Matrix: Jurnal Manajemen Teknologi dan Informatika
Volume 15 Issue 1 Year 2025 Pages 9-20
DOI: http://dx.doi.org/10.31940/matrix.v15i1.9-20
URL: http://ojs2.pnb.ac.id/index.php/matrix

Data acquisition of flow sensor based to measure water flow in underground drainage

I Made Adiswara Wirama [1]*, Rusminto Tjatur Widodo [2], Muhammad Udin Harun Al Rasyid [3], Hary Oktavianto [4]

[1,2,4] *Faculty of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia*
[3] *Faculty of Informatics and Computer Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia*

*Corresponding Author: *ramawiramas@gmail.com*

Abstract: This research focuses on water flow sensors in underground drainage. In Indonesia, the use of sensors and actuators to control and measure water velocity and water discharge in underground drainage is not very popular, although one of the causes of flooding is caused by clogged drainage or workers forgetting to turn on the pump at a certain height and water flow. This paper will explain how to find out the speed and discharge of water in an underground drainage without checking it directly on site. The water flow sensor is used to measure the water velocity and water discharge entering a drainage system. The data acquisition conducted with 3 section, data preparation, data collecting, and data processing. Data preparation is preparing the microcontroller, sensor, and data display to get the data. Data collecting is about collecting the data from sensor in this research the data collected is in pulse that can be calculated to water discharge and water velocity in the data processing. From the experiment, it can be seen that the highest error rate on the sensor is 7.64% and the lowest at 0% or no error with the average amount of error is 2.46%. The data obtained from the sensor can be converted into water velocity and water discharge depending on the shape of the drainage. The length, width and height of the drainage are assumed to be 10x4x3 m respectively, with a constant water level of 2 m, so the water flow sensor is placed at a height of 1 m because the safe height is 1 m. From the case study conducted the error rate of the water flow sensor error is 0%, because the case study conducted using imaginary data. Based from this, the knowledge gained from the research, it can be used to determine the water velocity and water discharge value of underground drainage using water flow sensor, which is expected to be applied to pump houses to more easily determine the state of drainage.

Keywords: microcontroller, sensor, underground drainage, water discharge, water velocity

History Article: Submitted 16 February 2025 | Revised 17 March 2025 | Accepted 22 April 2025

How to Cite: I. M. A. Wirama, R. T. Widodo, M. U. H. Al Rasyid, and H. Oktavianto, "Data acquisition of flow sensor based to measure water flow in underground drainage", *Matrix : Jurnal Manajemen Teknologi dan Informatika*, vol. 15, no. 1, pp. 9–20, 2025. doi.org/10.31940/matrix.v15i1.9-20.

Introduction

Flood is one of the disasters that can be caused by human negligence towards their environment, especially flood that occurs on the highway. Because the occurrence of flood in the road, it can hinder the flow of traffic in which will cause traffic jams. Therefore, it is necessary to reduce or mitigate flood on the highway, where one way is to make drainage. At 2023 flood is the third most occurring disaster in Indonesia [1].

Drainage is defined as a means of draining or disposing of water that is used to reduce excess water in an area so that the area is not flooded. The excess water can come from rainwater, seepage, or excess irrigation water. Drainage can be surface or subsurface. Underground drainage is a man-made structure built underground under roads or beside rivers. In addition, underground drainage also has the function of draining the water above it and directing it to the river [2].

One of the parameters that can be measured in the underground drainage is the water flow in the underground drainage. Knowing the speed of water flow is very important, by knowing the speed of water flow in the underground drainage, it can estimate the blockage in the drainage and estimate the water discharge parameter, so it can open the pump to direct water from the drainage to another drainage or the nearest river. In this way, it can mitigate the flood before it even happens.

Previously there have been other researches to check the state or condition of underground drainage such as monitoring underground drainage using ultrasonic sensor to determine the water level of the drainage [3], [4], [5], [6], [7], [8]. Using the gas sensor to check the condition of the underground drainage [9]. Many researcher is using the flow sensor to find the water velocity and water discharge [10], [11], [12], [13], [14]. None of these researches explain the water flow rate, nor the water discharge rate by utilizing the dimensions of the underground drainage. So the research in this paper is to measure the parameters of water flow rate and water discharge using a water flow sensor. This water flow sensor uses hall-effect technology to estimate the water flow rate. From the water flow rate obtained and the estimated drainage dimensions, the amount of water flowing in the drainage can be determined.

Methodology

Data acquisition on the water flow sensor is carried out to determine the speed of water flow and water discharge in the underground drainage. data obtained from the flow of water in the underground drainage and then processed through the water flow sensor using the Arduino UNO microcontroller and then the processed data is displayed using an OLED screen. Figure 1 illustrates the block diagram of the data acquisition process from the underground drainage to the OLED screen or its output.

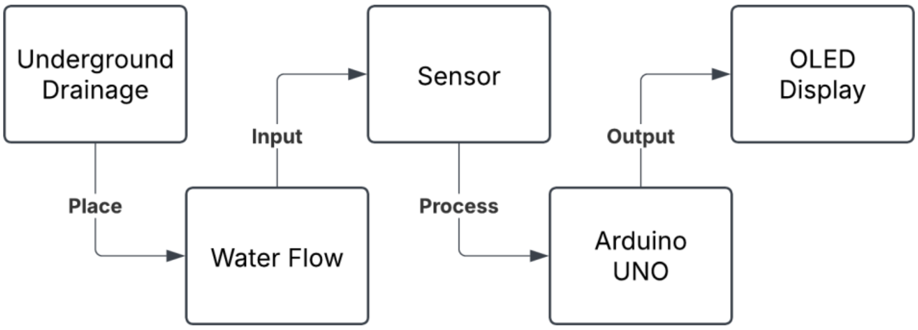
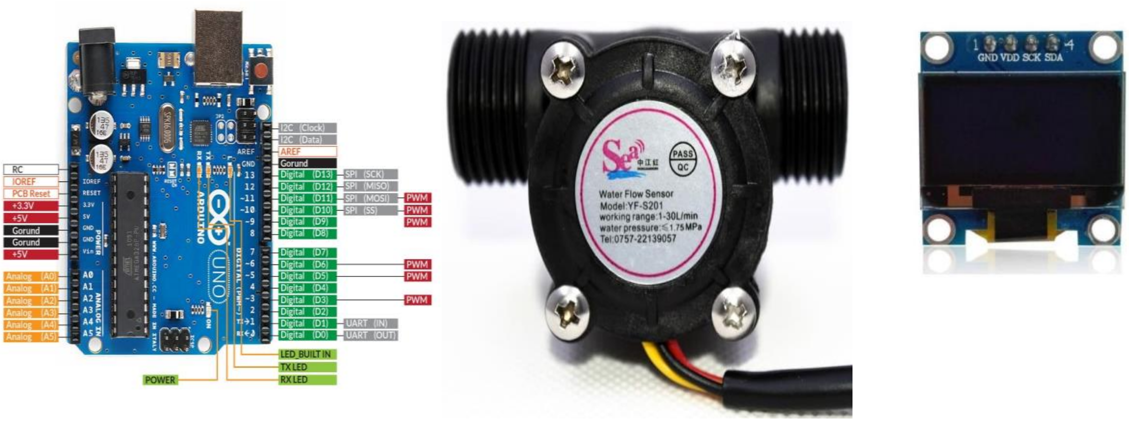


Figure 1. Block diagram

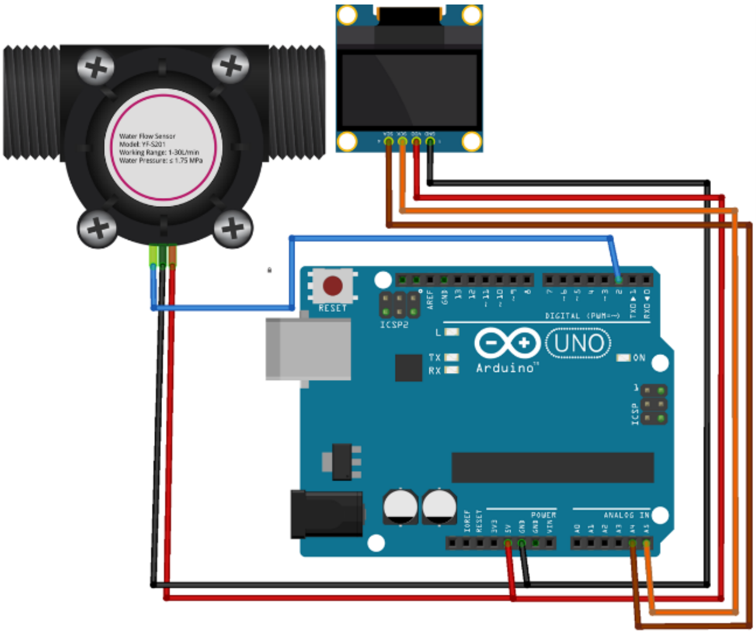
In Figure 1, the block diagram of the system is started from the place or location, then the flow sensor gets the data from the water in the underground drainage. The data obtained from the sensor then processed with microcontroller. After that the output of data that processed in microcontroller is displayed in OLED display.

From the block diagram the microcontroller used is Arduino UNO, it can be seen in Figure 2 (a). For the flow sensor it used YF-S201 water flow sensor to obtained the water data, the image of this sensor is in Figure 2 (b). Lastly, for the display it used OLED 128X64 display, this is in Figure 2 (c). The schematic of this project can be seen in Figure 3. From the microcontroller pinouts, this module requires a voltage of 5V to operate. This module also uses 1 digital pinout, and 2 ADC pinouts.



(a) (b) (c)

Figure 2. (a) Arduino UNO, (b) YF-S201, (c) 128X64 OLED Display



PIN LABEL	
YF-S201	**UNO**
GND	GND
VCC	5V
SIG	D2

PIN LABEL	
128X64 OLED	**UNO**
GND	GND
VDD	5V
SCK	A5
SDA	A4

Figure 3. Wiring diagram of water flow data acquisition

To understand how the water flow sensor work and how the data being acquisition it can be seen in Figure 4.

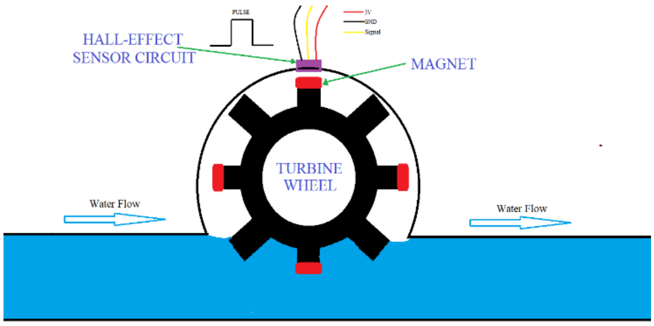


Figure 4. YF-S201 working principle

The water flows into the pipe on the sensor, which is then detected by hall effect technology on the sensor using turbine wheel. From Figure 4, there are 4 magnets in turbine wheel indicated by the color red. Every time the hall-effect detect the magnet it will increase the pulse by one, or equal to 1 pulse. That mean the speed of turbine wheel depends on the speed of the water flowing through the pipe [15].

After that is data acquisition, data acquisition is divided into 3 sections it is data preparation, data collecting, and data processing. The first step is data preparation, data Preparation section prepares the tools that will be used to perform the experiments. For data acquisition, the tools prepared in the previous section are described here, namely microcontrollers, sensors, and data display screens as it can be seen in Figure 3. For the place where the test will be carried out for now, it will still be carried out using a faucet to measure the speed of the water flow and the incoming water discharge depending on the number of impulses obtained in a certain period of time.

The next section is data collecting, this section is about collecting the data is with tools that already prepared in the previous section. In this research data collection is done using a water flow sensor on the microcontroller. The data is collected by connecting the sensor with a water tap using a hose in simulated condition. Conditions are simulated by turning the used water tap at different speeds within a given time. In this way, different impulse values and volumes of water are obtained in the same period of time. The measurement error rate of this sensor based from the data sheet is estimate to be around 10 or 5% and it is already enough precision for this research. The parameter obtained from this test is pulse, water volume, and frequency.

In order to determine whether the sensor used is working properly, a measurement test of the sensor is performed by experimenting twice on the same volume of water at the same height of the measuring cup in 15 seconds. To find the error value of each experiment and the average error of all experiments, Equation (1) and Equation (2) are used.

$$error = \left| 100 - \left(\left(\frac{f1}{f2} \right) 100 \right) \right| \tag{1}$$

$$\overline{error} = \frac{\sum error}{N_{Test}} \tag{2}$$

Where $f1$ is first test frequency (Hz), $f2$ is second test frequency (Hz), N_{Test} is the number of test conducted, $error$ is number of error (%) and $\overline{error}$ is average of total error (%)

Data processing is the third section of data acquisition, where the previously collected data is converted into parameters that will be used in the case study to prove the formulas used is correct. For this research, the frequency parameters obtained in the previous stage are converted into water discharge and water flow parameters.

After data acquisition, the parameters obtained are tested on a case study with random parameters with the limitations of the sensors used. for this experiment, the length, width and height of the drainage are 10x4x3 m. The length of the drainage is more than 100 m, but only the area within the 10 m will be calculated. The height of the water in drainage is assumed to be constant at 2 m, so the sensor is placed at a height of 1 m from the bottom of the drain. In the case study the limit of water flow velocity is 720 L/H or 12 L/minute using the linear exponential graph of the water flow sensor obtained from the sensor datasheet show in Figure 5.

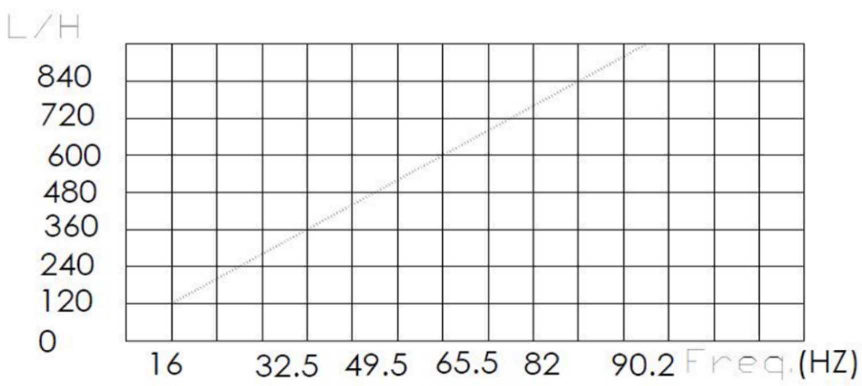


Figure 5. Flow Sensor Exponential Linear Graph

By looking at the graph in Figure 5, a table can be made that determines the relationship between frequency and water discharge. The relationship can be seen in Table 1.

Table 1. Frequency comparison with water discharge

Discharge(L/H)	Frequency(Hz)
120	16
240	32.5
360	49.3
480	65.5
600	82
720	90.2

Table 1 shows the comparison obtained from the linear exponential graph in Figure 5. This comparison is a benchmark for finding the water discharge with the frequency data obtained previously. The formula for finding the water discharge can be obtained by linear interpolation of two comparison data that are close to the frequency obtained. The formula is shown in Equation (3).

$$Q_x = Q_1 + \frac{(f_x - f_1)(Q_2 - Q_1)}{(f_2 - f_1)} \quad (3)$$

Where Q_x is interpolated water discharge (L/H), f_x is interpolated frequency (Hz), Q_1 is f_1 water discharge (L/H), f_1 is frequency smaller than f_x (Hz), Q_2 is f_2 water discharge (L/H) and f_2 is frequency bigger than f_x (Hz).

By knowing the formula for finding the water discharge, the speed of water flow can be found. To find the water flow velocity, the cross-sectional area through which the water flows and the water discharge are required. With the previous explanation, the water flow velocity can be found by using the continuity equation. Before executing the continuity equation, the hour unit on the water discharge from the results of Equation (3) must be converted to seconds by dividing by 3600. With the previous explanation, it can be seen in the formula Equation (4).

$$v = \frac{Q/_{3600}}{A} \quad (4)$$

Where v is water velocity (m/s), Q is water discharge (L/H), meanwhile A is water cross-section area (m^2).

The design of this project utilize Arduino IDE as it software tool. Arduino IDE is used to programmed Arduino IDE in the project. The program consists of receiving input from the flow sensor and displaying the pulse received in the flow sensor in the OLED display. Figure 6 display the code, library and syntax used in programming this project.

```
//Libraries
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
// OLED I/O
#define SCREEN_WIDTH 128 // OLED display width, in pixels
#define SCREEN_HEIGHT 64 // OLED display height, in pixels
#define OLED_RESET -1 // Reset pin # (or -1 if sharing Arduino
reset pin)
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire,
OLED_RESET);
//Define Sensor Pin
#define flowPin 2
volatile int count;
void setup() {
  //read pin
  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // Address 0x3C
for 128x32
    Serial.println(F("SSD1306 allocation failed"));
    for(;;); // Don't proceed, loop forever
  }
  pinMode(flowPin, INPUT);

  //Another Configuration
  attachInterrupt(digitalPinToInterrupt(flowPin), Flow, RISING);
  Serial.begin(115200);
}
```

```
void loop() {
  interrupts();   //Enables interrupts on the Arduino
  display.clearDisplay();
  display.setTextSize(4);              // Normal 1:1 pixel
scale
  display.setTextColor(WHITE);         // Draw white text
  display.setCursor(0,0);              // Start at top-left
corner
  display.print("Pulse:");
  display.println(count);
  display.display();
  Serial.println(count);
}

//Interrupt Count Sensor
void Flow(){
  count++;
}
```

Figure 6. The code of this project in Arduino IDE

Results and Discussions

Data acquisition in this project conducted in 3 step data preparation, data collection, and data processing. In every step the experiment is conducted to ensure the data obtained is not full of error.

Sensor Calibration

To ensure the flow sensor work correctly, an experiment is needed to prove that the equation before is correct by displaying the frequency pulse signal using an oscilloscope. In this experiment, the oscilloscope settings used are 5V for Volt/Div, 10ms Time/Div. The voltage is set to 5V because the highest voltage is at 5V, so it is easy to calculate div. The time is set to 10ms because the signal is clearly visible on the oscilloscope. The signal can be seen in Figure 7, the signal obtained is in the form of a step signal.

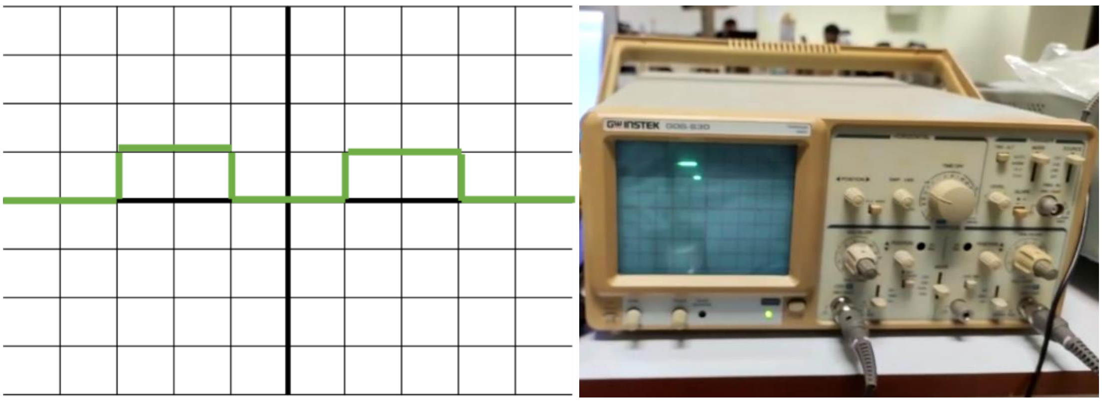


Figure 7. Oscilloscope signal

From the signal, it can be seen that one period is 4 Div, so to find the signal time, Time/Div set previously is multiplied by number of Div for one period (T) to get a time of 40ms. Because the time has been obtained, the frequency can be found using the Equation (5).

$$f = \frac{1}{T} \tag{5}$$

From the Equation (5) the frequency obtained is 25 Hz. Because Div in Volt/Div is only 1 Div, the voltage obtained is 5V. The frequency obtained will continue to decrease over time as the water tap is turned down until it closed as seen at the graph in Figure 8. It can be seen that the water flow velocity will continue to decrease as the water tap turned down more and more until it fully closed.

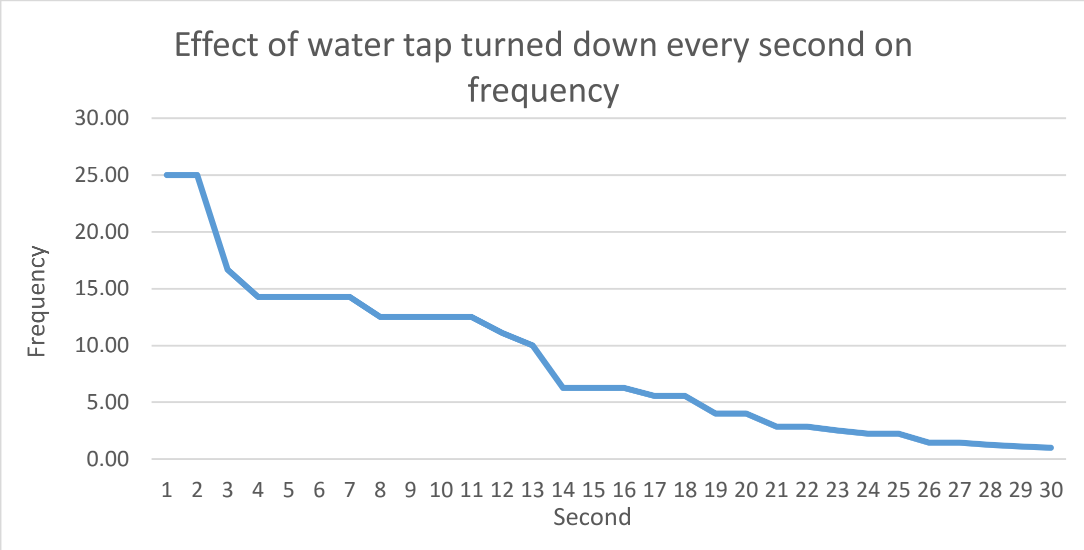


Figure 8. Effect of water tap closed slowly every second.

The parameter values of the graph can be seen in Table 2, which shows the effect of time (ms) on the frequency obtained. It can also be seen that the frequency value decreases the longer the faucet of the calibration tool is open. This is because the more water that comes out of the faucet, the more the volume of water in the calibration tool decreases, causing a decrease in the frequency detected.

Table 2. Frequency obtained over time

No (s)	Time/ Div	Div	Time (ms)	Frequency (Hz)
1	10	4	40	25.00
2	10	4	40	25.00
3	10	6	60	16.67
4	10	7	70	14.29
5	10	7	70	14.29
6	10	7	70	14.29
7	10	7	70	14.29
8	10	8	80	12.50
9	10	8	80	12.50
10	10	8	80	12.50
11	10	8	80	12.50
12	10	9	90	11.11
13	10	10	100	10.00
14	20	8	160	6.25
15	20	8	160	6.25

Data Collection

Based from the explanation in the methodology about data collection, the data collecting conducted can be seen in Figure 9 to get the pulse data.

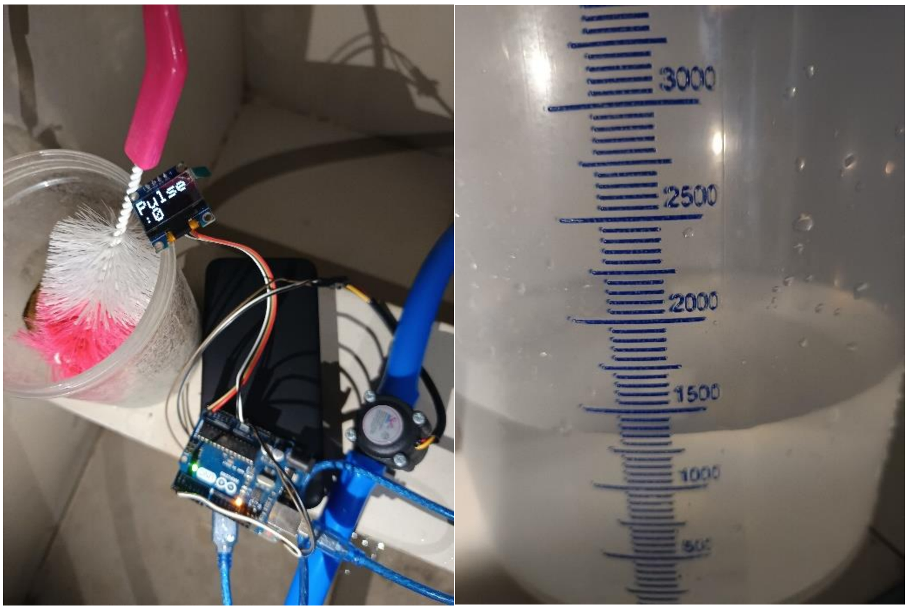


Figure 9. Data collection with water flow sensor

In Figure 9, the experiment was conducted on the direct sensor. The data collected in the experiment are two: pulse data and water volume data. The pulse data is obtained from the direct sensor, and the water volume data is obtained from the measuring cup. The first experiment was carried out by looking for pulses with a specified volume of water within 15 seconds. This experiment was repeated 25 times with different volumes to determine the number of errors and the average error of the sensor used. The second experiments were conducted in different time periods, namely 5 seconds, 7 seconds, 10 seconds and 12 seconds. By obtaining the parameters of the pulse and water volume, it can be find the frequency parameter using the formula on Equation (6). The obtained parameters are shown in Table 3 and Table 4.

$$f = \frac{x}{t} \tag{6}$$

Where f is frequency (Hz), x is pulse and t represent time (s).

Table 3. Experimental data from the calibration test in 15 seconds

No	Water Volume (mL)	Pulse 1	Pulse 2	Frequency 1 (Hz)	Frequency 2 (Hz)	Error (%)
1	600	325	343	21.67	22.87	5.25
2	650	373	378	24.87	25.20	1.32
3	700	405	398	27.00	26.53	1.76
4	750	425	410	28.33	27.33	3.66
5	800	455	461	30.33	30.73	1.30
6	850	509	488	33.93	32.53	4.30
7	900	522	522	34.80	34.80	0.00
8	950	579	551	38.60	36.73	5.08
9	1000	605	611	40.33	40.73	0.98
10	1050	613	631	40.87	42.07	2.85
11	1100	645	667	43.00	44.47	3.30

No	Water Volume (mL)	Pulse 1	Pulse 2	Frequency 1 (Hz)	Frequency 2 (Hz)	Error (%)
12	1150	679	644	45.27	42.93	5.43
13	1200	688	701	45.87	46.73	1.85
14	1250	713	722	47.53	48.13	1.25
15	1300	735	736	49.00	49.07	0.14
16	1350	785	787	52.33	52.46	0.23
17	1400	815	801	54.33	53.40	1.75
18	1450	811	845	54.07	56.33	4.02
19	1500	873	811	58.20	54.07	7.64
20	1550	902	904	60.13	60.27	0.22
21	1600	932	921	62.13	61.40	1.19
22	1650	961	991	64.07	66.07	3.03
23	1700	965	993	64.33	66.20	2.82
24	1750	1004	1022	66.93	68.13	1.76
25	1750	1049	1052	69.93	70.13	0.29
Error Average						2.46

Using Equation (1) and Equation (2), we can find the error and average error from the data obtained in Table 3. In the table, the highest amount of error is 7.64% at 1500 ml water volume and the lowest amount of error is 0% or no error at 900 ml water volume. By averaging the number of errors from the total error obtained in 25 experiments, the amount found is 2.46%. According to the data sheet, if the error does not exceed 10%, the sensor can still be properly used.

Table 4. Experimental data at various time intervals

Time (s)	Pulse	Water Volume (mL)	Frequency (Hz)
5	387	750	77.40
5	325	600	65.00
5	405	1050	81.00
5	386	600	77.20
5	425	650	85.00
5	397	700	79.40
7	411	800	58.71
7	309	600	44.14
7	427	800	61.00
7	338	650	48.29
7	368	750	52.57
7	407	750	58.14
10	713	1350	71.30
10	262	450	26.20
10	579	1150	57.90
10	613	1150	61.30
10	455	900	45.50
10	523	1000	52.30

Time (s)	Pulse	Water Volume (mL)	Frequency (Hz)
12	673	1300	56.08
12	679	1300	56.58
12	1047	2050	87.25
12	878	1800	73.17
12	605	1100	50.42
12	725	1500	60.42

Data Processing

With the data obtained in Table 4, data processing is then performed on the frequency obtained in the previous data, which can be seen in Table 5.

Table 5. Processed data of water discharge by time interval

Time (s)	Frequency (Hz)	Water Discharge (L/h)
5	58.71	429.7354497
5	44.14	323.1632653
5	61.00	446.6666667
5	48.29	352.755102
5	52.57	384.2328042
5	58.14	425.5026455
7	58.71	429.7354497
7	44.14	323.1632653
7	61.00	446.6666667
7	48.29	352.755102
7	52.57	384.2328042
7	58.14	425.5026455
10	71.30	522.1818182
10	26.20	194.1818182
10	57.90	423.7037037
10	61.30	448.8888889
10	45.50	332.8571429
10	52.30	382.2222222
12	56.08	410.2469136
12	56.58	413.9506173
12	87.25	676.8292683
12	73.17	535.7575758
12	50.42	368.2716049
12	60.42	442.345679

From Table 5 it can be seen that there is no water flow, this is because the area is not known, so Equation (4) cannot be used to obtain the parameters. For more depth, a case study is carried out with the shape of the sensor area.

Case Study

The shape of the underground drainage in this case study is shown in Figure 10. From the real image of the drainage system, it was converted into a schematic diagram to facilitate calculation. From the explanation of the methodology, it can be seen that the underground drainage is in the form of a beam, so the area of this drainage can be obtained using Equation (7) and the water volume can be obtained by multiplying the long, wide, and height.

$$L = 2[(l \times w) + (l \times h) + (h \times w)] \tag{7}$$

Where L is water cross-sectional area (m^2), l is water long (m), w is water wide (m) and h is water height (m)

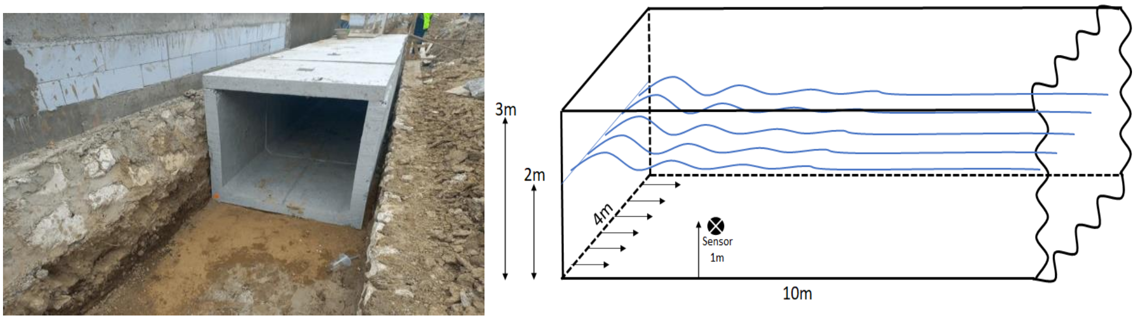


Figure 10. Underground drainage shape

After obtaining the area and the water volume, the experiment can be carried out by trying to enter the randomized pulse parameter 10 times for comparison. With the known parameters of area, water volume and pulse, we can find the water discharge with Equation (3) and water flow with Equation (4), the results can be seen in Table 6.

Table 6. Case study result

No	Pulse	Wtr Vol (Ltr)	Wtr Area (m^2)	Freq (Hz)	Wtr Discharge (L/H)	Wtr Flow (m/s)
1	1964	80	136	32.73	241.6666667	0.000493600
2	3753	80	136	62.55	458.1481481	0.000935760
3	5024	80	136	83.73	625.3658537	0.001277300
4	1663	80	136	27.72	205.2121212	0.000419142
5	2701	80	136	45.02	329.4047619	0.000672804
6	4876	80	136	81.27	589.2682927	0.001203571
7	3877	80	136	64.62	473.4567901	0.000967028
8	2257	80	136	37.62	276.5476190	0.000564844
9	2812	80	136	46.87	342.6190476	0.000699794
10	4528	80	136	75.47	504.3902439	0.001030209

From Table 6 it can be seen that the result of the previous calculation based from 10 imaginary number randomly selected for the pulse. Because it still in imaginary number the test is still 0% error if it based from the equation.

Conclusion

Data acquisition for underground drainage was performed. From the calibration of the water flow sensor, it can be proved that the frequency obtained when the water tap closes becomes smaller, which is proved by experiments with an oscilloscope. From the above experiment, it can be seen that the highest error rate on the sensor according to Table 3 is 7.64% and the lowest at 0% or no error with the average amount of error is 2.46%. Through this experiment, the sensor can be used to find the water discharge by using the frequency obtained from Equation (6). From the results, the water discharge can be found by linear interpolation by comparing two coordinates that are close to the frequency obtained according to Table 5. Then, the water flow velocity can be found with the obtained water discharge. For this case study, there is no average error because the use of formulas in calculations does not use sensors, but uses random data. In future research, water level sensors can be added and direct experiments on underground drainage can be conducted to obtain more complete research results.

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