A NEW DISCHARGE MONITORING SYSTEM WITH AN H-ADCP MEASUREMENT AND NUMERICAL SIMULATION

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ABSTRACT

To realize accurate and continuous monitoring for river discharge at a low cost, a new monitoring system with H-ADCP (horizontal acoustic Doppler current profiler) measurement and river-flow simulation has been developed. The H-ADCP can measure the velocity profile at a horizontal line. In the numerical simulation, the measured velocities are interpolated and extrapolated in a cross section with a proper physical background. The proposed computational method is therefore referred to as the dynamic interpolation and extrapolation (DIEX) method. To confirm the fundamental performance of the new monitoring system, the H-ADCP measurement was made at the middle reach of the Edo River in Japan and the river discharge was evaluated with this method. The simulated discharge was compared with the results measured with an ADCP and a Price current meter. The results indicate that the simulated discharge shows good agreement with the observed data, demonstrating the fundamental performance of this monitoring system for river discharge.

Keywords: discharge; H-ADCP; data assimilation; real-time monitoring; river flow

1 INTRODUCTION

River discharge has been widely used in not only hydrology and river engineering, but also limnology, oceanography, and so on. It is therefore desirable to perform automatic, continuous and accurate evaluations of river discharge under various flow conditions, including drought and flood conditions (e.g., Rantz, 1982, Oberg et al., 2005).

One possible way for discharge measurements to satisfy the above demand is to adopt an H-ADCP (horizontal acoustic Doppler current profiler), which can measure the horizontal profile of velocity across a channel (Wang & Huang, 2005), as shown in Fig.

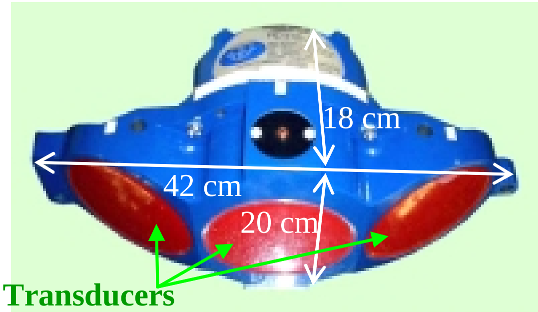

Fig. 1 Photograph of an H-ADCP.

1. This instrument transmits acoustic signals in a horizontal line and receives the signals reflected by suspended matter such as sediments. Then, the water velocity can be calculated by the Doppler effect. When using an H-ADCP for flow monitoring, although it can collect a velocity profile at a horizontal line, it may not measure directly the velocity distribution over the whole cross section and, hence, the discharge.

To solve this issue, Daitoh et al. (2001) developed an automatic scanning system with an H-ADCP that can change the vertical position of the H-ADCP and then collect the velocity in the whole cross section. This system has already been applied for discharge measurement in several rivers in Japan. However, the system is very large and expensive and hence is not yet widely used.

To evaluate river discharge from the horizontal velocity profile with a proper physical background at a low cost, one promising tool is to perform a river-flow simulation that assimilates the field data obtained by the H-ADCP. For this purpose, in this study, we developed a new monitoring system of river discharge with an H-ADCP measurement and river-flow simulation. In the numerical simulation, the measured velocities at a horizontal line are interpolated and extrapolated over a cross section with a proper physical background. The proposed computational method is therefore referred to here as a dynamic interpolation and extrapolation (DIEX) method. To confirm the fundamental performance of the new monitoring system, the H-ADCP measurement was conducted at the middle reach of the Edo River, Japan and the river discharge was evaluated with the proposed method. The simulated discharge is compared with the results measured with an ADCP and a Price current meter.

2 OUTLINE OF THE NEW DISCHARGE-MONITORING SYSTEM

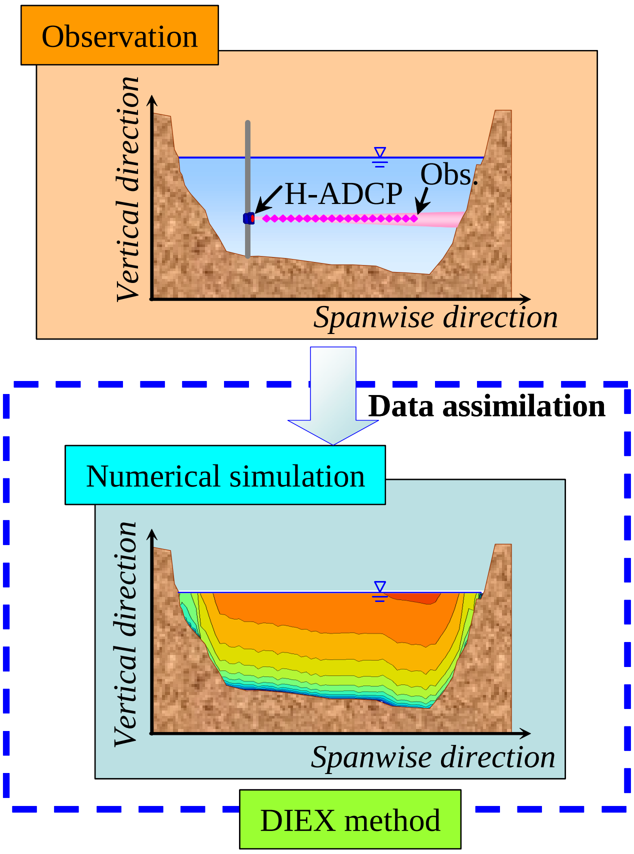

Fig. 2 Fundamental structure of this monitoring system.

2.1 FUNDAMENTAL STRUCTURE

The new monitoring system for river discharge consists of the combined two sub-systems, as shown in Fig. 2. One system is the field observations for the horizontal velocity profile by using H-ADCP, and the other is numerical simulations, in which the observed velocities at a horizontal line are interpolated and extrapolated over a cross section with the DIEX method.

In the field measurements, an H-ADCP is mounted near the bank in a main channel, as depicted in Fig. 1, to measure the horizontal velocity profile at a fixed height. The 600 kHz H-ADCP (Teledyne RDI) used in this study can collect the velocity profile at a horizontal range up to 70-100 meters. Since the river width in the field site of this study is about 70 m, as shown below, the H-ADCP may obtain the velocity profile near the opposite bank.

In numerical simulations, to interpolate and extrapolate the measured horizontal velocity profile with dynamic principles, a three-dimensional (3D) river-flow computation is performed and the velocity distribution over the whole section and discharge can be

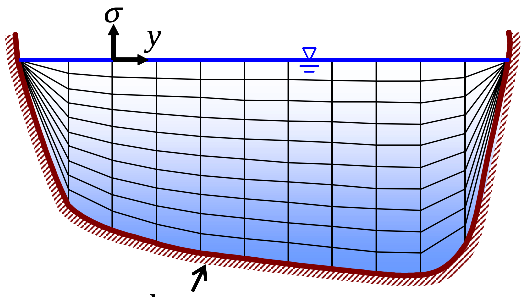

Fig. 3 Coordinate and computational grid in the DIEX method.

evaluated. To reflect the observed results in the numerical simulations, we present the DIEX method, which incorporates a new approach for data assimilation.

2.2 OUTLINE OF THE DIEX METHOD

To realize the real-time and accurate monitoring of river discharge, we present the DIEX method, in which a new approach of data assimilation is incorporated with less computational load. To appreciably reduce the heavy computational load inherent in general 3D current computations by using the DIEX method, we select the necessary terms in a 3D momentum equation for discharge evaluation and simplify the 3D momentum equation. For computational efficiency, a cross section is chosen as the computational domain, as shown in Fig. 3. A sigma coordinate, one of the boundary-fitted grids, is adopted in which y and σ are the transverse and vertical directions, respectively. An example of the grid arrangement of the sigma coordinate is displayed in Fig. 3. The simplified fundamental equation for fluid motion is then expressed as

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

where t is time, u is velocity in the streamwise (x) direction, D is water depth, g is the gravitational acceleration, I is the slope of the water elevation, and A_H and A_V are the horizontal and vertical eddy viscosities, respectively. Instead of the neglected terms such as advection terms in the equation, an additional term F_a is introduced, which compensates for the effects of the neglected terms (Nihei & Kimizu, 2006). The added F_a is determined from the measured horizontal velocities to assimilate the field data into the numerical simulation. The assimilated approach in the present method is based on that reported by Nihei & Kimizu (2006). As a more accurate method for data assimilation, the proposed method introduces a numerical procedure that minimizes the measuring errors of the velocity obtained by H-ADCP to satisfy the momentum equation.

To obtain the solution of the velocity *u* using Eq. 1, a finite difference solution has been adopted in the current study. Using a second-order central difference scheme for the horizontal and vertical diffusion terms in Eq. 1, the finite difference equation is given as:

$$\frac{A_{H_{i+1/2,j}}\left(u_{i+1,j}-u_{i,j}\right)-A_{H_{i-1/2,j}}\left(u_{i,j}-u_{i-1,j}\right)}{(\Delta y)^2}+\frac{A_{V_{i,j+1/2}}\left(u_{i,j+1}-u_{i,j}\right)-A_{V_{i,j-1/2}}\left(u_{i,j}-u_{i,j-1}\right)}{(D_i\Delta\sigma)^2}+gI+F_{a_i}=0 \quad (2)$$

where the subscript *i* and *j* refer to the grid number in the spanwise and vertical directions, respectively, and Δy and $\Delta\sigma$ are the grid intervals in the spanwise and vertical directions, respectively. To evaluate the velocity distribution and discharge, Eq. 2 is solved using the measured velocities in the cross section through the following four steps:

1. F_a at each observational point is evaluated with Eq. 2 and the measured velocities.
2. The spanwise and vertical distributions of F_a in the cross section are given by spatially interpolating and extrapolating F_a at the observational points.
3. The velocity in the streamwise direction *u* is given using Eq. 2 and the value of F_a obtained in step 2.
4. The calculation of steps 1, 2 and 3 is repeated until the solution of Eq. 2 converges.

A nudging scheme, one of the previous approaches for data assimilation (e.g., Robinson et al., 1998), has significant problems in assimilating smoothly observed data into numerical computations. On the other hand, the proposed method for data assimilation can incorporate smoothly the influence of the measured data into the computational results over a whole cross section by introducing the additional term F_a into Eq. 1.

3 APPLICATION OF THE NEW SYSTEM TO DISCHARGE MONITORING IN THE EDO RIVER

3.1 FIELD MEASUREMENT

Continuous monitoring of river discharge using the new system was conducted in the middle reach of the Edo River flowing into Tokyo Bay, Japan. Figure 4(a) and (b) show the plane and cross-sectional views of the field site. The 600 kHz H-ADCP was mounted in the staff gauge located near the left bank of the main channel. The H-ADCP emits three acoustic signals into the water column, as depicted in Fig. 4(c), and two of

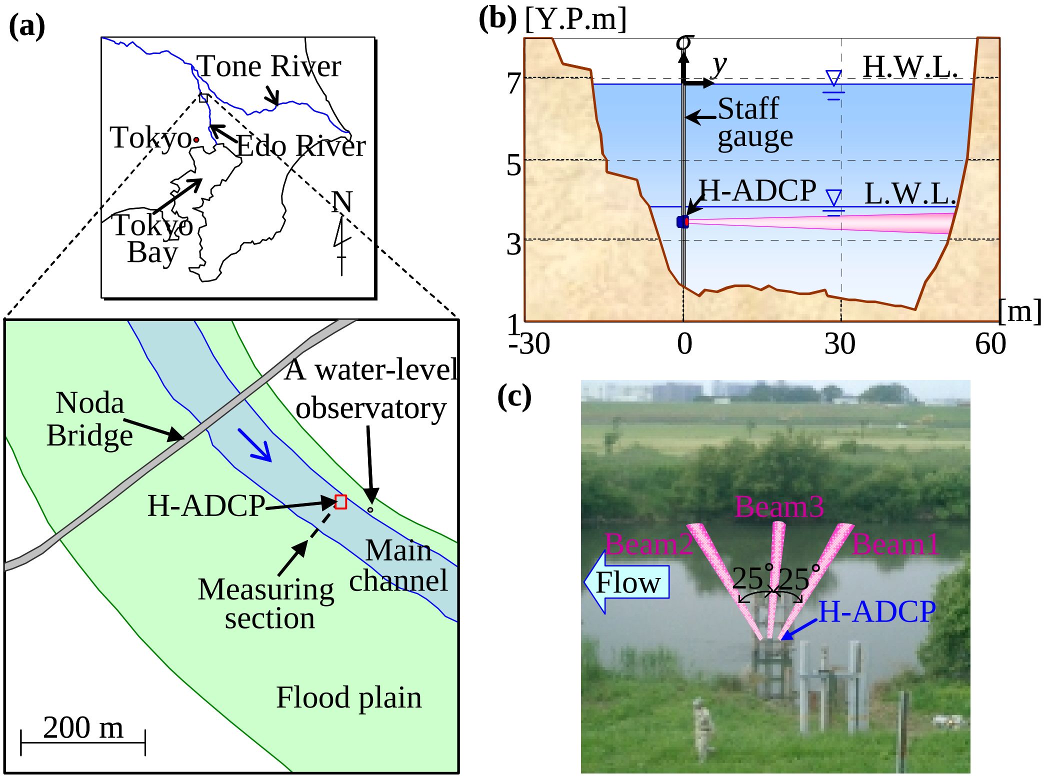

Fig. 4 (a) Plane view, (b) cross-sectional views, and (c) photograph of the field site.

three signals, Beam1 and Beam2, are used to calculate the streamwise and spanwise velocities. The observational period was from September 5 to December 6, 2005. The H.W.L. and L.W.L. in the period are depicted in Fig. 4(b). As shown in Fig. 4(a), the Edo River has a compound cross section. Although the flood plain was wet at H.W.L., there were no dominant currents on the flood plain. For the settings of the H-ADCP, the cell size and number were 1.0 m and 80, respectively, the sampling interval was 10 minutes and the blank distance was 1.0 m.

To validate the fundamental performance of the new monitoring system, a 1200 kHz ADCP (Teledyne RDI) was used to measure the velocity distribution and discharge at the field site. Also, the discharge measured by a Price current meter was also used to compare the discharge evaluated with our system.

3.2 NUMERICAL SIMULATION

After the horizontal velocities were measured with the H-ADCP, the discharge in the observational period is evaluated using the DIEX method. The computational domain is the main channel of the cross section, since a flood flow did not occur on the flood plain, as mentioned above. The grid numbers in the spanwise and vertical directions are 73

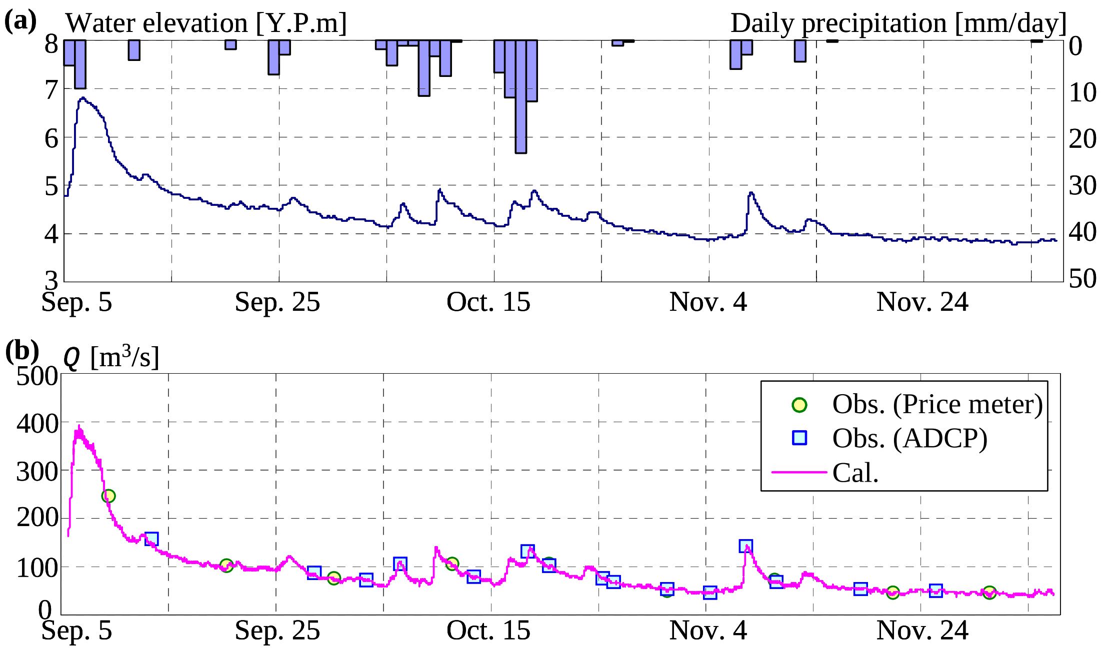

Fig. 5 Time series for (a) water elevation and precipitation and (b) discharge.

and 100, respectively. The grid interval is 1.0 m in the spanwise direction.

3.3 RESULTS AND DISCUSSION

Figure 5 indicates the temporal variations of the observed and simulated discharges with those of water elevation and daily precipitation. The observed discharges are obtained with the ADCP and Price current meter. The results indicate that the temporal variations of the simulated discharge are somewhat similar to those of the observed water elevation. Note that the simulated discharge shows good agreement with the observed results.

To validate the numerical accuracy of the new system in detail, the correlation between the observed and simulated discharges, Q_{obs} and Q_{cal}, is represented in Fig. 6. To indicate explicitly the difference between Q_{obs} and Q_{cal}, 0% and 10% of the relative errors are displayed with solid and broken lines, respectively. The figure illustrates that the results of this system are almost the same as those of the observed data, and the relative error of all simulated results is less than 10%. The RMS (root mean square) value of the relative error for the simulated results is 3.9%. These facts demonstrate that the new monitoring system achieves high performance for the continuous monitoring of river discharge.

4 CONCLUSIONS

To realize accurate and continuous monitoring for river discharge at a low cost, a new

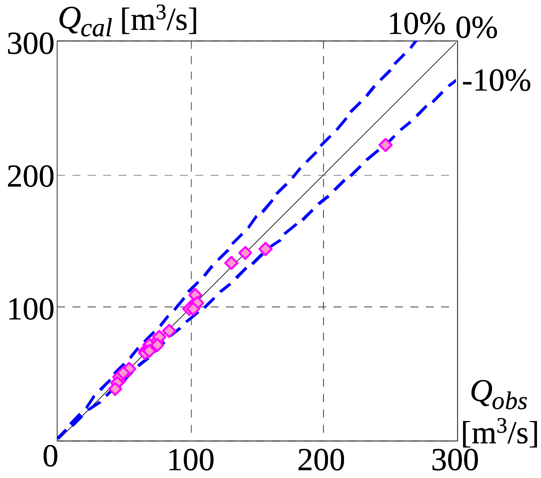

Fig. 6 Correlation of observed and simulated discharges, Q_{obs} and Q_{cal}.

monitoring system with an H-ADCP measurement and river-flow simulation has been developed. In the numerical simulation, the measured velocities at a horizontal line are interpolated and extrapolated in a cross section with a dynamic interpolation and extrapolation (DIEX) method. To confirm the fundamental performance of the new monitoring system, H-ADCP measurement was done at the middle reach of the Edo River in Japan. The simulated discharge was compared with the results measured with an ADCP and a Price current meter. The results indicate that the simulated discharge shows good agreement with the observed data, demonstrating the fundamental validity of this monitoring system for river discharge.

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