APPLICATION OF OPTICAL FLOW TECHNIQUES FOR RIVER SURFACE FLOW MEASUREMENTS

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ABSTRACT

Optical flow technique (OF) is one of the image-based techniques basically for detecting motion of moving objects. In recent years, accuracy and efficiency of the technique has improved significantly with developments of various types of novel algorithms and it has come to be used in quantitative flow measurements. The techniques are categorized into sparse and dense methods. The latter method based on the Horn-Schunck method are examined in this research. The dense-type OFs have the advantage that the optical flow vector is obtained at each pixel very efficient compared with the particle image velocimetry (PIV). Although there are many OF algorithms, we focused on DeepFlow in this study. DeepFlow was applied to river surface flow and compared with LSPIV and STIV. DeepFlow's accuracy was comparable to PIV, which is one of conventional flow measurement techniques. In this case, obliquely viewed surface images of the Shinano River in Japan were shot from a riverbank, in which surface textures composed of air bubbles or surface ripples were used as natural tracers instead of supplying tracers. It was made clear that OF is applicable to the river surface flow as long as a clear texture representing the surface flow is visible at the measurement site.

Keywords: optical flow, river flow measurement, LSPIV, STIV, image velocity measurement

1. INTRODUCTION

In recent years, flood damages caused by torrential rain have become serious in Japan due to extreme weather. In order to design river structures such as embankments against floods, it is important to understand the exact flow rate and flow conditions of the river. Up to now, the improvement of hydraulic measurement techniques has greatly contributed to the analyses in the field of river engineering. Regarding the flood discharge measurements, only the float method has been officially used in the past few decades in Japan. However, due to the difficulty of the float measurement under extreme discharge conditions in recent flood disasters, methods other than the float method have been proposed in the past decade. For the sake of safe measurement, image-based measurement methods have been paid attention for river surface flow measurement.

As for the image-based measurement methods, Large-Scale Particle Image Velocimetry (LSPIV) and Space-Time Image Velocimetry (STIV) developed by Fujita et al. (1998, 2007) are commonly known to be useful techniques. LSPIV is an application of Particle Image Velocimetry (PIV), which has been used on a laboratory scale for a long time, to a real river scale. In general, a correlation method is mainly used to obtain displacement from the cross-correlation of image intensities. In STIV, a space-time image (STI) is obtained by setting an inspection line in the mainstream direction on an image and vertically stacking the image intensities of the image along the inspection line. In this method, an inclined texture appeared in STI is used to extract the space-time averaged streamwise velocity.

Further development of the above methods is executed by Detert and Weitbrecht (2015) who analyzed river flows over a wide area by applying LSPIV to the airborne images captured using UAV. Fujita et al. (2018) studied a method for estimating river surface velocity more accurately by applying the aerial STIV technique. Thus, the image-based measurement technology has developed greatly in recent years in the field of river engineering.

On the other hand, an optical flow technique, a technique for tracking moving objects, has been greatly developed in recent years in the field of vision technology. The optical flow is based on either the Lucas-Kanade method by Lucas and Kanade (1998), which tracks sparse feature points in a Lagrangian manner, or Horn and Schunck's method (1998), which is termed a dense optical flow that can obtain a velocity field for each pixel on an image. Among these techniques, development of dense optical flows is especially remarkable in recent years. A variety of algorithms have been proposed, ranging from the variational approach that improves the Horn-Schunck's method to those using the CNN structure. As an example of applying the variational optical flow algorithm based on the Horm-Schunck's method, Liu et al. (2015) clarified the accuracy of turbulence measurements by using particle simulation images and experimental visualized particle images. Ansari et al. (2019) observed boil vortices on the river surface by using Horn-Schunck's method. Khalid et al. (2019) applied the optical flow to river surface flows and discussed the accuracy of river surface flows while comparing it with PIV. Although the optical flow techniques have been applied trying to analyze rive surface flows, there's not enough researches aiming at measuring the actual flood flows with reasonable accuracy in the past.

In this research, the DeepFlow algorithm developed by Weinzaepfel et al. (2013) is mainly used to compare with the other imaging techniques. DeepFlow calculates an optical flow using a matching between two frames called Deep Matching. Deep Matching can calculate the distribution of displacements involving non-rigid deformation between two frames at a high density from a composite size displacement map obtained by hierarchically repeating convolution operation, maximum pooling, and sub-sampling used in CNN. Figure 1 shows the flow chart of the DeepFlow calculations. The purpose of this study is to clarify the applicability of DeepFlow by comparing it with LSPIV and STIV by using the actual river surface images.

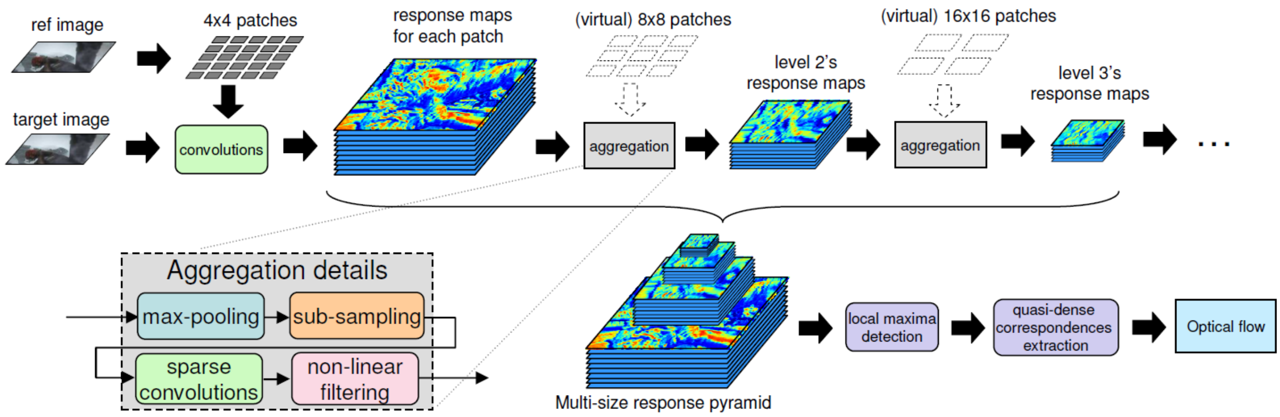


Figure 1. DeepFlow architecture (Weinzaepfel et al., 2013)

2. FIELD EXPERIMENT

The field experiment was conducted in April 2017 as a joint survey campaign by JSCE and ICHARM at the site of the Shinano River, Niigata Prefecture, Japan, as shown in Figure 2 (a). The flow rate was about 755 m^3/sec and the maximum depth about 5 m. The observation site used in this study is shown in Figure 2 (b). As a field survey, the video clips were taken by a video camera installed on the riverbank as shown in Figure 2 (c). The sampling frequency of the moving image is 30 Hz, and the frame size is 3840 pixels horizontally and 2160 pixels vertically, which is the 4K image quality. The shooting time was about 2 minutes. At the same time, the flow rate observation by towing the ADCP (Acoustic Doppler Current Profiler) from the top of the bridge is performed at the downstream of the bridge, and another radio controlled boat equipped with the ADCP traversed in a zigzag manner over a section that covers about 500 m in the upstream area of the bridge.

3. INSTRUMENTS AND METHODOLOGY

3.1 Image pre-processing

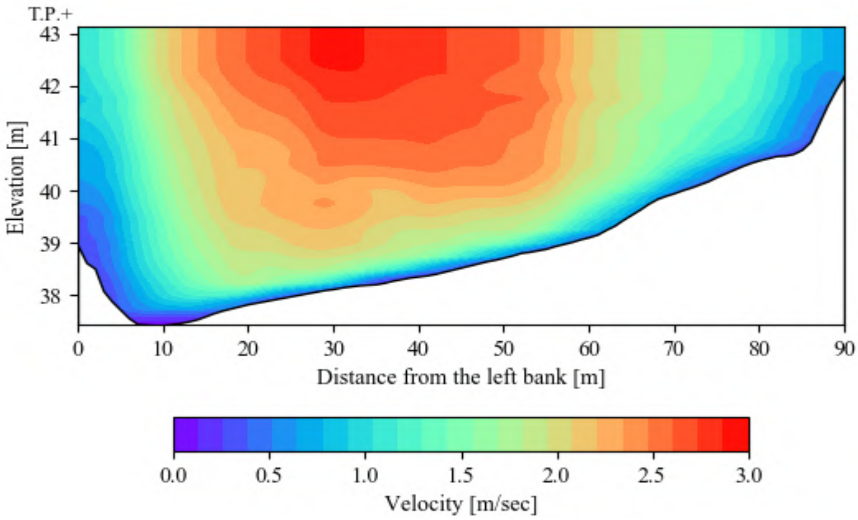
In this study, STIV, LSPIV, and DeepFlow are compared to examine each method's performance. Among them LSPIV and DeepFlow analyze geometrically transform images while STIV uses oblique images directly. Figure 2 (d) shows the image after the geometric transformation. Such an image process is commonly executed in the analysis of LSPIV (Fujita et al., 2007; Fujita et al., 2012; Fujita, 2017; Tsubaki, 2017; Fujita and Komura, 1994; Aya et al., 1995; Fujita et al. al., 1998; Le Coz et al., 2010; Tsubaki et al., 2011).

(a) Location of Shinano river

(b) Study area

(c) Raw image

(d) Ortho-rectified image



(e) Velocity distribution obtained by ADCP

Figure 2. Overview of study area

3.2 velocity measurement method

In this study, artificial tracers such as wood chips were not used, instead surface textures including air bubbles generated by turbulence are treated as unseeded natural tracer. It can be assumed that such surface textures are advected in the streamwise direction with the surface velocity. LSPIV was performed on a series of ortho images and estimated by the correlation method. The template size was 31 × 31 pixels and the time interval for the analysis was 1/10 seconds. Subpixel analysis was performed by a quadratic function fitting. In the STIV analysis, STI images were created from 20 seconds of image data. QESTA by Fujita et al. (2018) is used for the STIV analysis. Since STIV does not use ortho images, image degradation due to geometric transformation can be ignored. On the other hand, DeepFlow estimates the motion of an object in a moving image. In this study, we used what is provided as an extension module Contrib of OpenCV 3.4 which is an open source computer vision library. Although the parameters in DeepFlow is difficult to change, the default values would be enough to conduct the same measurements as in this study. The video clip to be analyzed is the same as that of LSPIV. Regarding the comparison of flow rate estimation, the measurement result by ADCP shown in Figure 2 (e) is treated as a true value. ADCP results were obtained from the cross-sectional flow velocity and the measurement area. The flow rate was estimated by the piecewise quadrature method using the surface velocity multiplied by the surface velocity coefficient of α, with its conventional value of 0.85. Thus, the discharge is calculated from

$$Q = \int_A \alpha u \, dA \tag{1}$$

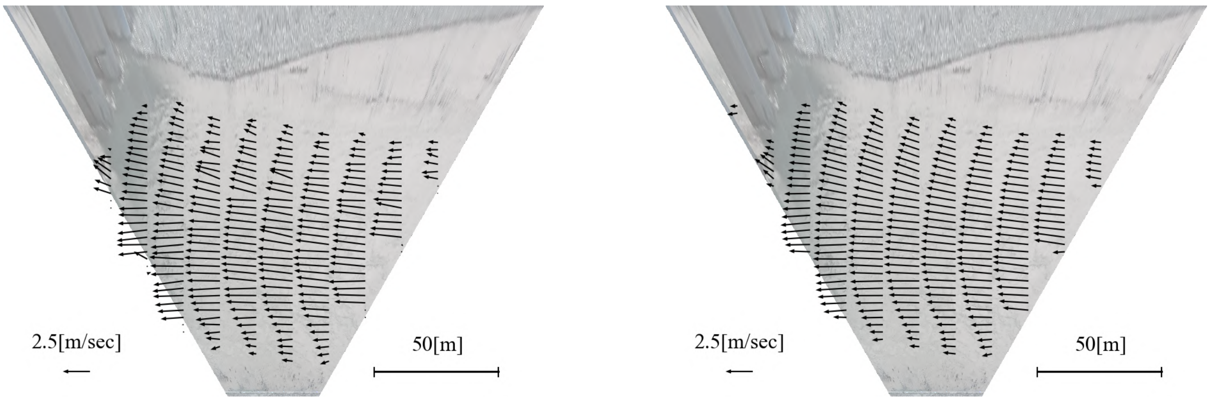
where, u is the streamwise velocity component and A is the cross-sectional area.

4. RESULTS AND DISCUSSION

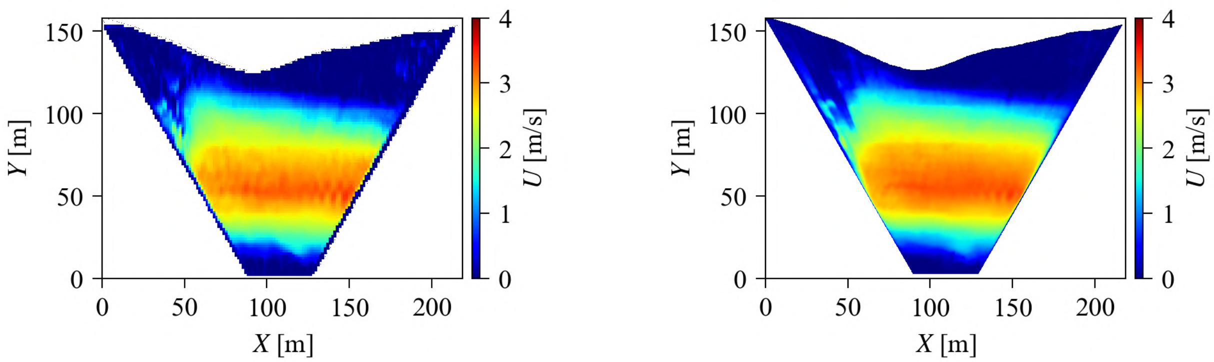
4.1 Comparison of time-average spatial distribution

Figure 3 (a) and (b) shows a vector plot of the time-averaged flow velocity by LSPIV and DeepFlow. The magnitude of the main flow velocity agrees well in both cases. However, DeepFlow yielded smoother variation than LSPIV. Figure 3 (c) and (d) shows a contour plot of streamwise component of the time-averaged flow velocity U by LSPIV and DeepFlow. DeepFlow shows smoother and sharper profile than LSPIV. This is because LSPIV measures at an interval of 20 pixels, while DeepFlow measures at every pixel coordinates. This is a significant feature of dense optical techniques. Table 1 shows a comparison of CPU time by LSPIV and DeepFlow. Here, two hundred sequential images at a sampling rate of 30 Hz with a size of 2990 × 2160 is used for each analysis, one of which is shown in Fig 2 (d). To compare the total CPU time, DeepFlow took twelve times longer than LSPIV but this is because the number of vectors analyzed is much larger than LSPIV. On the other hand, DeepFlow is thirty four times quicker in terms of the CPU time per vector. It should be noted that Table 1 is merely a rough comparison and ratios presented can differ depending on the calculation environments. However, it is clear that the calculation time by DeepFlow is at a practical level.

Figure 4 compares the time-averaged main flow velocity by LSPIV and DeepFlow. It is obvious that DeepFlow can provide surface velocity data quite similar to LSPIV quantitatively. As for the spanwise component, DeepFlow seems to give a little larger data that LSPIV but such variation can be negligible in the discharge measurements.



(a) Vector plot by LSPIV (b) Vector plot by DeepFlow

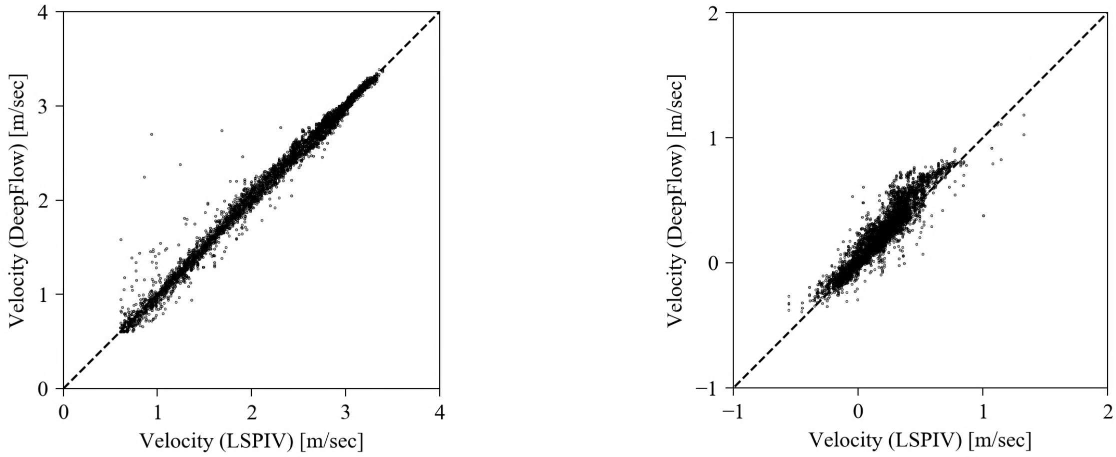


(c) Contour plot by LSPIV (d) Contour plot by DeepFlow

Figure 3. Mean velocity vector distribution

Table 1. Comparison of Calculation time

	Calculation CPU time per frame [minutes]	Calculation CPU Time per vector [msec]	Number of measurement points
LSPIV	26	100.12	147 × 106
DeepFlow	312	2.90	2990 × 2160



(a) Streamwise component (b) Spanwise component

Figure 4. Comparison of velocity between DeepFlow and LSPIV

4.2 Comparison of cross section average velocity and flow rate estimation

Figure 5 compares the transverse velocity distribution measure by the three image-based techniques and the ADCP data obtained nearest to the water surface. It can be seen that the three techniques yield quite similar results for the whole width of the river of about 90 m, except that STIV tends to show smaller value closer to the right bank. On the other hand, DeepFlow gives particularly consistent variation with LSPIV. It is interesting to note that ADCP data just below the water surface by 63 cm shows a non-uniform variation with high and low peaks but such an internal flow feature is not reflected on the surface velocity distribution. The cause of this discrepancy is not clear at the moment.

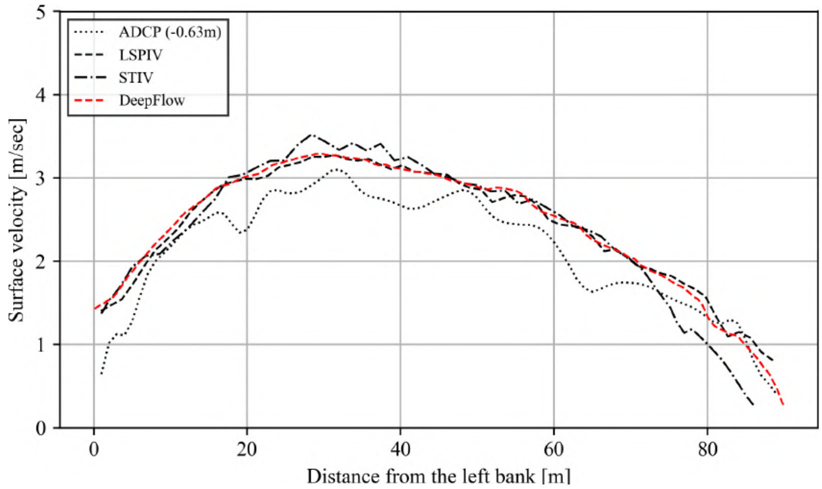


Figure 5. Cross-sectional distribution of streamwise mean velocity obtained by DeepFlow, compared with LSPIV, STIV and ADCP

Table 2. Comparison of discharge

	Discharge [cm^3/s]	Error [%]
ADCP	755.0	-
STIV	768.0	1.73
LSPIV	742.8	-1.61
DeepFlow	772.0	2.25

Table 2 compares the discharge measured by the respective method on April 27, 2017. The standard error with ADCP is also shown in the table. As a result, it can be concluded that either technique can provide discharge data comparable to ADCP in an image shooting condition in which river surface displays textures uniformly advected in the streamwise direction. The measurement error with respect to the ADCP data is less than 5%. From the above results, the optical flow technique is also applicable to the surface flow measurement as well as discharge estimation.

5. CONCLUSIONS

One of the optical flow techniques, DeepFlow, is examined for the surface flow measurement of the Shinano River. It was demonstrated through a comparison with the other image-based techniques such as LSPIV and STIV that DeepFlow can produce equivalent results to the existing techniques. It is interesting to note that DeepFlow gives almost the same results as LSPIV except that DeepFlow yields much smoother data. In addition, since DeepFlow is a high-density optical flow, velocity data at every pixel coordinates is obtained, which is difficult in the case of LSPIV. In that sense, high density optical flow techniques have a high potential for investigating detailed surface flow structures such as boiling vortices appeared on the water surface as long as a clear texture moving with the surface flow is observed in the video footage.

ACKNOWLEDGMENTS

The measurements at the site of the Shinano River was jointly conducted with the committee of advanced flow discharge measurement at the Japanese Society of Civil Engineers (JSCE) and The International Centre for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM). We are grateful for their support during the measurements. Also, we gratefully acknowledge the work of past and present members of our laboratory.

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