A DYNAMIC INTERPOLATION AND EXTRAPOLATION METHOD TO EVALUATE CROSS-SECTIONAL VELOCITY FROM POINT VELOCITY

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Abstract: This study presents a new technique to evaluate cross-sectional velocity from point velocity data with a numerical simulation, referred to here as the dynamic interpolation and extrapolation (DIEX) method, which has been developed to evaluate cross-sectional velocity from line velocity measured with a Horizontal Acoustic Doppler Current Profiler (H-ADCP). We apply the present method to evaluate cross-sectional velocity and discharge from simulated float velocity at several points derived from cross-sectional velocity measured using an ADCP in the Edogawa River, Japan, under high-flow conditions. The results indicate that the present method can readily be used to calculate the cross-sectional velocity from point velocity. Other results indicate that the relative errors of velocity and discharge evaluated using the present method are appreciably lower than when using the previous method. It should be noted that the relative errors in the present method may remain low even with fewer floats.

Keywords: discharge; DIEX method; point velocity; float; data assimilation; river flow

1. INTRODUCTION

For accurate river-discharge measurements, various velocimetric tools, such as floats, propellers, electro-magnetic sensors, image processing techniques, radio current meter and Acoustic Doppler Current Profiler (ADCP), have already been developed. On the other hand, although the point and line velocities measured by the above sensors should be translated into cross-sectional velocity and discharge, there isn’t any appropriate technique for evaluation of cross-sectional velocity from the measured point and line velocities. However, we have developed a new technique, referred to here as the dynamic interpolation and extrapolation (DIEX) method, to evaluate cross-sectional velocity from line velocities measured using H-ADCP, and demonstrated its validity under low- and high-flow conditions. Because point velocimetry is more common than line velocimetry such as H-ADCP, it is necessary to develop a technique to evaluate cross-sectional velocity from several point velocities, and as such, the DIEX method is a promising technique.

In order to further advance and promote the DIEX method, we introduce an algorithm of point-data assimilation into the DIEX method. We apply the present method to evaluate cross-sectional velocity and discharge from simulated float velocity at several points derived from cross-sectional velocity measured using an ADCP in the Edogawa River, Japan, under high-flow conditions. In order to check its performance, the evaluated cross-sectional velocity and discharge are compared with the results measured with an ADCP.

2. OUTLINE OF THE PRESENT METHOD

2.1 FUNDAMENTAL STRUCTURE

Figure 1 shows a schematic view for the fundamental structure of the present method, which comprises of field observations and numerical simulations. For the field observations, velocimetry was based on tools such as floats and radio current meter-observed point velocity at several points in a cross section. Next, for the numerical simulations, river flow simulations, which reflect the observed results using the data-assimilation technique, are performed over the cross section, and the cross-sectional velocity and discharge are evaluated.

2.2 IMPROVEMENT IN DIEX METHOD

For computational efficiency and assimilation of the measured velocity, a simplified fundamental equation for fluid motion is used in the DIEX method and given as:

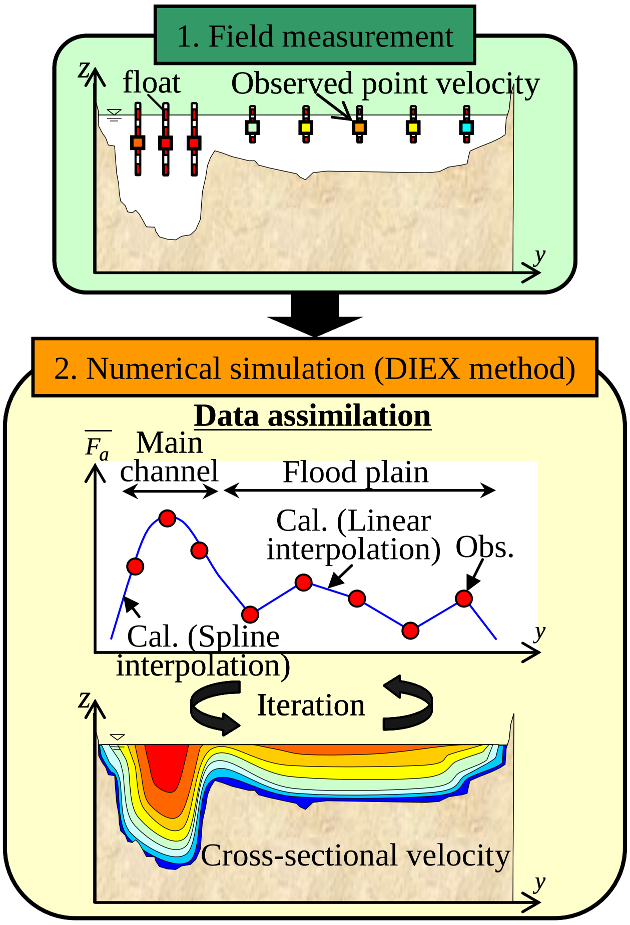


Figure 1. Fundamental concept of the present method

$$gI+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{1}{D^2}\frac{\partial}{\partial \sigma}\left(A_V\frac{\partial u}{\partial \sigma}\right)-\frac{aC_b}{2}u^2+F_a=0\,, \qquad (1)$$

where *u* is the streamwise velocity, A_H and A_V are the horizontal and vertical eddy viscosities, *D* is water depth, and *a* and C_b are the density and drag coefficients of the vegetation, respectively. To replace the omitted terms such as advection, diffusion and unsteady terms, an additional term F_a is introduced into the above equation and applied for the data assimilation in which the following depth-averaged momentum equation is solved:

$$gI+\frac{\partial}{\partial y}\left(\overline{A_H}\frac{\partial \bar{u}}{\partial y}\right)-\left(\frac{C_f}{D}+\frac{aC_b}{2}\right)\bar{u}^2+\overline{F_a}=0\,, \qquad (2)$$

where $\bar{u}$ is the depth-averaged streamwise velocity, $\overline{A_H}$ is the depth-averaged horizontal eddy viscosity, F_a is the depth-averaged additional term, and C_f is the coefficient of the bottom friction.

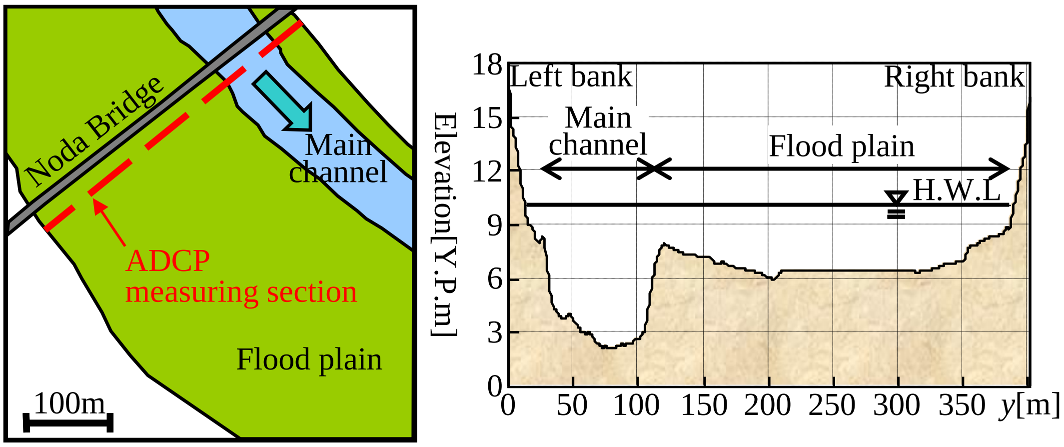
Although the original DIEX method assimilated the line velocity, it is necessary to advance the algorithm of data assimilation to assimilate point velocities in this study.

Firstly, vertical elevation of assimilated data is changed from the fixed H-ADCP's elevation to the point velocity-observed elevation. This study assumes the elevation where a float was observed to be half of the float's draft.

Secondly, if $\overline{F_a}$ is interpolated and extrapolated over the entire cross-section, then its distributions may be unnatural because the point velocity's spatial resolution is lower than that of the line velocity. Therefore, the range of interpolation and extrapolation of F_a is divided into main channel and flood plain. Using the least squares method, we obtained a cubic expression as an approximation in the same way as the original DIEX method in the main channel, a linear expression in the flood plain. In the flood plain, velocity resolution is very low and as the velocity profile spanwise is very complicated because of vegetations, a cubic expression is not appropriate.

3. CREATION OF SIMULATED FLOAT DATA

In order to evaluate the performance of the present method in detail, we verified the accuracy of the velocity and discharge with simulated float data created from the cross-sectional velocity under high-flow conditions measured using an ADCP in the middle reaches of the Edogawa River, which flows near Tokyo, Japan. In order to create simulated float data from cross-sectional velocities measured by ADCP, we averaged the velocity data located above draft, and assumed that the elevation at which the float was observed is half of the float's draft. The float's length and coefficient are changed according to the depth with reference to the Manual for River Works in Japan. The number of floats was varied between 3, 4, 5, and 6 in the main channel, and 3, 5, 8, and 14 in the flood plain to assess the influence of float data resolution. We regarded the case where three were used in the main channel and five in the flood plain as the reference case. The present paper shows the results only for the reference case. Using simulated float data, we evaluated the velocity and discharge using both the present and previous method, and then compared these with the velocity and discharge observed with an ADCP, which was used to create simulated float data. In the previous method, the depth-averaged velocity was calculated from the observed velocity and float's coefficient, and a uniform spanwise distribution is given for a section.



(a) Map **(b)** Cross section

Figure 2. Outline of the field site

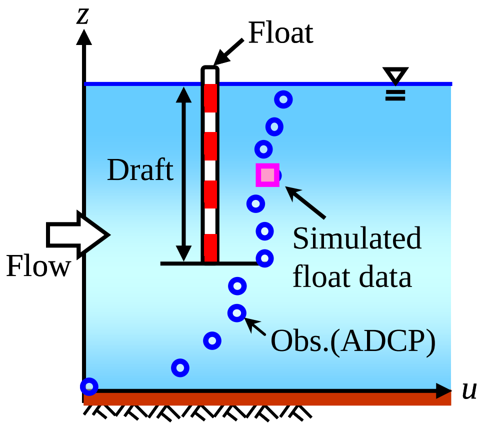


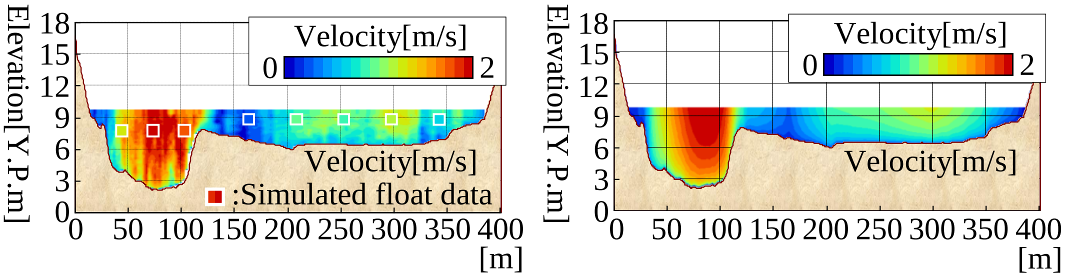
Figure 3. Creation of simulated float data

4. RESULTS AND DISCUSSION

4.1 Velocity

Figure 4 shows the counter for the streamwise velocity observed by the ADCP and calculated by the DIEX method (reference case) during peak flooding. In Figure 4(a), the simulated float data is also shown. Figure 4(a) indicates that velocity increases near the right bank in the main channel, and the spatial fluctuations of the velocity are large in the flood plain. Figure 4(b) indicates that the present method can smoothly calculate the cross-sectional velocity from point velocities. Generally, assimilation methods such as the nudging scheme struggle to assimilate observed data if it has low spatial resolution. A comparison of the measured and calculated contours reveals similar patterns between the calculated and measured velocities in the main channel.

As a detailed comparison, Figure 5 shows the observed and calculated depth-averaged streamwise velocity distributions. Figure 6 shows the vertical distributions of measured and calculated streamwise velocities at y = 60 m, 75 m, 210 m and 225 m. In those figures, the velocities assimilated for numerical simulations are also shown. The calculated results using the present method are in good agreement with the measured results in the main channel, but a little lower in the flood plain. On the other hand, the calculated results using the previous method do not agree with the measured results, because the velocity distribution is uniform in each section. Disagreement is most conspicuous near the bank. The accuracy of the velocity evaluated by the present and previous methods can be quantified by the root mean square (RMS) value of the relative error. The RMS values of the relative error for all results are 0.15 m/s and 0.33m/s respectively in the present and previous methods. Furthermore, the calculated results for vertical distributions at data assimilation points (y = 75 and 210 m) are in good agreement with the measured results. In non-assimilation data (y = 60 and 225 m), the calculated results are almost in agreement. Thus, the evaluation procedures in the DIEX method can accurately reproduce the lateral and vertical velocity distributions.



(a) Observed result **(b)** Calculated result

Figure 4 Counter for streamwise velocity during peak flooding on September 7, 2007.

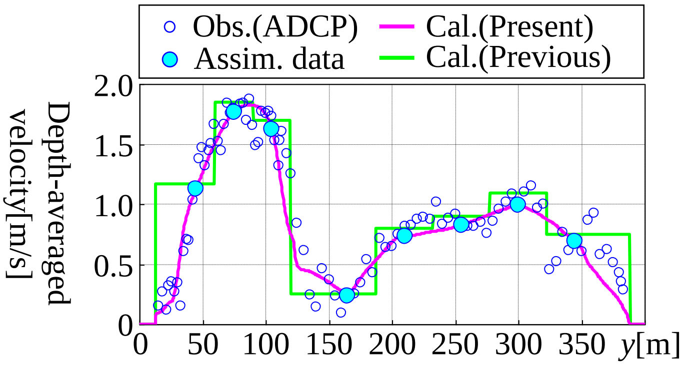


Figure 5 Lateral distribution of observed and calculated depth-averaged velocities on September 7, 2007.

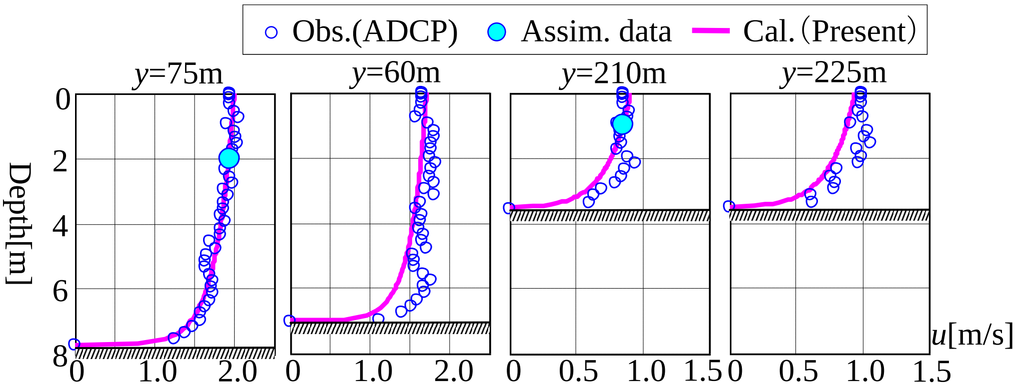
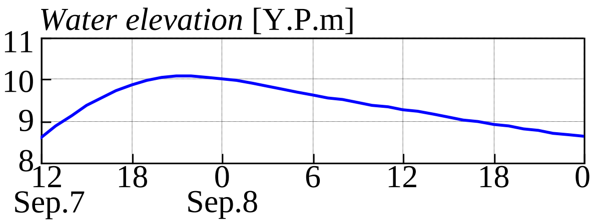


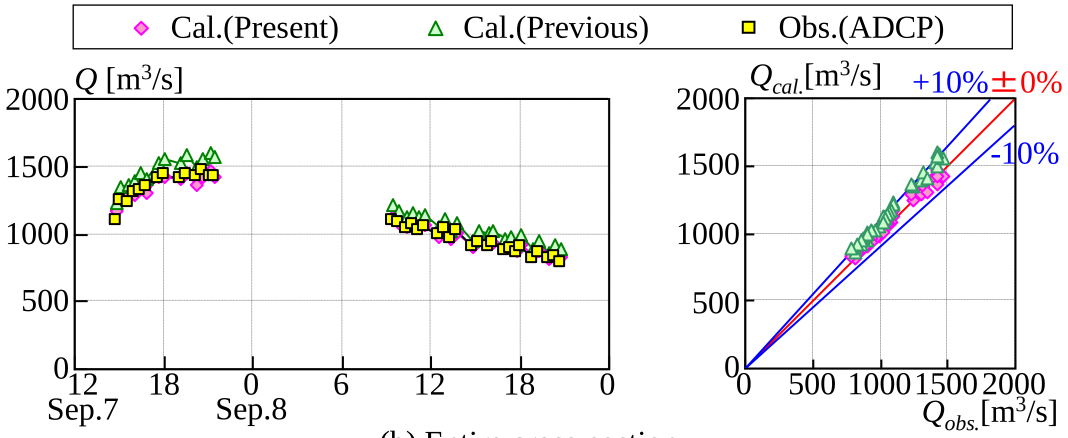
Figure 6 Observed and calculated vertical profiles of velocities u [m/s] on September 7, 2007.

4.2 Discharge

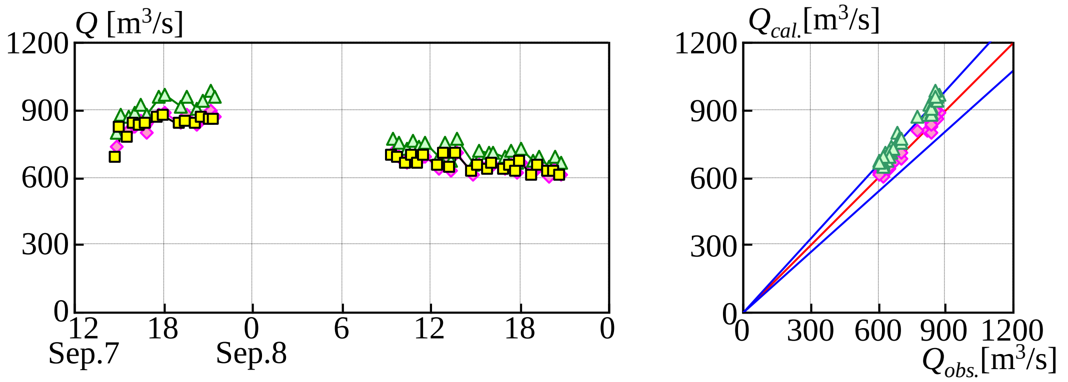
In order to validate the evaluation of discharge using the present method, Figure 7 indicates the temporal variations in river discharge measured by ADCP and calculated using both the present and previous methods, which are presented separately for the entire domain, the main channel and the flood plain. Over the entire domain, the calculated discharges using the present method are in good agreement with the observed discharges. On the other hand, the calculated discharges derived from the previous method are larger than the observed discharges. The same trend applies to the main channel. However, the difference between the present and previous methods is relatively small in the flood plain.



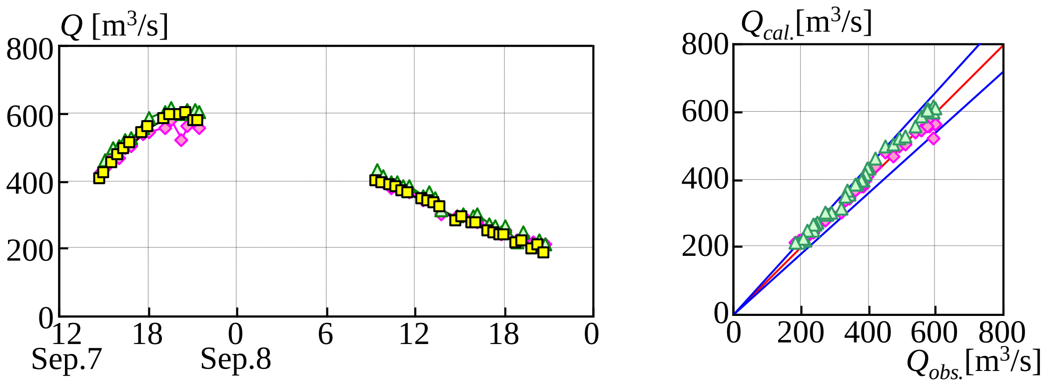
(a) Water elevation



(b) Entire cross-section



(c) Main channel



(d) Flood plain

Figure 7. Temporal variation of water elevation and the calculated and observed discharge, and Comparison of the observed discharge Q_{obs} and calculated discharge Q_{cal}

In order to validate the numerical accuracy of each method in detail, the observed and calculated discharges, Q_{obs} and Q_{cal}, are also represented in Figure 7 separately for the entire domain, main channel and flood plain. The difference between Q_{obs} and Q_{cal} is specified by the 0% and 10% relative errors, displayed with red and blue lines, respectively. Over the entire cross-section, the similarity between the results derived from the previous method and the observed data is almost illustrated in the figure, with a relative error of less than 10%. By contrast, the results for the present method were plotted with a near 0% discrepancy. The RMS values of the relative errors for all results are 2.6% and 8.9% respectively in the present and previous methods, demonstrating the greater accuracy of the present method over the previous method. In the same way, the RMS values of the relative errors of the present method are 2.6% and 5.4% versus that of the previous method at 10.3% and 7.5%, in the main channel and flood plain, respectively. This indicates the superior accuracy of the present method over the previous method in both the main channel and flood plain.

5. CONCLUSIONS

In this study, we applied the DIEX method, which has been developed as a technique to interpolate and extrapolate line velocities measured using an H-ADCP to evaluate cross-sectional velocity and discharge from point-velocity data measured using various velocimetric tools, and confirmed its performance.

We developed the DIEX method, which evaluates cross-sectional velocity and discharge from point velocity by improving the data assimilation algorithm.

The relative velocity errors derived from the DIEX method are less than half those of the previous method in a test using simulated float data derived from cross-sectional velocities measured with an ADCP in the Edogawa River, Japan, under high-flow conditions. In the reference case, the relative errors of discharge are 2.6% and 8.9% in the present and previous methods respectively. These facts demonstrate that the DIEX method enables highly accurate velocity and discharge evaluations.

This study was supported by the River Research and Development Institution in 2010 under the Ministry of Land, Infrastructure, Transport and Tourism of Japan. The authors would like to express their sincere appreciation to the students of the Hydraulics Laboratory at the Department of Civil Engineering, Tokyo University of Science, for their help in conducting field observations for this study.

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