UVP Measurement for Flows Accompanying Free Surface

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For environmental conservation, we attempted to develop a measurement system with high efficiency and high accuracy for fluid flow with interface; namely, fixed river bed with irregular surface and moving free surface. The detection method of the bottom position on a measurement line of UVP by using the probability density for zero velocity was established and confirmed by the laboratory experiment using an open channel. We measured velocity distribution in cross-section of an actual river by UVP, and the bottom of the river was determined by the established method. Discharge of the river was obtained by integrating the velocity distribution, and compared with a reference discharge determined by weir. We confirmed that this discharge measurement has high accuracy and high efficiency in comparison with the conventional techniques. On the other hands, we also attempted to establish the method to determine position of the moving free surface by analyzing Ultrasonic (US) echo signal. UVP measurement was synchronized with US displacement meter to confirm the method.

Keywords: Environmental flow, Ultrasonic technique, Velocity Profile, Free surface, Interface detection

1 INTRODUCTION

For environmental conservation, it is important to measure a discharge of environmental flow with high accuracy and high efficiency. The discharge is currently determined by applying an empirical equation estimated in an ideal system. Actual environmental flow in large scale, however, has many uncertain factors and thus the estimated discharge has large uncertainties and errors, which may be an order of several tens to one hundred percent. Therefore such an estimation method of discharge is not suitable, for instance, for a precise control of the volume of water kept in storage. On the other hand, the current measurement technique requires measuring the depth of water by a scale at several points to determine a shape of a cross-section of flow field in order to estimate the discharge. Such a measurement takes long time and reduces efficiency of the measurement.

Until now, we have studied environmental flow measurement by using ultrasonic velocity profiler (UVP) [1] to realize more accurate measurement of the discharge in two typical configurations; an open channel flow [2] and an overflow [3]. Cross-sectional velocity distribution in the both configurations was measured by UVP. Discharge, which is calculated by integrating the velocity distribution, was compared with discharge determined from the empirical equation, and it was confirmed that the obtained discharge has high accuracy for the both configurations.

In the measurement of the open channel flow, an ultrasonic (US) transducer was mounted at the top of the channel and the measurement line of UVP was set toward to the bottom. In this case, cross section of the channel has a certain form and thus it is not necessary to measure the depth of water. However, in an actual river, measuring the bottom position is required. On the other hand, in the measurement of overflow, an US transducer was mounted under the weir and the velocity profile was measured on the vertical direction upward. To reduce error in the measurement of the discharge, we must acquire the position of the free surface on the measurement line. But the detection of moving free surface has further difficulties than the detection of the bottom position in the open channel flow since it is time dependent. In the both cases, if detection of the interfaces becomes available without using another tool such as a scale, the efficiency of environmental flow measurement using UVP might increase significantly.

In this study, we established the detection method of bottom position on measurement line in the open channel. The method was confirmed in the laboratory open channel and was later applied to measurement of an actual small river. We also attempted to establish a method to detect moving free surface by analyzing ultrasonic echo signal, which is used for obtaining instantaneous velocity profile in UVP measurement.

2 MEASUREMENT OF RIVER

2.1 Detection of Bottom Position

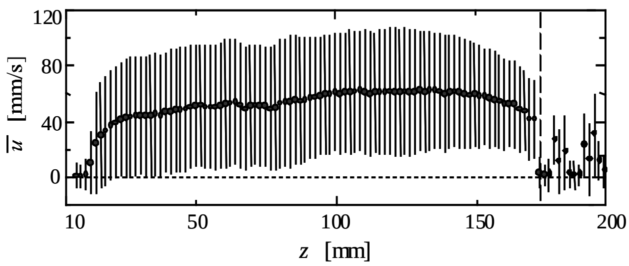
Figure 1(a) shows a temporally averaged velocity profile measured in the open channel. The horizontal axis, z, represents the distance from US transducer, and the vertical axis is the mean velocity. Error bar represents standard deviation of the velocity fluctuation. In this measurement, distance from the transducer to the bottom is 175 mm. Near the bottom, the mean velocity decreases to around zero and standard deviation also has small value. Viscous fluid has a no-slip condition at a rigid boundary and thus the profiles show such a behavior. Profile beyond the bottom position shows a velocity measured by reflected US beam at the bottom and it is difficult to determine which velocity was measured. In the ideal situation, a position at which the velocity becomes zero corresponds to the bottom. In UVP measurement, however, each measurement point has non-negligible measurement volume and velocity becomes not always zero even at the bottom.

Figure 1(b) shows the probability density distribution for zero velocity *Pd*, where “zero velocity” means a velocity smaller than the velocity resolution. The probability has a high value around the bottom. We attempt to utilize this value to determine the bottom position as follows: *Pd* is almost zero at the flow area, but rapidly increases near the bottom. We make a threshold for the probability density suitable to determine the bottom. The bottom is determined as a position at which *Pd* first passes this threshold at each measuring line.

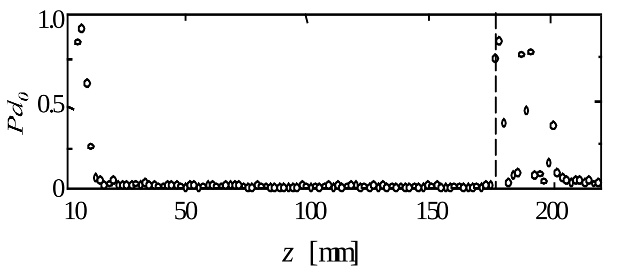
Figure 2 shows the detected bottom position of the open channel. The horizontal axis represents the spanwise position of the channel and the vertical axis is the depth of water. The continuous line represents the actual bottom measured by scale. Threshold is chosen as 0.3. The detected points are very close to the actual bottom measured by scale at every measure line. Error for the detected bottom is less than 3 mm. In this case, the spatial resolution of UVP is 1.78 mm, so this method might be practical.

2.2 Measurement

We obtained a data in a small river; of which a width is about 1600 mm. It flows out from a small lake in the Hokkaido University campus. Figure 3 is a photograph of measurement configuration in the river and Figure 4 shows the schematic of coordinate system and measurement location with some typical scale in the river. The interval between density for zero velocity in the open channel each measurement line is 100 mm. There is a big stone at upstream of the measurement location for y = 800 to1000 mm. The depth at y = 0 to 1300 mm is comparatively deeper and the bottom is covered by small stones, whose size is around 10 mm. The area around y = 1300 to1600 mm is shallow and waterweed coverers the bottom. Reference depth was measured by a scale at each measuring line. The rectangular weir was located at the inlet of the river from the lake and the reference discharge was determined by an empirical equation with the water level over the weir.



(a)



(b)

Figure 1: (a) Velocity distribution and (b) Probability

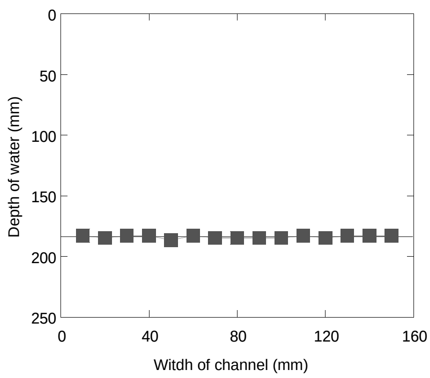


Figure 2: Bottom of the open channel determined by established probability density method

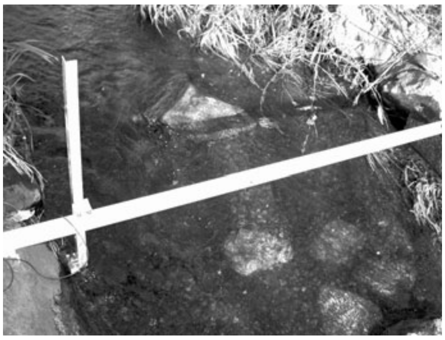


Figure 3: Photograph of the measurement configuration in river

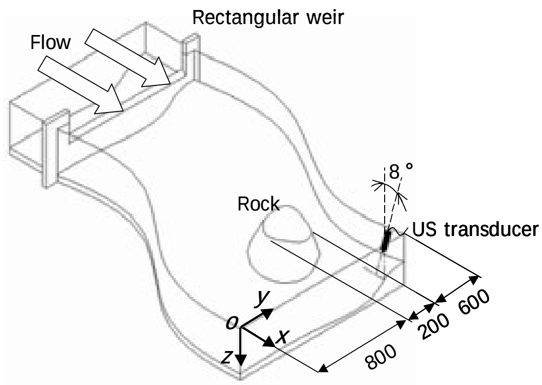


Figure 4: Coordinates and measurement location at the river

The number of profiles measured by UVP is 1024 and the sampling period is 100 ms. The number of measurement points on a measurement line is 128. The distance between each point is 1.48 mm. The velocity resolution is 30.6 mm/s.

2.3 Result

Figure 5 shows the form of the cross section in the river determined by the both method; the probability density method explained above and a scale measurement. The horizontal axis represents *y* and the vertical axis is *z*. The average of the difference between the results obtained by the both methods is negligibly small, 8 mm. In the range of y = 1400 to1600 mm, corresponding to the waterweed condition, the bottom position is detected shallower than the position measured by the scale, because the ultrasonic beam is scattered by waterweed and cannot reach actual bottom through the waterweed.

Cross sectional mean velocity distribution of the river is shown in Fig.6. as estimated being based on the both of the obtained velocity profiles and the detected bottom. The flow discharge can be estimated by integrating the velocity distribution. The distribution shows a reverse flow region around *y* = 800 to 1000 mm due to the wake behind the big stone. The obtained discharge is 48.5 l/s. Reference discharge measured by the rectangular weir is 55.0 l/s and thus the error of the provided measurement is 12%. This value is comparably smaller than conventional methods although the weir method has large error.

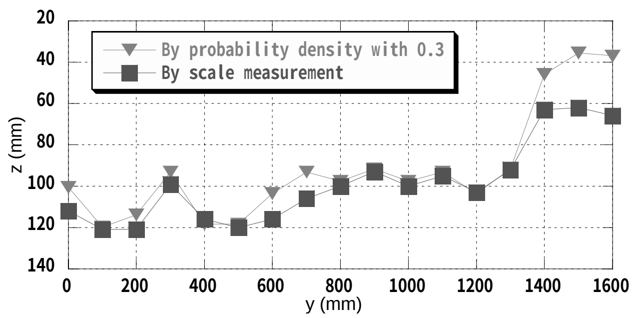


Figure 5: Bottom position of the river determined by the probability density method

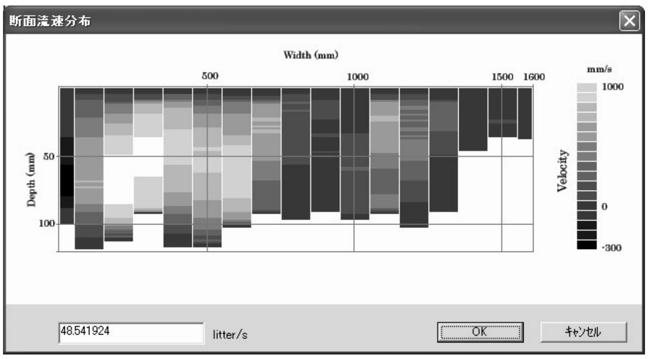


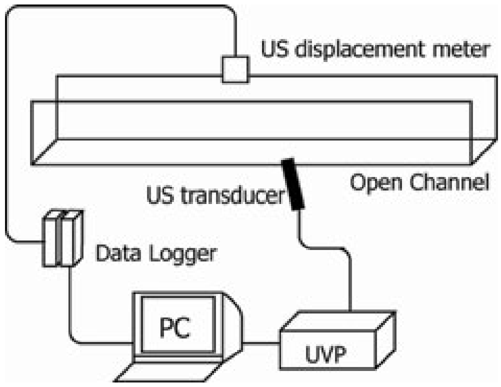
Figure 6:Velocity distribution at cross section of river calculated from the obtained velocity profiles and the detected bottom position.

3 MEASUREMENT OF FREE SURFACE

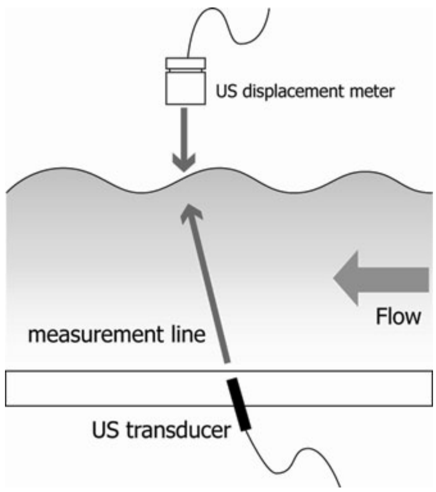
3.1 Experimental Apparatus

The commercial UVP systems in pulse-Doppler method use information of amplitude of ultrasonic echo only for detecting phase delay. We attempt to utilize the information to determine a moving free surface in flow accompanying free surface. We constructed UVP system by ourselves based on pulser/receiver board (Matec, TB-1000) and A/D board (Aqiris, DP105) to obtain temporal variation of ultrasonic echo.

We measured the flow in an open channel with the constructed UVP system to establish the method to detect moving free surface. Figure 7(a) shows the schematic illustration of the experimental setup. An US transducer is mounted under the open channel and the US pulse goes upward through the bottom plate. Measured amplitude of US echo is transferred to PC. At the same time, US displacement meter, which can measure the distance from the sensor to



(a)



(b)

Figure 7: Schematic illustration of experimental setup; (a) overview of the setup and (b) location of measurement lines

the free surface, is located the top of the open channel to obtain a reference data of moving free surface. Its spatial resolution is 0.15 mm. The US displacement meter and the UVP system were synchronized by using a trigger signal. Figure 7(a) shows the positional relationship of the measurement lines. The measurement was repeated 100 times and the interval between each measurement was 10 ms.

3.2 Result

Figure 8 shows the amplitude of US echo obtained by the UVP system. The vertical axis represents the distance from the US transducer. The gray scale represents the amplitude of US echo and black area means strong US echo. Strong echo due to multiple reflections of US pulse in the wall and the US transducer exists near the US transducer. The peaks of US echo around 30 mm in the distance represents the free surface of the open channel. We attempted to determine the free surface position by making a threshold and detected the position at which the echo first passes the threshold. Figure 9 shows the variation of the position of the moving free surface measured by two methods; the US displacement meter and the developed system. The position of the free surface slightly varies by wavelet and the displacement is around 5 mm. In comparison with the both results, determined position by the present method is more sensitive because of smaller measurement volume and of no averaging on raw data. We can observe that there is clear error for deformed free surface. Condition of ultrasound reflection at the free surface depends on the inclination of the surface and the echo signal from such a curved free surface changes from the flat condition. Currently, the variation of US echo due to the deformed free surface is a problem on measurement accuracy. But we might utilize the variation of US echo in order to detect the deformation of the free surface with the variation of the position.

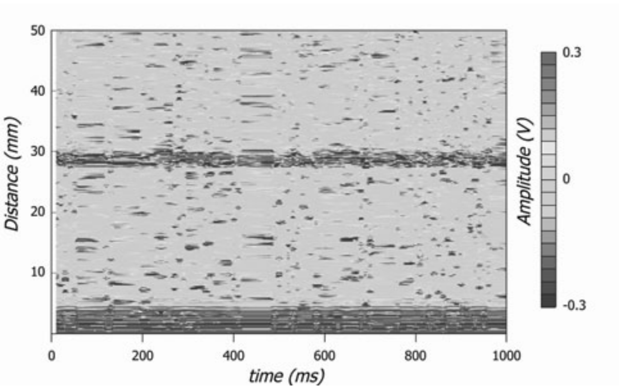


Figure 8: The amplitude of US echo recorded by UVP

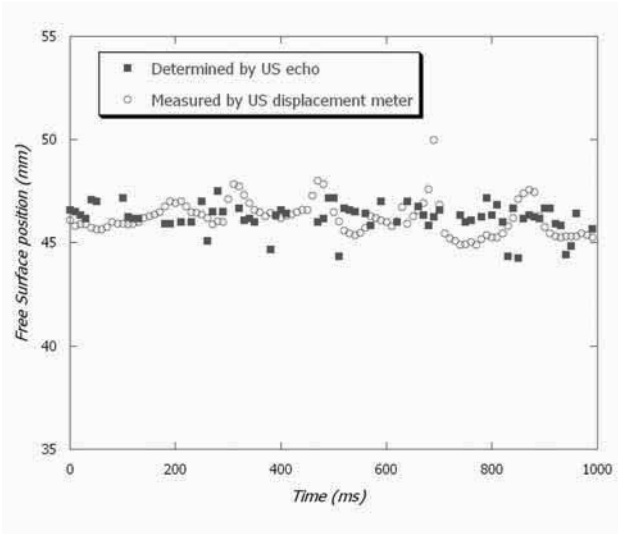


Figure 9: The displacement of the position of free surface measured by US displacement meter and determined by US echo

4 SUMMARY

1. We established the method to detect the bottom position of an open channel by using the probability density for zero velocity and applied this method to measure a small river. We confirmed that the measurement of discharge of the river by UVP has high accuracy and more efficient than the conventional measurement methods.
2. Amplitude information of US echo in UVP measurement was utilized to detect moving free surface. To establish the method for detecting free surface, temporal variation of the US echo was simultaneously recorded with surface position measured by US displacement meter.

Current UVP system uses US echo information only for determining instantaneous velocity profile. In the echo, however, other useful information remains. In the future, we attempt to advance UVP system to more useful measurement tool, e.g., simultaneous measurement of the instantaneous velocity profile and the position of moving free surface in an open channel flow.

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