Development of Cheap Flow Meter

Junji Tsuda, Tokai University, Japan
Naohiko Shimizu, Tokai University, Japan

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Abstract
In this study, we developed a cheap flow meter. There are two purposes in this study. One is to reduce a cost of flow rate measurement in rivers. Another purpose is to measure a flow rate at many points at the same time. The principle of the flow meter is Bernoulli's theorem. Main material of the flow meter is PVC pipe. The control unit of the flow meter is Arduino. Moreover, we used ultrasonic sensors to measure a differential of a water level. The cost of the developed flow meter is only little over 5000 yen. After we developed flowmeter, we did an experiment. As a result of the experiment, the flow meter showed a potential to measure a flow rate.

Keywords: Environment sensing, flow meter, Bernoulli's theorem

Introduction

There are many rivers in Japan. The Regular investigation is necessary to manage them. There are various items to survey such as flow rate, water quality, pH etc. Currently, a large number of personnel and expenses are required to investigate each item. Also, it is preferable to measure flow rate at many points, Sera (1991, p.292), Nezu, Nakagawa and Seya (1991, p350). However, in the previous study, they used one flow meter to measure at many points. It takes a lot of labor. So we consider that measure flow rates many points at the same time. There are various methods for measuring the flow rate. Currently mainly used in Japan is a system using a float and a system using a machine called ADCP. A method called float type has been used for a long time in Japanese rivers. It is a method of dropping a float with a mark from a bridge and calculating the flow velocity from the time elapsed while float flowed a certain distance. The method of float type needs at least 5 people (leader, subleader, the person dropping, 2 people signaling the passage of a float), Hashiba, Kai, Tsuda and Tsuchida (2014, p.39). Therefore, this method needs personnel expenses and increases human error. In recent years, the method of using ADCP have been studied and used to practical use. ADCP is a machine that generates ultrasonic waves in water and calculates the flow velocity from the phase shift of the reflected ultrasonic waves. By using ADCP, it became possible to measure the flow velocity in the depth direction at once. In addition, by manipulating a small unmanned boat with ADCP with a rope from above the bridge, it became possible to measure the flow velocity in the horizontal direction in a short time. However, because of ADCP's price, organizations that can be introduced are limited. Moreover, in order to measure the flow velocities of multiple points by these methods, it is necessary to measure multiple times while shifting the measurement point. The float type is difficult to follow the flow of multiple floats. Also, since the flow of the river is not straight, it is impossible to measure the flow velocity at pinpoint by dropping the float. On the other hand, multiple ADCP can't be used at the same time. The reason is a possibility of misdetection, because of another ADCP's ultrasonic waves. As a result, it was impossible to survey a flow rate at multiple points at the same time by the method of float or ADCP. Also, there are other methods for measuring. That is a method of using propeller and a method of an electromagnetic flowmeter. Usually, these methods are not used in the river. Moreover, the price of these flow meter is more than 300,000 yen. Therefore, prepare many flow meter spends much money, and it is difficult to measure the flow rate at many places at same time. So we decided to develop a cheap flow meter which can measure flow rate many points at the same time.

Principle of developed flow meter

We developed cheap flow meter using Bernoulli's theorem. Bernoulli's theorem is that total amount of followings is constant: pressure, flow rate, and potential energy. Bernoulli's theorem is used for pitot tube. Pitot tube is mainly used for measuring the speed of the airplane. The general shape of pitot tube is shown in fig. 1. Pitot tube is made of transparent material such as glass. There are 3 holes at the pitot tube under the water. One is a total pressure hole, which is in the flow. Other two holes are static pressure hole, which does not in the flow. The purpose of pitot tube is to measure the dynamic pressure for measure the flow rate. However, there are not only dynamic pressure but also water pressure in the water. Therefore, the pitot tube is calculating differential pressure from total pressure and static pressure. There are two methods for measure differential pressure. One is to use a differential pressure gauge and the other is to read the difference in water level. The method of use a differential pressure can't achieve the purpose of this study: develop a cheap flow meter. The reason is that differential pressure gauge isn't cheap. On the other hand, a method of reading the difference in water level is not suitable for measuring many points at the same time. The reason is that this method is conventionally read by a human. As a result, it does not solve a problem of the method which uses float. So we use an ultrasonic sensor to read a difference of water level. By using the ultrasonic sensor, the acquired value can be sent directly to the database etc. As a result, it is possible to prevent human error and reduce personnel expenses.

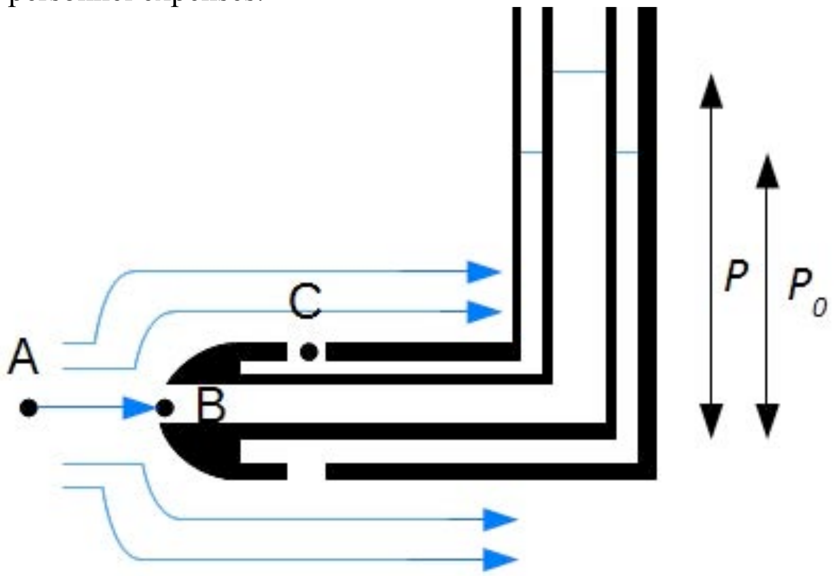

Fig. 1 General shape of pitot tube

Developed flow meter

Fig. 2 is a picture of flow meter which we developed. It can divide into two parts: measuring part and calculation part. Table 1 shows parts and price of the flow meter. This flow meter developed at little over 5000 yen. It shows that this flow meter is much cheaper than any other flow meter.

Fig. 2 Developed flow meter

Table 1 Parts and price of flow meter

parts	Price
PVC pipe	￥500
Ultrasonic sensor ×2	￥800
Arduino	￥3240
Bord,wiring,etc.	￥500
Total	￥5040

Measuring part

There are two tubes at flow meter: total pressure tube and static pressure tube. These tubes use 5 cm diameter PVC pipes. These tubes are same long and both tubes have a cap set at the tip of the underwater. Total pressure tube has a hole on the side and static pressure tube has a hole on the bottom. These holes correspond to total pressure hole and static pressure hole in the pitot tube. Also, there are ultrasonic sensors at the top of both tubes. These sensors measure the distance between a top of tube and water level. The difference of water level between total pressure tube and static pressure tube can calculate from 2 ultrasonic sensors.

Calculation part

Fig. 3 shows the connection diagram of the machine used in the calculation part. There are some machines for calculating difference of water level: PC, Arduino, and two ultrasonic sensors. Arduino gets the value from two ultrasonic sensors and sends calculation results to PC with serial communication. The calculation result is the average value of the 30-second water level difference.

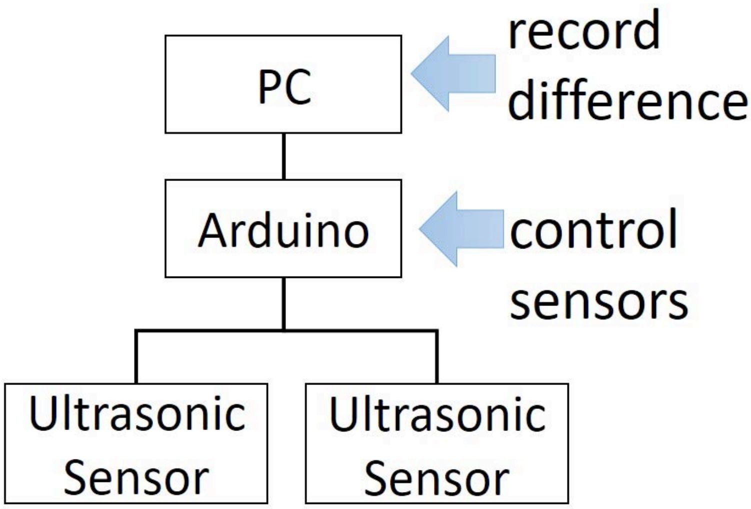

Fig. 3 Connection diagram of the machine used in calculation part

Principle of measurement

Fig. 4 shows the principle of measurement in a developed flow meter. The flow meter has two holes. To measure the flow rate from the water level difference, use the following equations from Bernoulli's theorem. Eq. (1) shows that total of the pressure of point A and the flow rate is equal to the pressure of point B. Eq. (2) is a modified version of Eq. (1). It is an equation for flow velocity. From these equations, the flow rate can be measured by the difference in water level between the total pressure pipe and the static pressure pipe.

$$p_A + \frac{1}{2}\rho v^2 = p_B \quad (1)$$

$$v = \sqrt{2 \cdot (p_B - p_A)} \quad (2)$$

$$= \sqrt{2 \cdot \Delta h} \quad (3)$$

v	: Flow rate$[m/s]$
Δh	: Difference in water level [m]
p_A, p_B, p_C	: Pressure of point A,B,C
ρ	: Density of the fluid (≒1)

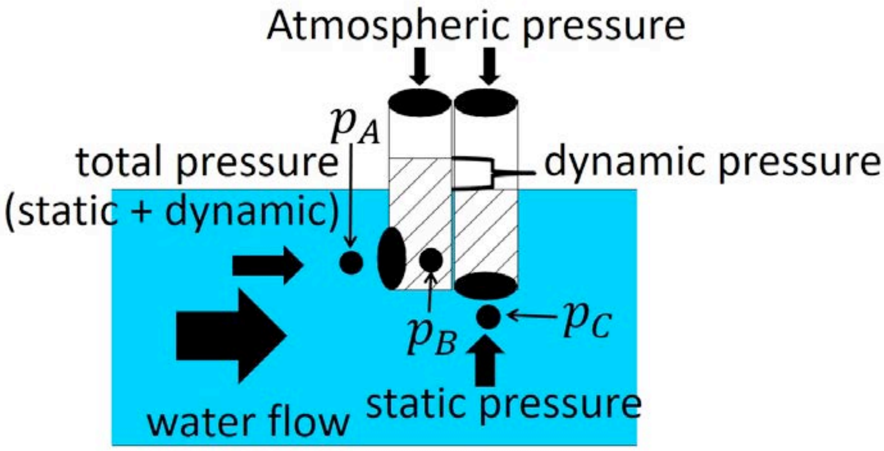

Fig. 4 The principle of measurement in a developed flow meter.

Experiment

We experimented to confirm the measurability of flow meter which we developed. Our experiment has held at the experimental water tank at Tokai University, Japan. The experimental water tank is 0.5m width and 8m long. It can create water flow artificially. Experiment situation is shown in fig. 5. In the experiment, we hanged the flow meter over the water tank.

Fig. 5 Experiment situation

Result

Fig. 6 is a graph of the experimental result. Measured range of this experiment is 0.51m/s to 0.79m/s. The reason why under 0.51m/s and over 0.79m/s couldn't measure is that depending on constraints of facilities. Too slow flow rate doesn't make sufficient water level. The reason for low water level is a correlation of outflow and flow rate. Also, too fast flow rate make drainage cannot catch up. The theoretical value and the measured value maintain almost the same slope between 0.5 m/s and 0.6 m/s in fig. 6. On the other hand, the measured value showed a steep increase from the theoretical value after 0.6 m/s. For that reason, we can judge whether the flow rate is getting faster or slower from the flow meter.

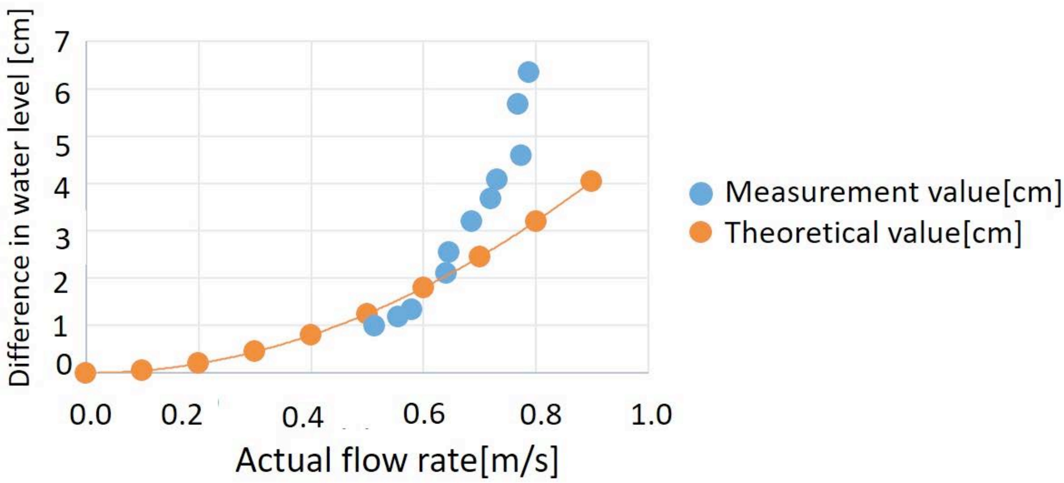

Fig. 6 Experimental result.

Discussion

The goal of this research was to develop a cheap flow meter that could be used simultaneously. Fig. 7 is the picture of flow meter from the side. This picture shows two reasons why the result of measurement is not expected value. The first reason is that water level is changing at the front and behind flow meter. This is caused by the fact that the flow meter disturbs the flow. Fig. 8 is the top view of the experimental facility. The flow meter is made of 2pipes which are 5 cm diameter. Wide of the experimental water tank is 50cm. In other words, the flow meter is blocking one-fifth of the waterway at the experimental tank. As a result, it is expected that complicated water currents are generated behind the water flow meter. Thereby, it seems that the water level is changing at the front and behind flow meter. The second reason is that pipe is leaning. The reason of leaning is strong water resistance. Water resistance increases as the flow rate increases. Therefore, as the flow rate increases, the lean of pipe increases. Fig. 9 shows the change in the distance of the ultrasonic sensor due to the lean of the pipe. The measurement value of the ultrasonic sensor is measured by the distance from Tx: a transmitter to Rx: a receiver. When the pipe is set vertical to the water surface, the distance from Tx to Rx is 20cm. However, if the pipe tilts 10 degrees, the distance from Tx to Rx is 20.9cm. As a result of the lean of the pipe, distance from the ultrasonic sensor to the water surface is not accurate. For these two reasons, it is considered that the measured values after 0.6 m/s showed a rapid rise. In order to reduce the fluctuation of the water level by the flow meter, it is considered that miniaturize the flow meter itself. Especially, it is considered that reduce the diameter of the pipes which diameter are 5 cm is important.

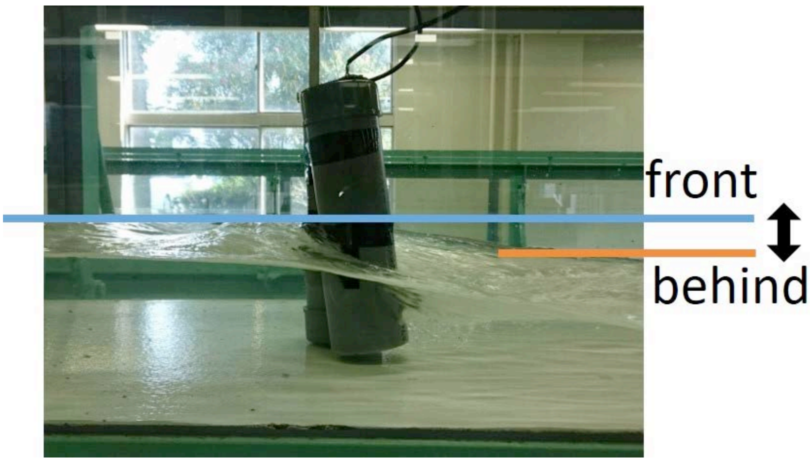

Fig. 7 Picture of flow meter from the side

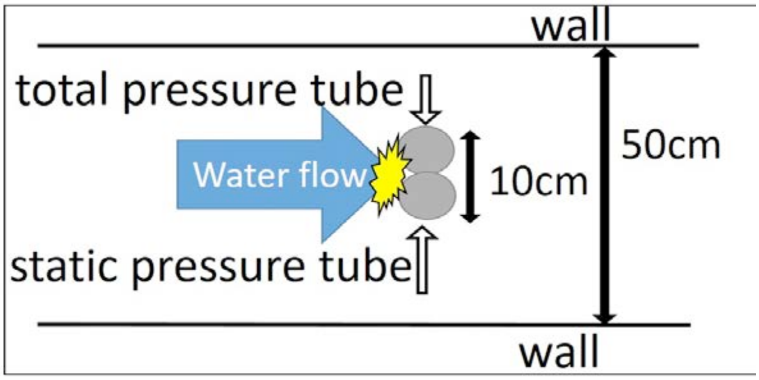

Fig. 8 Top view of the experimental facility

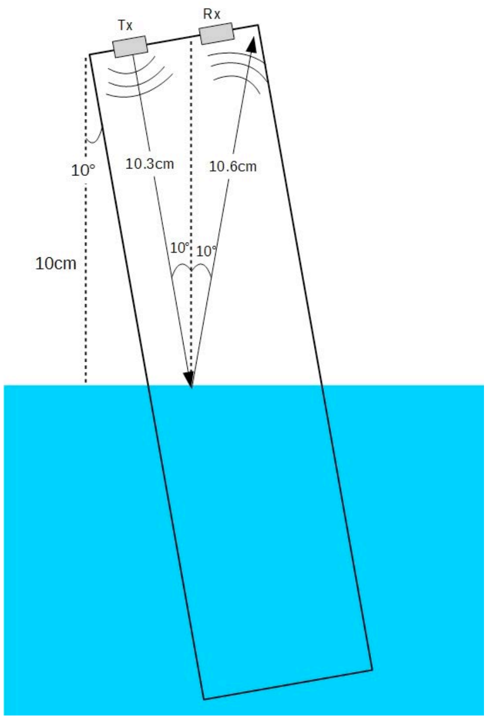

Fig. 9 Change in the distance of the ultrasonic sensor due to the lean of the pipe

Conclusion

We developed cheap flow meter as compared with conventional ones. We also showed the possibility of measuring flow meters developed. However, there is still room for cheapness. The reason is that most of the cost is Arduino. It is considered that change Arduino to microcontroller chip, and flow meter get cheaper. For the future plan, we miniaturize the flow meter and improve the accuracy of the flow meter.

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Contact email: 3bjk2115@gmail.com