through its applications to the actual river flow measurements.

Keywords : Unseeded visualization, Seeding, PIV, River flow, Flood, Helicopter.

1. Introduction

Measurement of velocity distributions of a river is one of the most important issues in the design and management of river channels, since the river discharge, the most significant hydrologic factor, can be estimated directly from velocity information and the location of hazardous region with highly shearing stresses near the riverbank can also be detected from spatial velocity information. However, in contrast to laboratory measurements, three-dimensional or internal flow measurements are quite difficult in the river field due to its extensiveness, especially in flood conditions. Hence it is rather preferable to measure surface velocity distributions for practical and engineering purposes. Conventionally river surface flows have been observed using floats, but due to its low spatial resolution the measurement accuracy was usually not satisfactory for a detailed analysis of river flow structure. Thus, the image-based techniques, with much higher spatial and time resolutions, have been paid attention in recent years.

In flood flow conditions, river surface elevation is randomly deformed due to the effects of various-scale turbulent vortices mostly generated near the riverbed. Mixed effects of numerous vortices impinging on the water surface together with the effect of turbulent pressure fluctuation eventually produce ripple-like patterns on the water surface, which appear as randomly distributed specular reflections sometimes accompanying large-scale spots created by the so-called boil vortices. In the application of the Particle Image Velocimetry (PIV) to river flows, the authors assumed that these surface patterns are convected with the surface flow and utilizable as a kind of tracer representing the surface velocity distribution (e.g., Fujita and Komura, 1994). This assumption has been verified through the applications to various actual flood flow measurements and comparison with other methods(e.g., Aya, Fujita and Yagyu, 1995; Fujita, Aya and Deguchi, 1997; Fujita, Muste and Kruger, 1998). Natural objects such as driftwoods, ice blocks (e.g., Ettema et al., 1997) or foams can also be used as tracers forming the surface image pattern. Since this PIV method covers relatively large area viewed from an oblique angle, we labeled this method as the Large-Scale PIV (LSPIV). In normal low flow conditions, in which no appreciable turbulence effect is observed on the water surface, the ripple-like patterns disappear. In such cases, we have to use tracers to visualize the slow water surface flow.

However, the measurable area from a single viewing location is relatively small when compared with the actual river scale; that is, the streamwise scale of a river manageable by riverside measurements is at most on the order of river width. Hence, in order to investigate flow features along a river for a longer streamwise river reach, we may have to take the images from aerial location such as an airplane or a helicopter. The advantage of a helicopter over an airplane is, of course, its capability of hovering and its maneuverability in case of a disaster. In this research, a new PIV system capable of measuring river surface flow videotaped from a helicopter was developed and its applications to a flood flow and a low flow were demonstrated.

2. Image Analysis Method

2.1 Subtraction of Background Shift

The main feature of the images taken from a helicopter is that recorded landscape (or background) image changes from frame to frame. In the present method, such background shifts were subtracted in the following manner.

We set two coordinate systems (x,y) and (X,Y) on the first and the second image frames sequentially captured from a videotape as shown in Fig.1 and assume the following projection relationship between the two coordinates,

$$x = \frac{a_1 X + a_2 Y + a_3}{a_4 X + a_5 Y + 1}, \qquad y = \frac{a_6 X + a_7 Y + a_8}{a_4 X + a_5 Y + 1} \tag{1}$$

where $a_1, a_2 ... a_8$ are the transformation coefficients to be determined from the known coordinates of fixed points (target points) included in the both images, such as buildings, bridges, or corners of roads. Since an arbitrary (raw) vector on river surface region $\boldsymbol{V_S}$ $(=(x_{t+Dt} - X_t, y_{t+Dt} - Y_t)/\Delta t)$ obtained by simply applying PIV between two consecutive images is the sum of an actual flow velocity $\boldsymbol{V_0}$ $(=(x_{t+Dt} - x_t, y_{t+Dt} - y_t)/\Delta t)$ and a background shift vector $\boldsymbol{A_0}$ $(=(x_t - X_t, y_t - Y_t)/\Delta t)$, the actual river flow velocity can be obtained by subtracting the background shift vector from the raw vector;

$$V_0 = V_S - A_0 \tag{2}$$

The background shift vectors can be calculated easily at any points in the image once the mapping relationship eq.(1) was established; thus, spatial velocity distributions relative to the background can be obtained by applying eq.(2) to arbitrary vectors within a river flow region.

2.2 Features of Surface Flow during Flood

As explained previously, river water surface during flood exhibits various-scale characteristic patterns such as surface small ripples generated by wall turbulence or relatively large-scale patterns caused by boil vortices. Although small ripples are identifiable by video images from a riverbank, they cannot be easily distinguished in video images taken from a helicopter because of the reduction of spatial resolution. Hence, in order to apply PIV to video images from a helicopter, aforementioned large-scale patterns, whose scale is on the order of water depth, have to be utilized to trace the surface flow. An example of such large-scale surface patterns is shown in Fig. 2, in which the image enhancement procedure was applied to emphasize the difference of surface color. The image was captured from a helicopter while investigating the location of the bank failure that occurred during the flood of the Shin River in Japan. As shown in the figure, the river was severely damaged for about eighty meters along the left bank. It is apparent from the figure that clear patch-like patterns have appeared on the water surface with scales on the order of several meters, which is equivalent to the order of water depth.

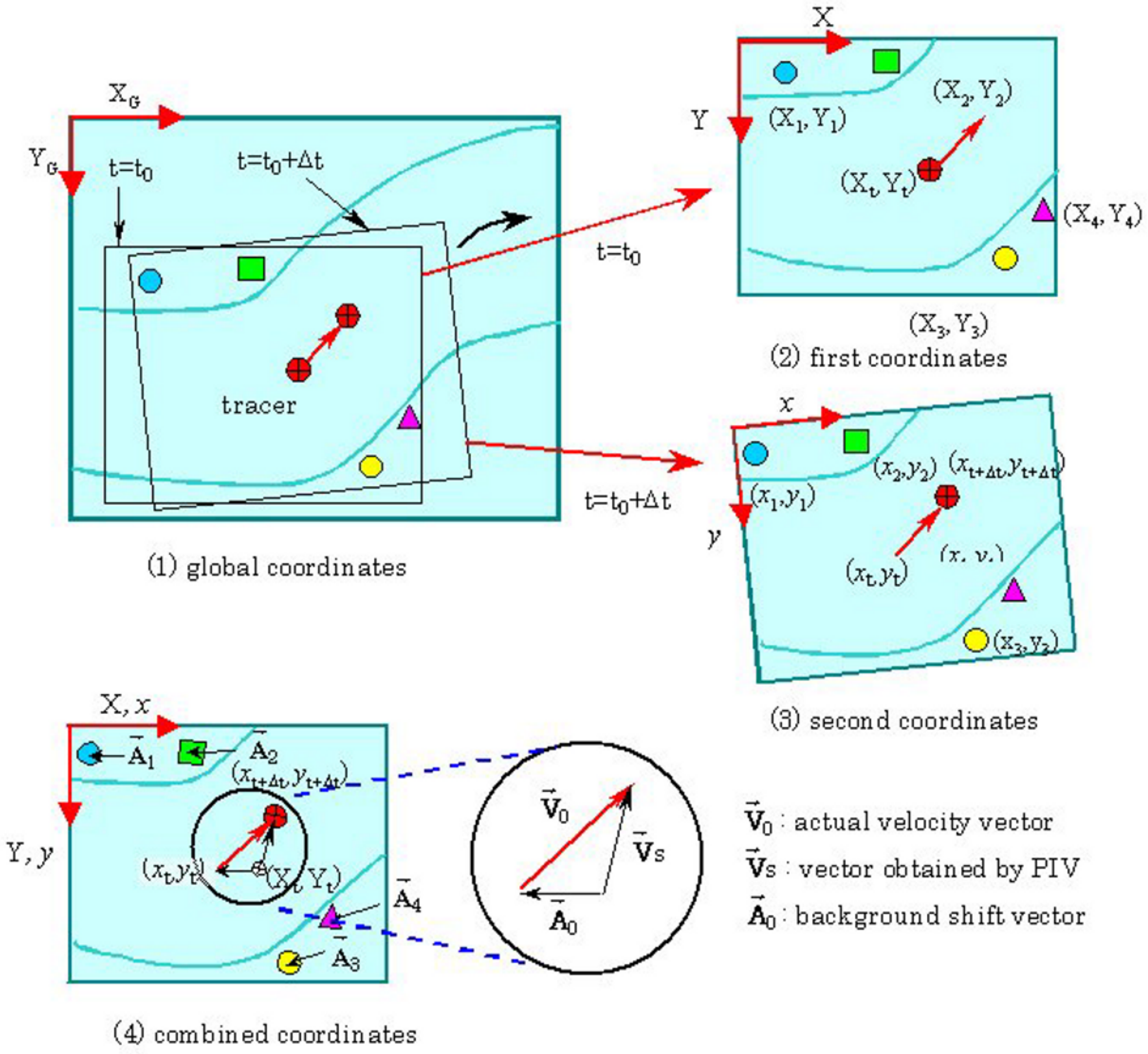


Fig. 1. Relationship among coordinates and vectors.

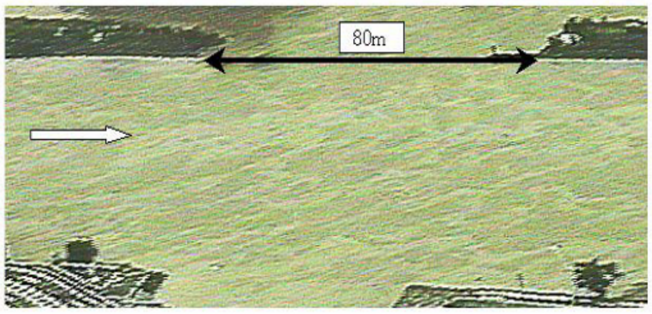


Fig. 2. Large-Scale Pattern Appeared on River Surface.

These patterns were created by the confliction of large-scale boil vortices against the water surface. The difference of surface color is attributed to the concentration change of suspended sediment rolled up by boil vortices. It can be considered that darker regions correspond to the upwelling part of the boil vortices. Since the flood flow velocity is usually several meters per second, the local small wave velocity generated by the confliction of vortices against the water surface can be negligible in a practical sense. Hence, PIV can be applied assuming these surface patterns are convected with the surface flow. The only problem in trying to use these patterns is that they do not appear in normal flow condition, because in such a slow flow situation boil vortices cease to occur and water surface will have little interaction with vortices generated near the bottom flow. In such a flow condition, biodegradable tracers such as those made of cornstarch (e.g., Fujita et al., 1998) or rice crackers can be used to visualize the surface flow as will be shown later.

3. Application of PIV to Flood Flow Measurement

3.1 Outline of the PIV System

In the present study, a Windows application for PIV was developed so that all the image measurement procedures can be performed smoothly with a proper user interface. The application was developed using a programming language Delphi (version 5). An example of user interface screen is shown in Fig. 3. In the figure, two consecutive images with a time separation of 1.5 seconds are shown together so that manual operation to find target objects would become more efficient. The arrows in the figure indicates background shift vectors obtained by applying PIV to the local target points using a small template also shown in the figure. The matching of the target objects (mark points) was performed manually in the first image pair, but for the subsequent image pairs, the information on the previous object locations was efficiently utilized so that manual operation was minimized. The accuracy for obtaining background shift vectors was improved by searching the CRT coordinates in a sub-pixel level by using a parabolic fitting in the space of cross-correlation coefficients. The effect of the image distortion was corrected by comparing the location of target objects for both the CRT coordinates and the physical coordinates.

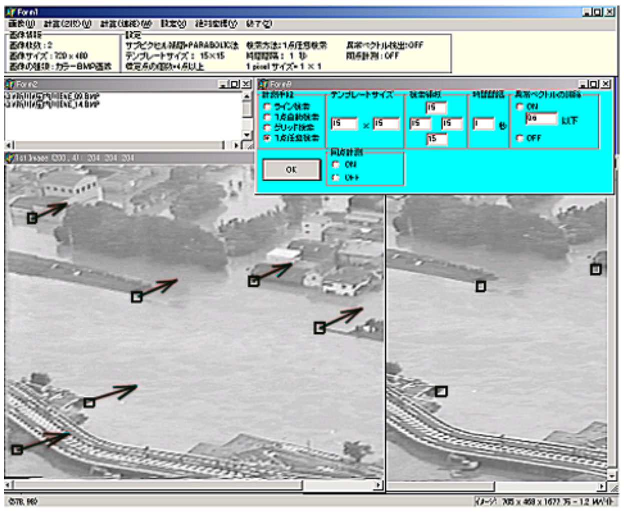
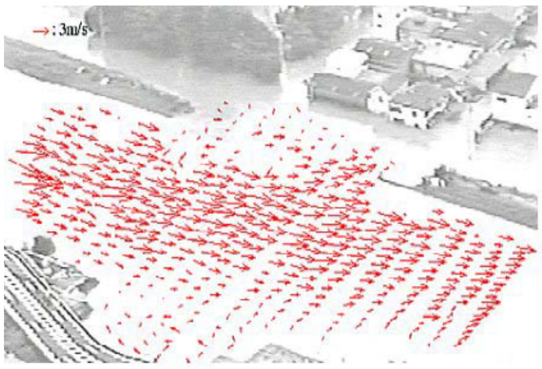


Fig. 3. User Interface of the New PIV System.

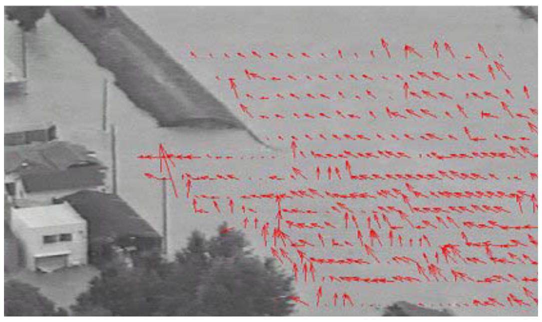
3.2 Measurement of the Flood in the Shin River

We applied the new method to the videotaped images of the flood of the Shin River as shown in Fig. 2. The problem with this video is that, as the images were not recorded for the purpose of river flow measurements but for the examination of the damaged bank, the number of frames available for the present PIV analysis was very little; that is, the background image changed largely from frame to frame, which is a unsuitable condition for PIV measurements. Another problem is that the videotape we obtained had low-quality images due to a dubbing from an analogue VHS videotape. However, thanks to the robustness of the PIV algorithm and a clear appearance of large-scale surface patterns we could obtain instantaneous surface velocity distributions from three angles as shown in Fig. 4. Although there appear some scatters or erroneous ones in the vector fields, overall flow features at this location were successfully obtained.



(a) angle A

(b) angle B

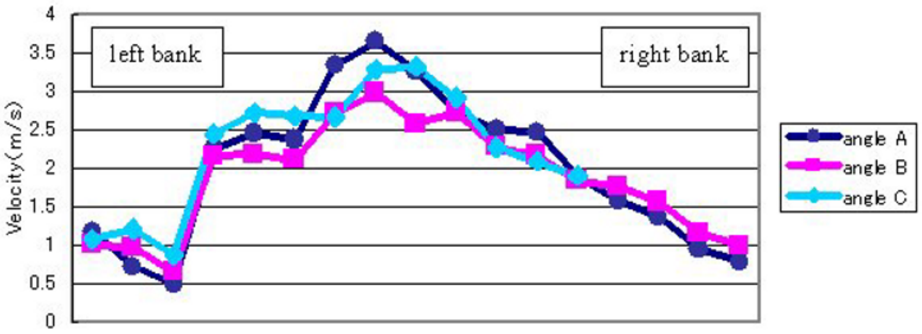


(c) angle C

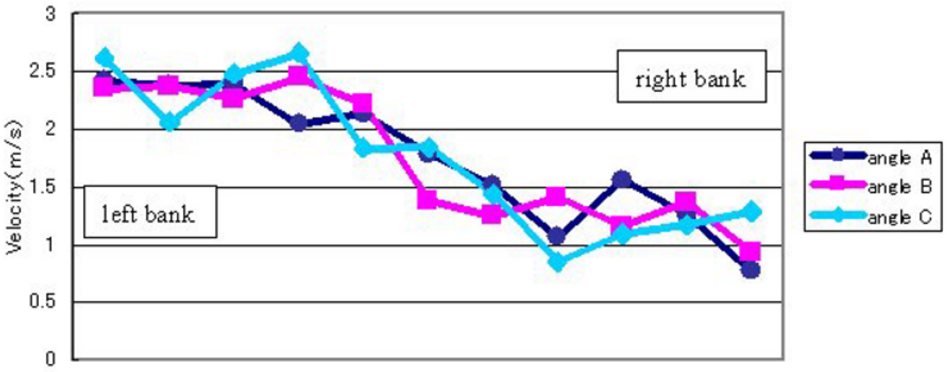
Fig. 4. River surface velocity distribution; flood of the Shin River in Japan.

In the PIV analysis, we used images with a time separation of 1.5 seconds so that surface patterns in the main flow region would move about ten pixels relative to the ground. For the pattern matching in PIV we chose a relatively large template size, say 71 by 71 pixels for the case shown in Fig. 3, so that the template includes the characteristic scale of the surface pattern created by the large-scale vortices.

In order to check the consistency of the PIV results, we compared the instantaneous cross-sectional velocity distributions obtained from different angles of a helicopter. The cross-sections are indicated in Fig. 4(b). Figure 5(a) shows the velocity distributions in front of the damaged part. The three velocity distributions agree with each other fairly well except for the maximum velocity. The difference of the maximum velocity is attributed to the unsteadiness of the flow and the difference of recorded time, or due to the error in the mapping relation. It should be noted that the location of the main flow was shifted nearer to the left bank due to the outflow from the broken part. Figure 5(b), indicating the velocity distribution downstream from the damaged part, also shows fair agreement between velocity profiles, in which the main stream is shifted largely towards the left bank due to the bank failure.



(a) In front of the damaged part



(b) Downstream of the damaged part

Fig. 5. Comparison of velocity distributions obtained from different viewing angles.

3.3 Measurement of the Normal Flow Using Tracers

As explained previously, river flows with low velocity or flows with low Froude number display no ripple-like patterns with only a flat water-surface. In such cases, tracers made of non-toxic material such as cornstarch or rice can be used to visualize the surface flow. In order to investigate the performance of the presented PIV system, we have conducted field measurements using a helicopter flying above the Uji River in Kyoto. A large number of tracers, rice crackers in the present case, were thrown continuously from a small boat drifting upstream of the measurement region. A helicopter, hovering above the measurement region, gradually moved with the crowd of tracer particles while videotaping the surface flow. The velocity distribution obtained by analyzing about thirty seconds of the video images is shown in Fig. 6. The mapping relation was established with the aid of the mark points (indicated in Fig. 6) placed along the riverbank. Although each frame size was at most the order of the river width as indicated in Fig. 6, velocity distribution was obtained fairly well in the region several times longer than the river width by smoothly combining the respective velocity profiles. The figure demonstrates higher velocity nearer to the right bank, which is caused by the centrifugal force acting towards the right bank. With more mark points in an extended region, measurements could have been performed for a longer river reach. The problem with this method is, as revealed in Fig. 6, it is impossible to obtain velocity data in the region where tracers are absent owing to the separation of streamline. In order to obtain velocity vectors in the entire region we have to devise a method how and where to throw tracer particles to have a uniform particle distribution.

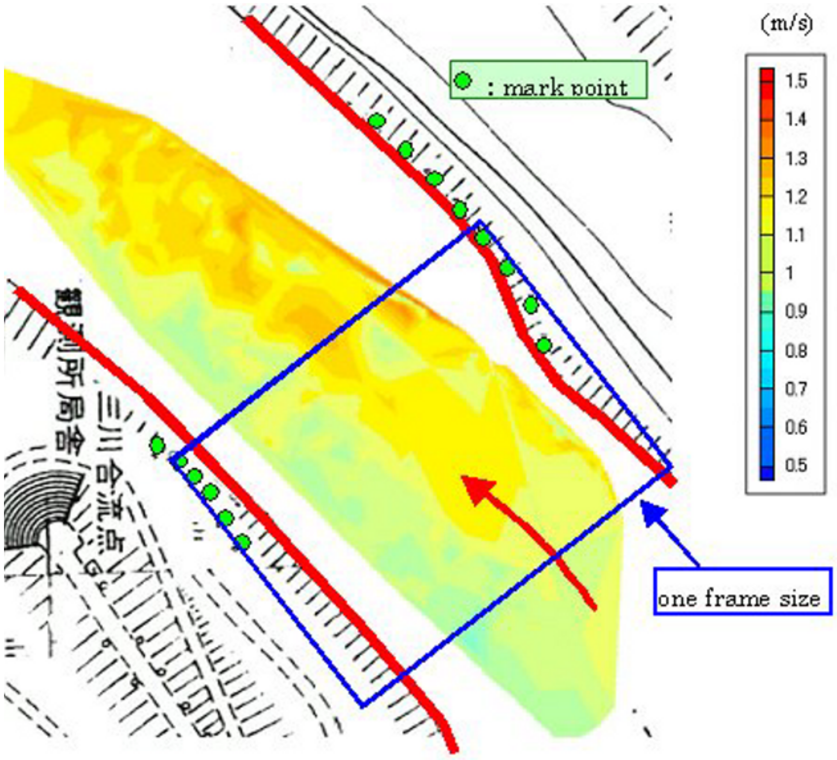


Fig. 6. Surface velocity distribution obtained by tracing particle clouds from a helicopter hovering above the Uji River.

4. Conclusion

A PIV system was developed applicable to the video images taken from a helicopter and its efficiency and consistency were verified through its application to the flood flow and low flow measurements. The presented method is especially more advantageous over the other field measurement methods in case of flood disaster, because of its non-intrusiveness and safeness. Unfortunately, the flood movie used in this study was not intended for PIV measurements with not enough recording time and resolution, but still the present system yielded reasonable results. The presented system would become more effective if the images were taken while hovering above the target area using a video camera with higher resolution.

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