Arduino-based automated system for determining water flow consumption in open flow

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Abstract. The article provides an overview of modern methods and devices for measuring water flow in open channels and natural watercourses, reflects the shortcomings and errors in their application. Considered the possibility of using the Arduino element base for creating an automated system for metering water consumption in an open stream and sending data via a Bluetooth module. Has been investigated the eventuality of using the pipe sensor YF-S201 for measuring the flow rate of liquid, in conjunction with the ultrasonic sensor of distance HC-SR04 for determining the level of water in the flow. The results of the experiment carried out on the basis of the laboratory stand "Hydraulic structures" in KSTU are presented. There were performed processing of the measurement results on the basis of the Arduino UNO board and a laptop, as well as remote data transmission and their visualization on a smartphone. The absolute and relative errors of the proposed system have been calculated.

1. Introduction

Commercial metering of water consumption is important and the requirements for its organization are determined by the decrees of the Government of the Kyrgyz Republic (KR) dated 12/08/2005 No.142 "On approval of the Rules for the use of municipal water supply and sewer systems in the Kyrgyz Republic" [1] and dated 02/25/2002 No.100 "On approval of the Regulation on the implementation of state monitoring of water bodies" [2], as well as the Code of the Kyrgyz Republic dated 01/12/2005 No.8 "Water Code of the Kyrgyz Republic" [3].

Water in the processes of water supply and sewerage is transported through pressure or gravity pipelines and open channels [10]. In the first case, the water is pumped by pumps, in the second it goes through pipes and channels "by gravity". Measuring the volume of pressure effluents is a long-established task. There are a large number of instruments used both for measuring incoming water flow-rate and for wastewater disposal. A more difficult task is to account flow-rate of free-flow. An open channel or a natural riverbed is often used here, along which water flows under the action of gravity, and its speed in the mountainous terrain of the Kyrgyz Republic can be significant [11].

Existing water flow measurement systems use two main methods. These are the “variable flows” method and the “velocity -area” method [4].

The “variable flows” method only measures the water level. This can be done in two ways: manually and automatically. In the first case, it is necessary to have a stilling well, where a gauge ruler will be
installed, showing the level [12]. In the second case, the level is measured using ultrasonic level gauges. The recalculation of the level value into the flow rate is carried out according to the programmed pressure-flow characteristics of the monitored channel.

For this method, various standardized weirs and flumes such as Chipolletti weir (WC), SANIIRI flume (SF), parabolic flumes "PL", etc. are used [5]. The disadvantage in this case is that the accuracy of calculating the pressure-flow characteristics of the flume or weir affects the accuracy of determining the flow rate. And also, over time, the walls and bottom of the tray become dirty and destroyed. Recovery is a laborious and difficult task, since it requires stopping the work of hydraulic structures.

More modern and correct two-channel sewage metering devices work on the principle of "area-velocity". These instruments provide direct measurement of the level and flow rate. The geometric parameters of the channel are entered into the memory of the device in advance: using these data and information about the filling level obtained in real time, the device calculates the cross-sectional area of the flow at a given time and, multiplying it by the measured average velocity, calculates the flow rate and volume of liquid. Also, these devices determine the direction of movement of water in the channel [10].

A significant number of companies are known that manufacture ultrasonic level gauges, as well as spinners designed to measure the water flow rate averaged over the observation time at cross-sections of natural and artificial watercourses. For example, turntables are of the following types: HMS-1 (hydrometric micro-spinner), WFRM-H-21M1 (Water flow rate meter), FRM-1M (Flow rate meter) [6]. These devices have high measurement accuracy, but they are very expensive.

At the same time, there is a need for cheap, affordable methods and means to control water consumption in agriculture, urban economy and in laboratory research. Therefore, a search was made for cheap devices that allow measurements to be made with satisfactory accuracy. In this direction, the possibility of using the Arduino element base for creating an automated system for determining the flow of water in an open flow was considered.

**2. Description of the automated system for determining the flow of water based on the Arduino board and its testing.**

The designed Arduino-based water metering system includes several components, as shown in figure 1.

![Figure 1. System for automatic remote determination of water consumption based on the Arduino board.](image)

The YF-S201 sensor is designed to measure the flow of liquid in a pipe. The possibility of its application in an open stream was investigated. To determine the water level in the stream, an HC-SR04 ultrasonic distance sensor was used.
The Arduino UNO board and laptop were used to process the measurement results and visualize them, and the HC-06 Bluetooth module was used to remotely transfer data to a smartphone. The measurements were carried out with a period of 47 milliseconds, which corresponds to a frequency of 21 Hz.

The developed system was tested at the Department of Renewable Energy Sources of KSTU named after I. Razzakov. The design of the test laboratory stand "Hydraulic structures" is shown in figure 2.

The principle of operation of this stand is as follows: the flow of water with the help of pump 3 comes from the lower tank 1 filled with water through a closed pipeline 2 into the hydraulic system 7, through which it is fed to the upper tank 8.

After filling the upper tank, the water flow enters the open channel 9. Through the open channel (tray with rectangular cross-section) 9, the water flow flows at a certain slope and enters the lower tank 1.

The parameters of the flume are as follows: length – l = 7.61 m, channel width – b = 0.26 m, depth – (wall height) H = 0.43 m.

The method of fixing the layout of the system with sensors in the tray is shown in figure 3. Figure 4 shows the devices for processing and visualizing the results: Arduino board and laptop. A fragment of the code of the program for processing the measurement results is illustrated in figure 5, and in figure 6 - a screenshot from the smartphone screen displaying the value of the water level and its consumption.
Figure 3. Fixing the model of the device in the tray: a, b, c - method of fixing individual elements; d - appearance of the device layout.

Figure 4. Devices for processing and visualization of results.

Figure 5. Screenshot of a code fragment of the program for processing measurement results.

Figure 6. Screenshot from the smartphone screen displaying the value of the water level and its consumption.
3. Results and discussions

The data of 50 measurements of the flow rate $Q$ using the YF-S201 sensor are shown in figure 7. It can be seen that the obtained values are random. Statistical processing of the obtained data was carried out using MS Excel. As a result, we found the average value of the flow rate $\bar{Q} = 4.7 \times 10^{-5} \text{ m}^3/\text{s}$, the standard deviation $\sigma = 1.5 \times 10^{-6} \text{ m}^3/\text{s}$, while the coefficient of variation is 3%. Taking into account the obtained characteristics of the data set and the significant measurement frequency, the random error can be neglected and the averaged value of the flow rate $\bar{Q}$ can be used.

![Figure 7. The results of flow measurement by the YF-S201 sensor.](image)

To determine the real value of the flow rate $Q_p$ of water in the tray, it should be taken into account that the diameter $\varphi$ of the cross-section of the through-hole in the sensor is 0.007 m. Therefore $Q_p$ can be determined by multiplying the sensor readings by the coefficient $k$:

$$Q_p = \bar{Q} k,$$

where the value of $k$ is equal to the ratio of the cross-sectional area of water in the flow $S_a$ to the cross-sectional area of the sensor pipe $S_s$:

$$k = \frac{S_a}{S_s},$$

where $S_s = \frac{\pi d^2}{4} = 3.8 \times 10^{-5} \text{ m}^2$, and $S_a$ is calculated synchronously, taking into account the operation of the flow meter according to the formula:

$$S_a = b(H - g).$$

In expression (3), the value of $g$ is the ultrasonic sensor reading equal to the distance from the sensor to the water surface.

The average value $\bar{g}$ of the readings of the HC-SR04 ultrasonic sensor was 0.035 m. In this case, according to (2), the coefficient is $k = 237$.

From the above data, it is possible to calculate by the formula (1) the real water flow rate for the flume, which is $Q_p = 0.011048 \text{ m}^3/\text{s}$.

For the error estimates developed system $Q_p$ obtained value was compared with the flow quantity $Q_n$ calculated standard method [8] by measuring of floats velocity and determining the height of the water flow with a ruler. This value was $Q_n = 0.01215 \text{ m}^3/\text{s}$. 

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Assuming the result of measurements according [8] to be true, the value of the absolute error of the developed system will be [7]:

\[ \Delta Q = Q_p - Q_n = -0.0011005 \text{ m}^3/\text{s}. \]

In this case, the relative error will be equal to:

\[ \delta = \frac{\Delta Q}{Q_n} \times 100\% = -9\%. \]

4. Conclusions

Under the described conditions of testing the prototype of the proposed flow measurement system, the difference in results equal to 9% can be considered satisfactory. The main limitation in the applicability of this system can be considered high requirements for the purity of water. Taking into account the cheapness and availability of the used Arduino elements, the proposed system for determining the flow rate is recommended to be used in laboratory conditions during research, as well as in the educational process.

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