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Development of Automated Velocity Measurement Method in Natural Rivers

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ABSTRACT

We developed autonomous-mobile floating-robot using one-board microcomputer arduino which could measure automatically mean velocity in an open-channel flow. Combination of camera tracking system and PID control could make the robot remain the position against main stream, and then mean velocity was evaluated reasonably by a duty-ratio of screw propeller motor. Reliable laboratory experiments with electromagnetic velocimetry provided the calibration curve that connects the duty-ratio and mean current velocity. Furthermore, the present boat-type robot could be found to move successfully in not only the laboratory flume but also in natural creek.

KEY WORDS: Automatic velocity measurement system; autonomous boat robot; field survey; open-channel

INTRODUCTION

We developed autonomous-mobile boat-type robot using one-board microcomputer called “arduino” which could measure automatically mean velocity in an open-channel flow such as natural rivers. Combination of camera tracking system and PID control method could make the robot remain the position against main stream, and then mean velocity was evaluated reasonably by a duty-ratio of screw propeller motor.

It is very important to observe discharge rate and streamwise velocity in natural rivers for the river management. Conventional floating method is the most popular technique for discharge evaluation of natural rivers (Song et al 2012). The advantage of this method is that principle to measure the velocity is very simple, whereas it lacks measurement reliability and working efficiency. Therefore various interesting techniques have been proposed in order to solve such disadvantages of the floating method. Recently, digital imaging technique with video camera and acoustic method with ADCP can obtain a velocity profile which is used to evaluate discharge rate accurately (Fujita et al. 1998, Tsubaki et al. 2011).

The present study suggests the boat robot system which has a unique measurement way quite different from existing methods. First version of prototype was made by using LEGO Mindstorm system (see Sanjou & Nagasaka 2015). A propulsion motor is controlled for the robot to remain stationary at a measurement point. As rotation speed of propulsion screw required varies with attacking velocity, the streamwise velocity could be expected to be measured in river. A side thruster was also equipped to be allow a planar two-dimensional motion.

However, there are some problems before application to the natural rivers. Maximum velocity of the previous prototype by Sanjou & Nagasaka can measure right is paltry 15 cm/s. Further, time series of robot position could be detected by ultrasonic sensors, two reflection plates must be placed in a test flume.

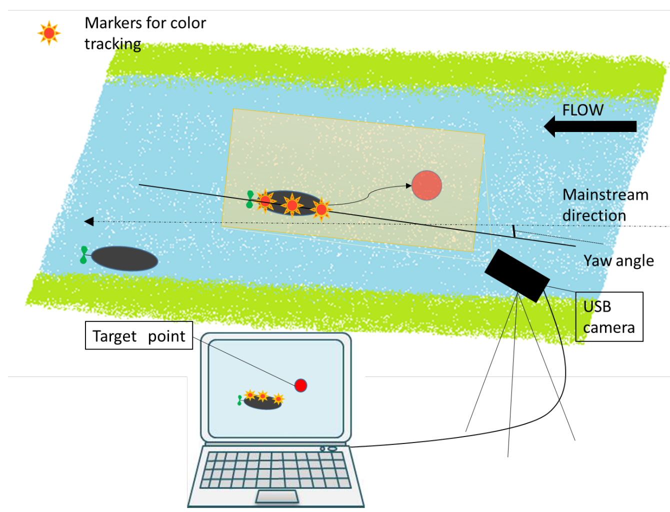
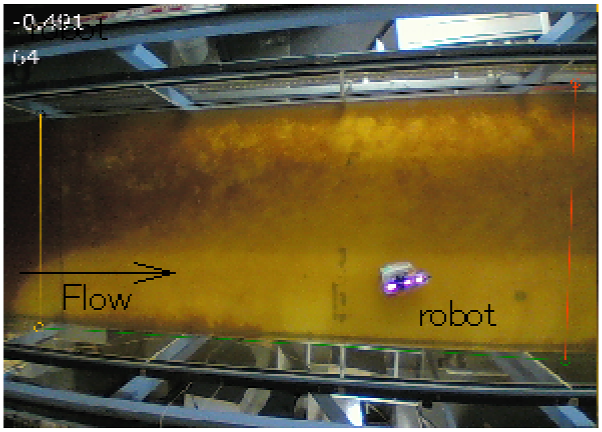
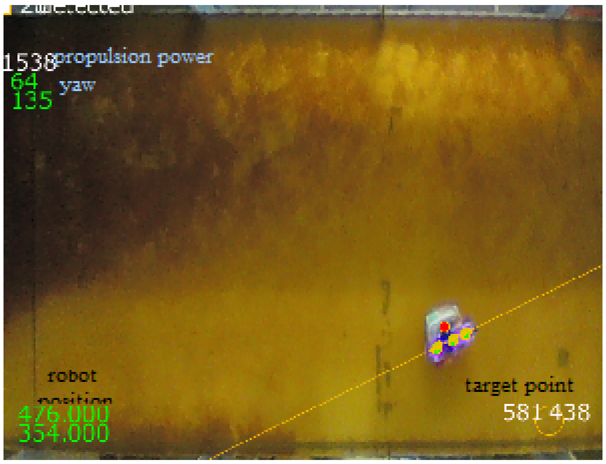


Fig. 1 Schematic image of automatic measurement for river velocity by present robot system

For that reason, an image tracking system is newly introduced in the present prototype. We observe the robot position and yaw angle to the streamline through the digital image of a USB camera, and make the boat robot navigate autonomously sending the position coordinate to the robot in real time. This method is available even in indoor flume where GPS is unusable. One board microcomputer (arduino UNO R3) was used as a processor to control collectively several sensors and motors. Reliable laboratory tests with electromagnetic velocimetry provided the calibration curve that connects the duty-ratio and mean current velocity, and we examined that robot moves reasonably in two-dimensional plane. Furthermore, the present floating robot could be found to move successfully in not only the laboratory flume but also in natural creek.

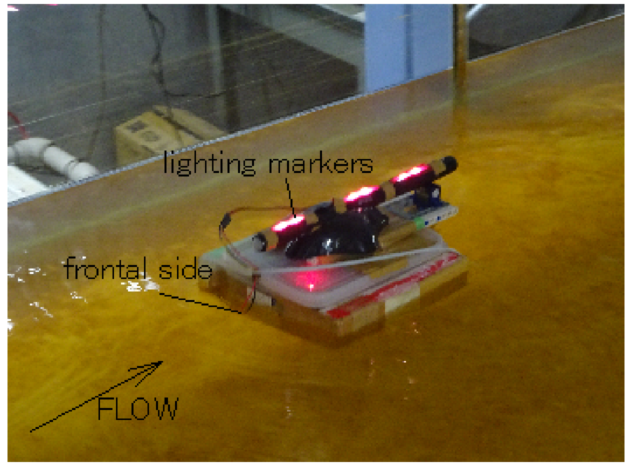


(a) Raw image of top view for prototype robot in the laboratory flume

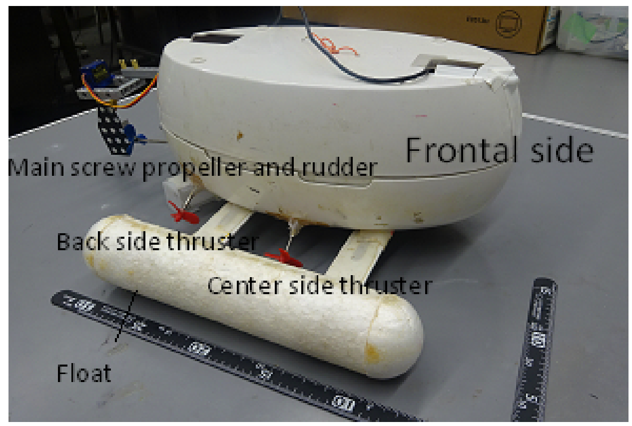


(b) Transformed figure of above image

Fig. 2 Control screen of processing (For control test of the robot type MS01)



(a) Type MS-01 for laboratory use



(b) Type RX-05 for field use

Fig. 3 Prototype robots

PRINCIPLE OF AUTOMATED VELOCITY MEASUREMENT

Idea of positioning operation by using a USB camera is indicated in Figure 1. The USB camera is connected with a personal computer. Strong light sources or painted markers are placed on upper surface of the robot considering the color tracking method. An integrated development environment software called processing is installed in the personal computer. It manages positioning information, i.e., the robot location, distance and direction to the measurement point analyzed on the basis of the digital images of the camera, and send wirelessly them in real time to the robot equipped with a one board microcomputer. The robot moves to the measurement point (target point) and remain the position controlling rotation speed of a screw propeller. Free software “processing” is used for management of the boat position.

Figure 2 shows an example of driving screen by “processing”, in which the upper-side is a raw image and the lower-side is a corresponding image after projective transformation. This system aid users’ works to manage the automatic measurement. When users click the target position on the screen, the robot starts to move toward the target and stop at the measurement point. The robot is driven by a following PID method.

Proportional/Integral/Derivative (PID) control is one of the most popular feedback methods, which is composed of three kinds of following operations.

Fist is a proportional operation which defines input value corresponding difference between the desired and the present output values, second is an integral operation corrects offset of the output value and third is a differential operation moves the output value smoothly close to the desired goal. The present study applies the PID method to control propulsion motors in which the input value at time step n, Ip_n was given in following form, feeding back time-series of the robot position obtained by the above mentioned tracking method.

$$Ip_n = Ip_{n-1} + \Delta Ip_n \tag{1}$$

$$\Delta Ip_n = K_p(x_n - x_{n-1}) + K_i x_n + K_d\{(x_n - x_{n-1}) - (x_{n-1} - x_{n-2})\} \tag{2}$$

The right hand side in Eq.(2) indicates the proportional, differential and integral operations, respectively. ΔIp_n is the time interval between previous and present steps. x_n is distance from the target. K_p, K_i and K_d are coefficients chosen on the basis of behavior tests in laboratory flume.

Figure 3 shows photo of the present prototypes. Fig.3(a) shows the 1st prototype for the laboratory use (type MS-01). The total length is 24cm, width is 24cm, height is 18cm and the weight is 1012g. 7.2 V battery, microcomputer and motor controller were mounted inside. Water proof motors (Mabuchi 260) were equipped outside. Fig.3(b) shows the 2nd one for the field survey use (type RX-05). This is trimaran type with excellent roll stability. All motor, processor and battery were placed in the center cluster and two styrene-made floats were equipped. The total length is 40cm, width is 33cm, height is 14cm and the weight is 1653g. A draft is 7cm. Mabuchi 540 motor was used to drive main screw behind which rudder is mounted. Under low rotational speed condition of the screw propeller, the rudder could not act for direction control. Therefore, side thruster driven by Mabuchi 260 motor was mounted in the tail side of the robot body. Another side thruster was equipped in the middle of the body to move the robot in the lateral direction.

In the present study, *x* and *z* mean streamwise and spanwise directions, respectively.
The present system controls independently propulsion screw, side thruster and rudder in the following ways.

(1) Control of propulsion screw
The PID method makes the robot floating on the current remain stationary to the ground before moving to the target position. When more than 20 sampling statuses accompanied by condition, Ip_n <0.1 occur in succession, we judge the robot keeps the position and calculate the average input value $\overline{Ip}$. Subsequently, the input value is recalculated adding and subtracting one tenth of $|x|$ (distance from the present position to the desired goal) to move to the target point. The robot is required again to remain stationary in the current when $|x|$ is smaller than 3.0cm.

(2) Control of side thruster
The PID method is applied to the side thruster in the same way as mentioned in the propulsion screw. This control could return the robot even when natural disturbance keep it far from the target point.

(3) Control of rudder
Rudder is controlled every 1 degree to make the boat robot parallel to the mainstream, feedbacking the yaw angle transferred from the compass sensor.

Laboratory tests were conducted in two types of open-channel flumes. Their widths are 40cm and 150cm. A definition of control parameters and examination of correlation between the screw speed and current velocity require accurate velocity data measured by electro-magnetic velocimetry (EMV), and therefore, 40cm-width flume was used for these tests. Generally speaking, long-distance spanwise cruise is often needed in the field measurements, because we have to move the robot placed on the free-surface near the shore to the target point near the center line of the channel. The 150cm-width flume was used to test the planar two-dimensional navigation of the present robot. In the 40cm-width flume measurements, Several types of bulk-mean velocities were chosen ranged from 15cm/s to 40cm/s, water depth *H* is fixed at 12.5 cm. Mean velocity was measured 2cm under the free-surface at 7m downstream from upstream intake section for each hydraulic condition by using EMV after removal of the robot.

EXAMINATION

Relationship between the Propulsion Force and the Attacking Velocity

Drag force F_D and Propulsion force F_T could be given by following forms, respectively.

$$F_D = \frac{1}{2}\rho U^2 C_D \tag{3}$$

$$F_T = \frac{1}{2}\rho m^2 D^4 C_T \tag{4}$$

, in which ρ is water density, *U* is streamwise mean velocity, *A* is frontal area of the robot boat, *m* is rotation speed of screw (rpm) and *D* is diameter of screw. C_D and C_T are coefficient of drag and propulsion, respectively. When they are balanced in the stationary stage, attacking velocity is proportional to the screw speed as follows;

$$U \propto \pi D m \tag{5}$$

Laboratory tests provided relationship between the input value (duty ratio) and attacking velocity measured by an electromagnetic velocimetry as shown in Figure 4. The duty ratio means a magnitude of drive voltage corresponding to the screw speed. The following fitting line could be obtained for the first prototype 1 (MS-01) as indicated in Fig.4. Same feature was observed for the other prototype (RX-05).

Two Dimensional Navigation Test

Spanwise motion is also required to remain stationary at the measurement point as well as streamwise motion. We examined the planar two-dimensional navigation in the 150cm-width flume, in which

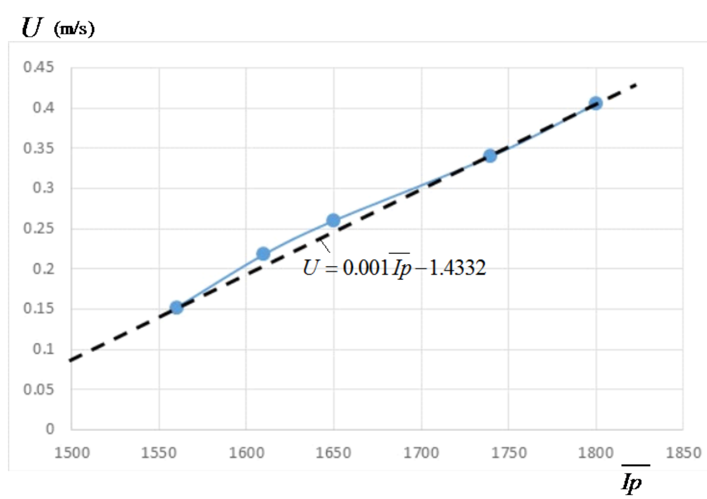


Fig. 4. Calibration curve for prototype MS-01

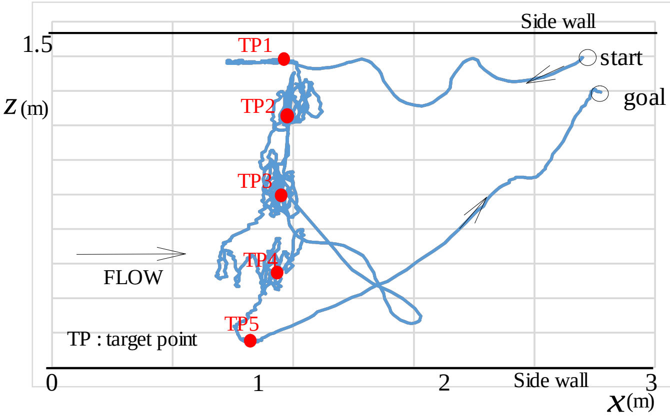


Fig. 5 Horizontal navigation line (MS-01)

Q =32 l/s and H =12.5cm. We released the robot near the side bank corresponding to a circle indicated by "start" in Fig.5. Five target points are situated, and the robot tried to measure the attacking velocity there. After the measurement, the robot moves to the next target.

Figure 5 shows time-variation of horizontal position, in which we can see that the robot tried to stop around each target point after departure starting position. Further, the robot returns successfully to the goal point near the side-wall.

Application to Field Survey

Figure.6 shows a state of operation test in a 2m-width Japanese creek, in which second prototype (RX05) was used. We mounted the USB camera on riverside to gain the robot position as shown in Fig.6(a). The robot boat could be controlled successfully by the PID method and it results in the robot kept the position at measurement points to obtained mean velocity in the natural river as shown in the lower figure. The navigation was conducted under no-wind condition, and thus, the above-mentioned calibration line could be used. Two target points were chosen, i.e., point A (80cm far from the left-hand-side bank, water depth is 20cm) and point B (30cm far from the left-hand-side bank, water depth is 50cm) as shown in Fig.6(b). The duty ratios required to remain stationary for these points, are 1585 and 1650, respectively. The converted velocity are U = 25.6 cm/s and 43.7 cm/s, respectively. Actually it was recognized by eyes that surface streamwise velocity is larger at the point A than the point B. Although this test covered only two target points, it was found that the present system is useful in not only laboratory flume but also natural river.

CONCLUSION

We suggested a new idea of autonomous-mobile floating robot, which measure directly attacking streamwise velocity remaining the stationary status. The color tracking system by USB camera

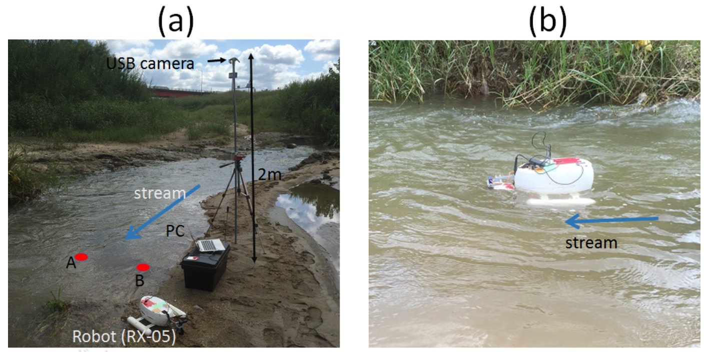


Fig. 6 Control test in Japanese natural creek (RX-05)

is introduced in the present prototype. We observe the robot position through the digital image of a USB camera, and make the boat robot navigate autonomously sending the position coordinate to the robot in real time. This system is practical to use in field survey, because it is easy to carry out. The relationship between the duty ratio and the attacking velocity could be obtained. Two-dimensional planar navigation tests proved that the present robot moves accurately from the release point to the desired target one. Furthermore, we are planning to measure not only the velocity but also the water quality such as dissolved oxygen and temperature in rivers.

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