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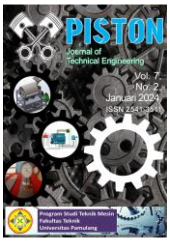

Design and Implementation of Rain Gauge Measurement using Ultrasonic Sensor HC-SR04 (Case Study using Ombrometer Method)

Frengki Simatupang[1,a)], Waldo Owen Nainggolan[2,b)]

[1]*Teknologi Komputer, Fakultas Vokasi,Institut Teknologi Del Toba 22381, Indonesia*
[2]*School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Indonesia*

E-mail: [a)]frengki.simatupang@del.ac.id
[b)]waldo.o.nainggolan@gmail.com

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Abstract: There are several types of rainfall measurement method, such as tipping bucket, siphon, rain water weight and other various methods. This research developed the alternative and affordable method to measure the rain gauge using ultrasonic sensor. The method used to convert the volume of collected rain water to the level of a rain gauge is Ombrometer method. Ultrasonic Sensor HC-SR04 is chosen as a sensor to measure the water level in the collected rain water tank because it categorized as a low-cost sensor. Measuring the level of rainfall using an ultrasonic sensor is influenced by the design of the reservoir tank and also the resolution of the ultrasonic sensor. This research found that the difference the measurement using ultrasonic sensor between ombrometer formula is sufficiently linear with the difference average at 32.63%. The lookup table method is implemented to linearize the measurement based on the ombrometer value method. By using the linearized value, the design is capable to measure light rain category because the design has the sensitivity/resolution measurement of rain gauge on 0.48 mm. This research also found that the average value of the measurement using the ultrasonic sensor for each measured volume water injected to the tank using this design and use this value as a trigger to send the actual measurement result to the users. All parameters from this system are sent using Wi-Fi connectivity to the server and can be monitored using Online Web Dashboard.

Keywords: Ombrometer; Ultrasonic Sensor; Microcontroller; Rain Gauge Measurement; Wi-Fi.

Abstrak: *Berbagai jenis metode pengukuran curah hujan, seperti tipping bucket, siphon, rain water weight dan berbagai metode lainnya. Penelitian ini mengembangkan metode alternatif dan terjangkau untuk mengukur curah hujan menggunakan sensor ultrasonik. Metode yang digunakan untuk mengubah volume air hujan yang tertampung ke tinggian alat pengukur hujan adalah metode Ombrometer. Sensor Ultrasonik HC-SR04 dipilih sebagai sensor untuk mengukur ketinggian air pada bak penampung air hujan karena dikategorikan sebagai sensor yang murah. Pengukuran tingkat curah hujan dengan menggunakan sensor ultrasonik dipengaruhi oleh desain tangki penampung dan juga resolusi dari sensor ultrasonik tersebut. Penelitian ini menemukan bahwa perbedaan pengukuran menggunakan sensor ultrasonik antara rumus ombrometer cukup linier dengan rata-rata perbedaan sebesar 32,63%. Metode lookup table diimplementasikan untuk linierisasi pengukuran berdasarkan metode nilai ombrometer. Dengan menggunakan nilai linierisasi, desain mampu mengukur hujan kategori ringan karena desain memiliki sensitivitas/resolusi pengukuran alat pengukur hujan sebesar 0,48 mm. Penelitian ini juga menemukan bahwa nilai rata-rata pengukuran menggunakan sensor ultrasonik untuk setiap volume air terukur yang diinjeksikan ke tangki menggunakan desain ini dan menggunakan nilai ini sebagai pemicu untuk mengirimkan hasil pengukuran yang sebenarnya kepada pengguna. Semua parameter dari sistem ini dikirim menggunakan konektivitas Wi-Fi ke server dan dapat dimonitor menggunakan Online Web Dashboard dengan ThingSpeak IoT.*

Kata kunci: *Ombrometer; Sensor Ultrasonik; Mikrokontroler;Wi-Fi; Rain Gauge Measurement.*

INTRODUCTION

Recent research conducted by Xu and Zheng [1], [2] has introduced a rain measurement method utilizing two ultrasonic transducers, achieving high precision with an absolute error of less than 0.15 mm. Nevertheless, challenges emerge due to the brittleness of piezoelectric ceramic chips at ultrasonic frequencies exceeding 5MHz. Conversely, research by Yudhana et al. employs the HC-SR04 sensor for the Ombrometer method, incorporating online monitoring through a web application. However, this system faces energy limitations in the mechanical component of water delivery and has not yet conducted tests regarding measurements related to the increase in water volume per stage.

Rainfall measurements are widely used in meteorological research, water conservation research, oceanography research and industrial fields. Recently, there are several types of rainfall measurement methods, such as rainfall measurement using tipping bucket, siphon, rain water weight etc [3]–[6]. They are applied in different occasions with their own characteristics. For example, the absolute error in rainfall measurements using tipping bucket method is more than 1% in light rain and measurement errors will increase by more than 10% when heavy rains occur [6].

The ultrasonic sensors are developed based on the characteristics of ultrasonic waves and used in many industries for measurement purposes [7], [8]. Measurement of rainfall using ultrasonic sensor has been used as an alternative method for measuring the rain gauge based the height of collecting rain in the tank, but the number of ultrasonic sensors used are two pieces and they are placed on the bottom of the tank. The first ultrasonic sensor is used as the standards to measure of water level. In other words, it used as the comparison of measurements from other ultrasonic sensor that is used to measure the distance of the sensor to the surface of the water, so that the obtained measurement become more accurate and precise because the results is obtained based on the calibration from these sensors [1], [9].

The design described in this paper is focused on how to measure the level rain gauge using an ultrasonic sensor by placed it on the top of the collected rain water tank and integrate it with other sensors. The water tank has been designed to have a water circulation that automatically drains out whole water if water reaches the top of the tank. This system was designed to have the compatibility to send all of the measurements from the sensor using the microcontroller, and send them through the serial communication such as an Ethernet port, and also wirelessly using Wi-Fi, using radio frequency such as Zigbee and Lora. But on this paper used Wi-Fi connectivity to send the measurements to the server based on cloud computing technology and each parameter can be monitored using Online Web Dashboard.

RELATED WORKS

This section will discuss the current state of researches on rain gauge measurement using ultrasonic sensor HC-SR04, which is divided into two parts, which are contained the current researches about the design of measurement of rain gauge using the ultrasonic sensor for high precision and similar works using ombrometer method using HC-SR04.

A. High Precision Rain Gauge Measurement using Ultrasonic

Xu and Zheng [1] mentions that acoustic self-calibration can take out the vulnerability of the speed of ultrasound and accomplish precise estimation of precipitation. By using two ultrasonic transducers which both are installed at the bottom of the rainwater container. One of the transducers is used to receive the reflected ultrasound from a standard gauge installed on the top of it. The other is used to receive a reflected ultrasound for the liquid surface where these sensors emit ultrasound simultaneously and use a high-speed timer to measure the time of ultrasound from launch to return. By comparing these values, get the high of the rain gauge. By using this method, the absolute error of the rain gauge is less than 0.15 mm under different conditions.

The ultrasonic propagation velocity of the liquid is affected by temperature, density, viscosity and other factors. It is difficult to accurately correct the velocity of the reflected ultrasound, so the high frequency ultrasound is used to improve the accuracy. Nonetheless, when the recurrence of the ultrasonic transducer is higher than 5MHz, the piezoelectric ceramic chip is extremely flimsy, which is the principal part of the ultrasound transducer. This causes hardships in the creation of the transducer. The system also used a water pump to clean the surface of the ultrasonic transducer periodically once per six hours, which results in wasteful use of energy.

B. Similar Ombrometer Method using HC-SR04

Yudhana et al. [2] had worked on the rain gauge measurement system using HC-SR04 where the sensor was placed below the reservoir tube and the measurement method by using an ombrometer. The measurement is not only displayed via LCD but also online using Web application by using Wi-Fi transmission. The drain of the reservoir tank will be opened using the pump and the drain of the water works periodically every day at 07.00 am and when the water reaches the sensor. The maximum level measurement of this system is adjusted in the low rainfall intensity, between 0mm – 100 mm per day. So, the measurement will be restarted at 07.00 am per day.

The system has a mechanical part to drain the water, which is consumes more energy. The correlation measurement was compared by using BMKG manual with modification and manual measurement and it shows the limitation of modification measurement of low-level manual measurement. The measurement testing on this system does not include the increase in the volume of water per stage to identify the behavior of the measurement whether the error measurement has a linear graph or not.

C. Proposed Design

In the beginning, the author's question is how to design a self-calibrate and affordable rain gauge measurement by using an ultrasonic sensor that can optimize the capabilities of the sensor, using no mechanical parts, adding some climate measurement to support these parameters. The parameters of the measurement are displayed using the Web Application these parameters are sent using IoT Technology through the Wi-Fi connection.

The main constraint is how to design the affordable and simple rain gauge measurements using a low-cost and low-maintenance ultrasonic sensor which will impact the lack of rain gauge measurement accuracy if compared with other rain gauge measurements i.e., Tipping bucket. Otherwise, based on that the rain gauge measurement can be done on many spots, and for future research, the rainy climate will be predictably caused the area of measurement has been mapped and analyzed using machine learning technologies.

CURRENT SYSTEMS

A. Sensors System

This system is responsible for retrieving each measurement parameter from the environment and regulating the measurements from the sensors and converted based on the measurement needed. This subsystem consists of several components as follows:

1. Wemos D1
   The microcontroller used in this design is Wemos D1, which provides Wi-Fi integrated module to ease sending the measurements to the internet.
2. Ultrasonic Sensor
   HC-SR04 is chosen as a sensor to measure the water level in the tank because it is categorized as a low-cost sensor. If compared with HY-SRF05, it is a more expensive improved model and has the maximum possible measurement distance. If it is compared with US-015, it has greater accuracy, but is slightly expensive because this sensor is less popular [10].
3. Temperature and Humidity Sensor
   Temperature and humidity sensor are used to measure the air temperature and humidity from the environment. The sensor used is DHT11.
4. pH Sensor
   pH sensor is used to measure the acidity of rain collected on the tank. The pH sensor used is SEN0161.

B. Additional Hardware

To run the entire sensor subsystem, some of additional hardware is needed as follows:

1. 12 V Adaptor: The adaptor is used as the power source whole system.
2. Water Hose: The water hose is used to distribute the rain collected in the main tank.
3. Funnel: The funnel is used as the rainwater collector that will be channeled to the main tank.

PROPOSED DESIGN AND IMPLEMENTATION

A. Block Diagram of Measurement System

The measurement system used for the testing method is shown in Figure.1 that are consist with Ultrasonic Sensor, GPS Module, Temperature and Humidity Sensor, pH Sensor and Microcontroller (Wemos D1 Wi-Fi Uno) that support Wi-Fi connection.

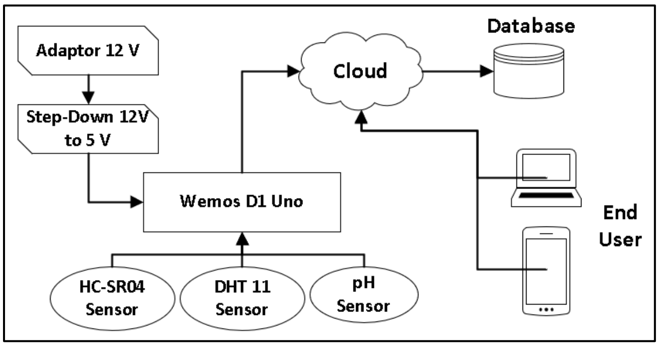

Figure 1. Block diagram of measurement system

Each sensor working on 115200 baud rates and send the measurement to the microcontroller and routes the measurements to the IoT platform using ThingSpeak and also save each measurement to the online database. The Graphical User Interface (GUI) for the system is designed to be connected to the internet, so the web app has been hosted and can be monitored using a personal computer and the mobile phone that connected to the internet.

B. Design of Rain Reservoir Tank and the Funnel

On the outside of system design, planning will be covered shown in Figure. 2, so the measurement on the tank can precisely run because the whole measurement system will be isolated in an addition to reducing evaporation in the event of extremely hot weather. The design done based on climate characteristics occurs in Indonesia, so the design can optimally designed considering each sensors limit capabilities.

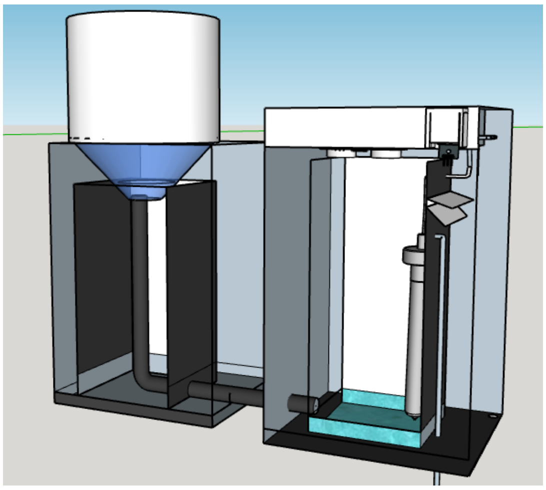

Figure 2. Rain gauge measurement system

According to rain classification data from Agency of Meteorology, Climatology and Geophysics of Indonesia [11], criteria of rainfall intensity, especially in Indonesia is divided into 5 parts in units of day and hour, as is shown on Table 1.

Table 1. Criteria of rain intensity in Indonesia

Category	Level of Rain Gauge
Cloudy	0 mm/day
Light	0.5 – 20 mm/day
Medium	20 – 50 mm/day
Heavy	50 – 100 mm/day
Very Heavy	100 – 150 mm/day
Extreme	>150 mm/day

By using Table 1, assumed that the design is able to measure the heavy rain intensity, assume on 25mm. The method used to convert the volume of collected rainwater to the level of rain gauge by using the Ombrometer method. The first step is to specify the shape of the rainwater collector which used the funnel with the base area have a circumference shape and calculate the area of rainwater collector by using Eq.1 follows.

$$A = \pi r^2;\ A = \pi \times 10^2;\ A = 314\ cm^2 \text{……….} \ (1)$$

where: r = radius of the base of the funnel (10 cm)
h = maximum level of rain gauge designed (25 mm)
A = base area of the funnel (cm^2)

So, obtained the top area of the funnel is $314\ cm^2$. To measure the rain gauge level using Ombrometer method shown on Eq. 2.

$$h = \frac{V}{A} \text{ ....(2)}$$

where: h = level of the rain gauge measurement (cm)
A = base area of the funnel (cm^2)
V = volume of collected rain water by funnel (cm^3)

Then, substitute Eq.1 to Eq.2 results.

$$V = A \times h;$$

$$V = 314\ cm^2\ \times 2.5\ cm;$$

$$V = 785\ cm^3; V = 785\ mL = 0.785\ Litre$$

For the maximum rain gauge measurement, the volume of collected rain is $785\ \mathrm{cm}^3$. Because there is a pipe to connect the funnel to the water tank and assumed the pipe has a diameter 1.5 cm and height 14 cm, so obtained the total volume of the water on the pipe is 24.72 cm^3. The total volume of collected rain at the measurement at 25 mm is 809.72 cm^3.

Abdulkhaleq et al. [12] mentions that his experimental results confirmed that HC-SR04 has a resolution range of within 7 cm between two adjacent objects and the distance from the sensor to the target is 11 cm, where this poor resolution comes from its small radiant aperture. This means, the beamwidth of the sensor can detect the object in the range 7 cm on 11 cm distance from the sensor to the object. Zhmud et al. [10] also said that the most effective measuring angle for HC-SR04 is 15^0 and the signal is propagated by a wave directed at an angle of 30^0. Based on that, the appropriate dimension of the water collector is a rectangle, with the size as follows. Length = 7 cm, Width = 7 cm, Height = 16 cm.

The dimension type of the water collector is chosen to increase the sensitivity of the ultrasonic sensor to measure the water level change on the tank, give adequate space to the pH sensor on the tank, and also improve the water circulation on the tank through the disposal water system. To measure the sensitivity level of the ultrasonic sensor, the ultrasonic sensor has a level of resolution. Based on HC-SR04 Datasheet [13], this sensor provides 2 cm – 400 cm non-contact measurement function and ranging accuracy can reach to 3 mm.

Based on that, the capability of the HC-SR04 to read the water level change is 3 mm or 0.3 cm and the measured volume of water on the tank is shown in Eq.3. Assume, $\Delta \mathrm{h} = \text{resolution of ultrasonic sensor}$, so

$$V_{total} = (Area\ of\ the\ tank + Area\ of\ the\ pipe) \times \Delta h; \text{ ....(3)}$$

$$\mathrm{V_{total}} = (49\ \mathrm{cm} + 1.76\ \mathrm{cm}) \times 0.3\ \mathrm{cm} = 15.228\ \mathrm{mL}$$

Based on the total volume, obtained the sensitivity result for the design is shown on Eq.4.

$$h = \frac{V\ total}{Area\ of\ the\ funnel}\ ;\ h = \frac{15.228\ cm^3}{314\ cm^2}\ ; h = 0.48\ mm \text{ ....(4)}$$

It can be concluded that if the resolution of the HC-SR04 sensor is 0.3 cm, the sensitivity/resolution measurement of the system is 0.48 mm. By this parameter, this design has th capability to measure the light rain category by using the HC-SR04 sensor.

1. Ultrasonic Sensor Placement: The ultrasonic sensor is placed on the middle top of the water tank with the angle to the water is tuned to 15^0, so the measurement runs to all surface of the water on the tank.
2. Temperature and Humidity Sensor Placement: The temperature and humidity sensor is placed on the outside of the system because the sensor measures the temperature and humidity from the outside environment. But this sensor is isolated so the reliability and durability of the sensor can be maintained.
3. pH Sensor Placement: The pH sensor is placed on the bottom of the water tank and designed not to resist the ultrasonic sensor to measure the height of the water. The probe of pH sensor also designed in order to be submerged to the water, so the calibration periodically minimalizes.

C. Design of the Water Disposal System

The method used to drain the collected water by utilizing the earth's gravitational force or commonly called the siphon method. Siphon is used to evade using other actuators like a water pump to drain the water beside to reduce power consumption. This method will work to drain the water in the reservoir when the water level in the tank passes through a maximum point in the tank. However, if the water discharge entering the reservoir is greater than the drained water discharge, the design of the rainwater reservoir is equipped with a cut-off from the excess water level if the siphon subsystem does not work properly so that the water does not hit the sensor and microcontroller. The siphon is implemented on the system as shown in Figure.3.

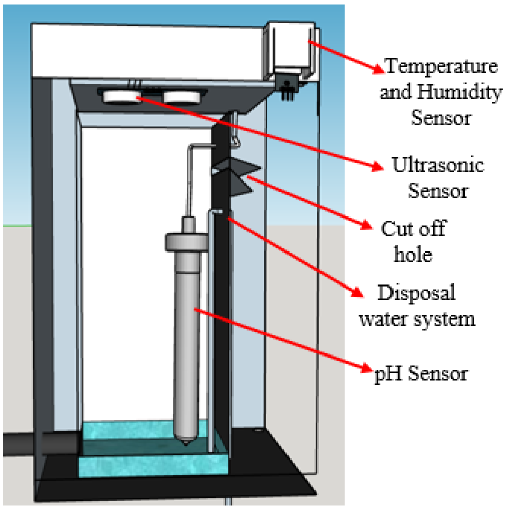

Figure 3. Sensors placement and water disposal

RESULT AND DISCUSSION

A. Result

In the experiment, the measurement of rainfall was carried out by comparing the measurements manually with the reading of the ultrasonic sensor directly on the serial monitor. Experiments are carried out by manually injecting water into the rain collected water tank, while the steps of the calculation are using Eq.1 follows.

r = radius of the funnel 10 cm
L = area of circle on the funnel
h = rain gauge level
V= volume of collected water

$$L = \pi r^2$$
$$L = \pi \times 10^2$$
$$L = 314\ cm^2$$

Then, the area of the funnel circle is 314 cm^2. To calculate the level of rain gauge by using Eq. 2. Then, the experimental steps are done by injecting water with measured volume water that has been attached to Table II. The comparison table of rainfall level sensor reading with calculation with ombrometer method is as follows.

Table 2. The comparison of rain gauge measurement

No.	Volume of water (mL)	Result of rain gauge measurement	
		Calculation Method (mm)	Using Ultrasonic Sensor (mm)
1	0	0	0
2	3	0.096	0.247
3	5	0.159	0.465
4	7	0.223	0.682
5	10	0.314	0.9
6	12	0.382	1.118
7	15	0.478	1.335
8	17	0.541	1.553
9	20	0.637	1.84
10	22	0.701	1.964
11	25	0.796	2.185
12	27	0.86	2.407
13	30	0.955	2.628

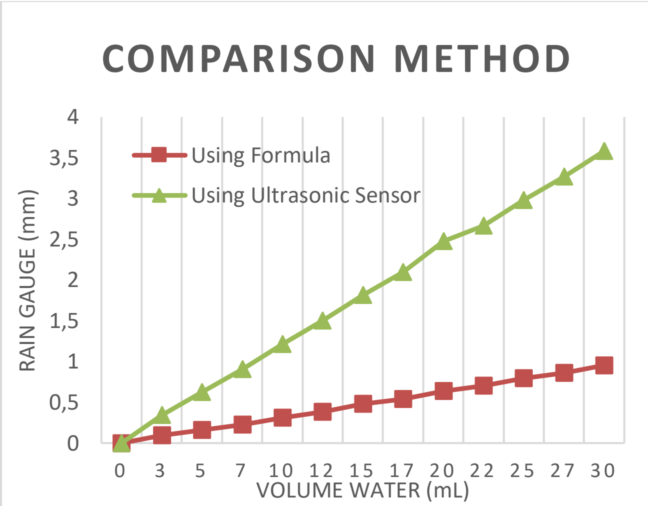

Figure 4. Graph of comparison between rain gauge measurement using ultrasonic sensor and using the ombrometer formula

Based on Table 2 and Figure 4 can be analyzed that the measurement of rainfall levels using ultrasonic sensor has a level of accuracy and precision that is less than the measurement with a calculation method, which results from the difference in measurement results is further between measurement method using calculations and measurement methods using sensors ultrasonic. Also found that the difference in the measurement using ultrasonic sensor between ombrometer formula is sufficiently linear with the average difference is 32.63 %. This is caused by the resolution of the ultrasonic sensor which is too large and the interference of ultrasonic waves reflected back from the wall of the holding tank so that the sensor is not consistent in displaying measurement data that requires high sensitivity due to changes in water level in the relatively smaller reservoir tank. As a solution to this problem, the calculation of the average value of each measurement at a water level in the tank is calculated. After that, a lookup table is performed to display the measurement results using the calculation method based on Table II. The measurement data delivered to the user is the measured data using the ombrometer formula. Based on the research, has been found on Table II and Figure 4, that the average value of the measurement of a measured volume of water injected to collected rainwater tank using the ultrasonic sensor using the design of this paper, and this value is used as a trigger to send the actual measurement result to the users.

B. Discussion

All of the parameters of the sensor will be received by the microcontroller then the microcontroller will send measurement data on each sensor by using a previously selected communication system. Based on Figure. 5, it is shown that the measurement results for each sensor are as follows: 1. The ultrasonic sensor reads the results of the measurement of rainfall level which is equal to 17.89 mm with the level of change in rainfall that is equal to 7.37 mm. 2. Temperature and humidity sensors read the measurement results of air temperature of 260C and measurement of air humidity by 74%. 3. The pH sensor reads the acidity of the water collected in the holding tank, which is equal to 6.19.

```
AT+CIPSTART="TCP","184.106.153.149",80
AT+CIPSEND=103
GET /update?api_key=SL8SXSAWU9NI2CQV&field1=17.89&field2=26.00&field3=74.00&field4=6.19&field5=7.37

Rain Gauge: 17.89 mm    Temperature: 26.00 degrees Celsius    Humidity: 74.00 %    PH: 6.19    Delta: 7.37 mm
Sending data to Thingspeak
Waiting 5 minutes
```

Figure 5. Parameters read by microcontroller

All of the measurements are sent to the ThingSpeak IoT platform over the Wi-Fi connection every 5 minutes and can be monitored using Web Dashboard as shown in Figure. 6. Through this Web Dashboard, the measurements can be filtered by timestamp to make the Web more intuitively viewed by users. As shown in Figure 6, the measurement of rainfall can be categorized in units per hour or per day. Figure 7 also shows how the system is implemented based on the proposed design previously described it also shows the methods how the sensors placed on the system and the other important thing like microcontroller and adaptor placed on the rain gauge measurement system.

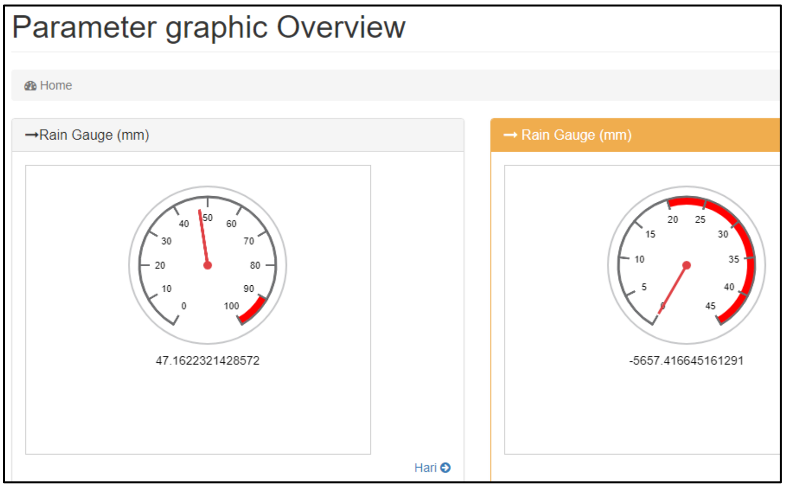

Figure 6. Monitoring web dashboard using ThingSpeak IoT

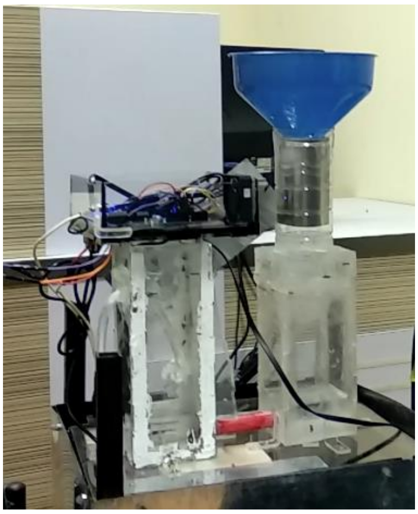

Figure 7. Implemented system

CONCLUSIONS

Based on this research which works on developed the alternative and affordable method to measure the rain gauge using an ultrasonic sensor, it is found that there are some limitations using this method, like on the accuracy and the precision of the measurement. Based on usage the HC-SR04 as the sensor to measure the level of the water on the tank, it is known that the resolution of the HC-SR04 sensor is 0.3 cm, based on this value obtained the sensitivity/resolution measurement of this system is 0.48 mm. Further, this research found that the difference the measurement using ultrasonic sensor between ombrometer formula is sufficiently linear with the difference average at 32.63%.

Measuring the level of rainfall using an ultrasonic sensor is influenced by the design of the reservoir tank and also the resolution of the ultrasonic sensor. By using the high resolution of ultrasonic sensor and precise design of reservoir tank that suit to the wave characteristic of ultrasonic sensor used, can be concluded that the precision of the rain gauge measurement increased. The placement of each sensor must be precise so that the measurement results from each sensor are appropriate with the final design of the measurement system.

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