March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

Rainfall Measurement Method Using Tipping Bucket Raingauge

[1] Amri Khurniawan, [2] Suci Aulia, [3] Dadan Nur Ramadan

[1,2,3] School of Applied Science, Telkom University ,Bandung, Indonesia
[1]amrikhurniawanazga3@gmail.com, [2]sucia@tass.telkomuniversity.ac.id, [3]dadannr@telkomuniversity.ac.id

Article Info
Volume 83
Page Number: 7712 - 7719
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 09 April 2020*

Abstract

Rainfall is total of rainwater that fall into an area which is measured in time domain. Rainfall measurement can be conclude as 1 mm if the water as high as 1 mm / m2 can be collected without evaporation, seeping water, and also flowing water. Rain variation is different in each region, so it needs a measurement to calculate a rainfall on each points location in a region.

In this study, a system that can be used to calculate rainfall in real time is proposed by the algebraic approach using four rainfall measurement locations to determine the volume of rainfall in the rainfall measurement area. This system is a real time device that uses an Automatic Rain Gauge with the tip of the bucket as a rainfall sensor. The bucket tip calibration method is the ratio between the volume of water collected and the volume of rainfall per 1mm. This device is connected to firebase to show the value of rainfall to the website as media information in real time.

In this paper presents a rainfall counter with automatic rain gauge that uses tipping bucket sensor. The information of rainfall will be easier to get because it will showing and updating in real time on website with this system. In the study, the data experiment that used was 10.13 Kb. Based on testing, rainfall measurement approach 1.46 mm with 91 % of accuracy on tipping bucket. Rain detector could detecting 100 % of accuracy with power availability more or less 69 hours.

Keywords; *rainfall, automatic rain gauge, tipping bucket.*

I. INTRODUCTION

Rain is an event of falls the droplets water from clouds to the surface of the ground [1]. The droplets rain that reaches the ground can be measure by measuring the height of the rain water based on rain volume of rain water per unit area. The results of these measurements are called rainfall. Rainfall measurements are carried out using rain gauge [1] in millimeters (mm). Rainfall in millimeters (mm) is the amount of rain water in liters that falls to the surface area in m^2 [2]. 1 mm of rainfall means that as much as 1 liter of water volume. Each area has different rainfall characteristics at each location . Thus, rainfall measurement have to applied on each points location to carry out the rain fall value in its area. So, the system that consist of both hardware and software to calculate the rainfall was require with good calibration and can be process in real time [3] [4] [5]. Tiping Buckets have a simple working principle to determine the rainfall value automatically at different locations [5] [6]. In the previous study, rainfall was initialized to be 1 mm if the water was held as high as 1 mm /m^2[1]. In this research was proposed a hardware system to measure the rain fall using tiping bucket as type of *Automatic Rain Gauge*. This *tipping bucket* was used to calculate the rainfall on the ground in *milimeter* (mm). This system also had *Global Positioning System* (GPS)[7] feature to determine the rain location and to detect rain condition using *Raindrop Sensor*. The system had been working in real time to transmit the data through firebase so that

Published by: The Mattingley Publishing Co., Inc.

March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

the information of rainfall value can be showing on the website.

II. RAINFALL MEASUREMENT METHOD

A. Rinfall

Rain is a natural phenomenon in the hydrological cycle [8]. Rain can be interpreted as an event of falling water in droplets from the surface of the sky to the surface of the earth. Rain occurs when water droplets contained in low clouds and medium clouds have a large amounts. If the cloud is unable to resist the buoyant force for the air below , so that the water droplets will fall to the surface of the earth in the form of rainwater or snow [1] [9]. The water cycle on earth occurs as shown in Figure 1. below:

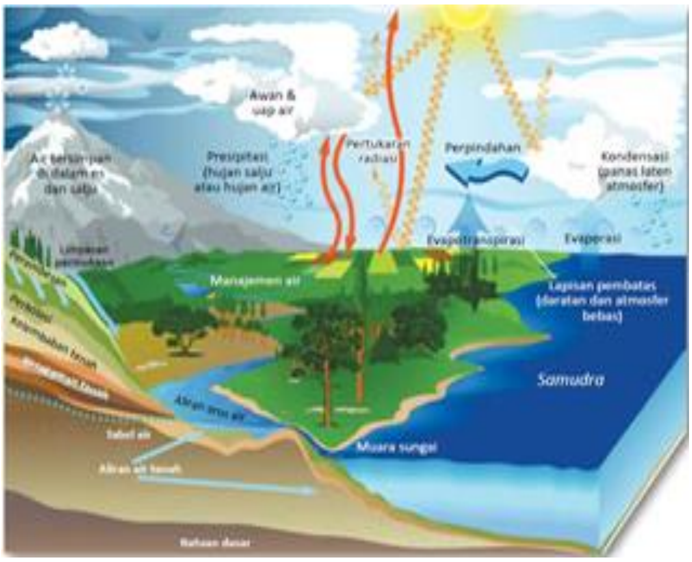


Fig. 1 The Water Cycle (*Source: US Global Change Research Program*)

The process of rain starts from evaporation of water due to the sun's heat. Then, the evaporation process produces water vapor and gradually make a clouds form. Furthermore, the cloud will be blown by the wind and merge with the other clouds, causing more and more water grains to be contained in the cloud and causing the cloud's color changes to gray. If the water droplets found in clouds have a mass heavier than air, it causes the water will be far from clouds called rain [2]. The Rainfall is amount of rainwater that falls from the sky to the surface of the land per m2 without evaporation, seeping water, and also flowing water in millimeter (mm) [6]. 1 mm of rainfall same as 1 liter volume of water accommodated in 1 m2 [1] [2] [10].

Rainfall gauge is a tool used to measure the amount of rainfall per unit area [1]. 1 mm of rainfall per m2 means that in 1 m2 there is 1 liter of water. In Indonesia, rainfall measurements are carried out by the Badan Metereologi dan Klimatologi (BMKG) which has 179 weather monitoring stations[10]. There are 2 types of rainfall measurements [1][4] [8] :

1. Manual Gauge

In this method, the staff of rainfall data record will take notes manually from manually gauge rainfall every rainy period. This Manual Gauge is a funnel and measuring cup which have a function to measure the amount of rainwater that collected in a measuring cup through a funnel on the side of the measuring cup [8].

2. Automatic Gauge

Data from the measurement results of rainfall using automatic gauge is data recording continuously on the measuring instrument. Automatic gauge has three types [8], namely Weighting Bucket Raingauge, Float Type Raingauge, Tipping Bucket Raingauge.design of rainfall measurement.

III. RAINFALL MEASUREMENT SYSTEM DESIGN

A. Rainfall measurement system design

In this research, was proposed hardware part of the rainfall measurement system as seen in Figure 1. Rainfall calculator hardware will be integrated with Firebase Realtime and Website as media information for the next project. This system works, started with the status from raindrop sensor, if there were droplets so the Tipping Bucket Sensor would active to calculate the rainfall value in 60 s period.

Published by: The Mattingley Publishing Co., Inc.

TEST Engineering & Management

March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

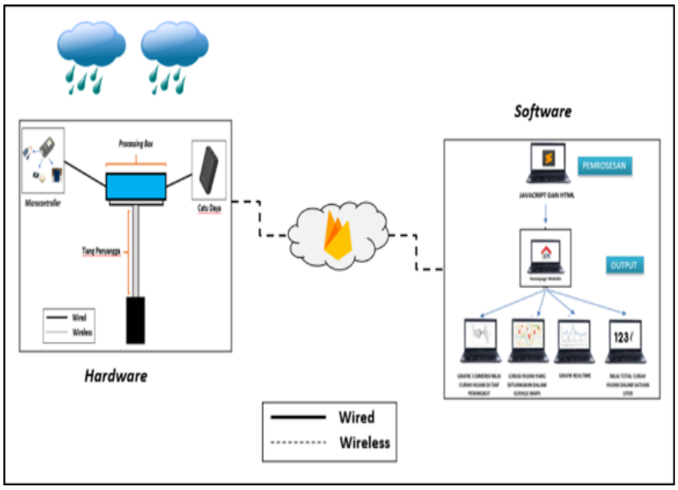


Fig. 1. Diagram Block of Rainfall Measurement

Then each point location would detect the condition rainy or not, so the raindrop sensor would be identify and gave the status as "1". There for, the tipping bucket sensor would calculating rainfall value by given the value input through hall effect sensor. Rainfall value would be calculated in 60 seconds interval from the total of raindrop value from each point location in rainy period. Last, the result from rainfall calculation or measurement in 60 seconds would be transmiting to the firebase in real time through wifi network.The schematic of rainfall measurement hardware can be seen in Figure 2.

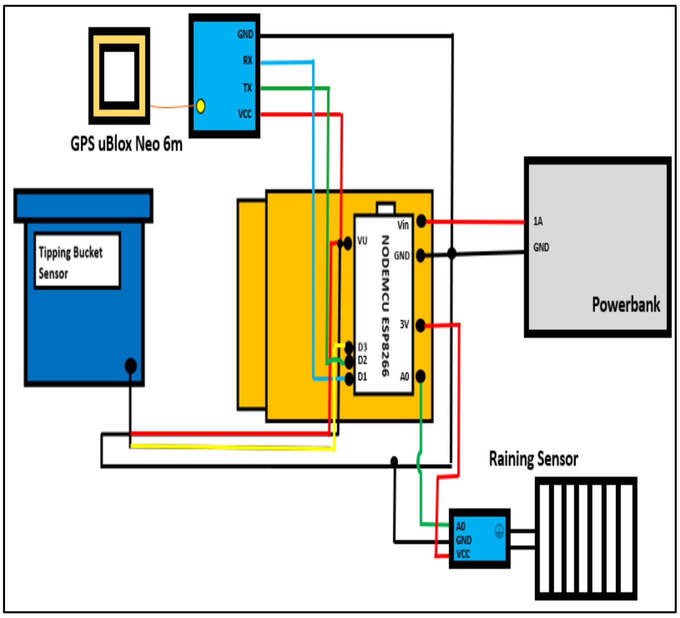


Fig. 2. Schematic of Rainfall Measurement System

This system could detect rainy condition using Raindrop Sensor. The droplets that was into the raindrop sensor would produce an input values for the system as the status for the system was "ON" and initiate the program variable NodeMCU ESP8266 v3 Lolin. After the initiation process, the device would connect to the internet network through the Wi-Fi Modem. Then the device would continue reading the raindrop sensor which produces data for rain or not rain conditions. If the Raindrop Sensor detect rain conditions, it would get an analog output value range of 1-1023 and would produce the rain status with the logic "1" and the logic "0" vice versa. The "1" or "0" logic status that have been generated by device through the Raindrop Sensor would be sent to Firebase in Realtime through Wi-Fi network.

B. Design of Raindrop Sensor

Raindrop sensor is a sensors that used to detect rain. This sensor can be used as a switch when raindrops falls on the raining board on the raindrop sensor as seen in Figure 3.

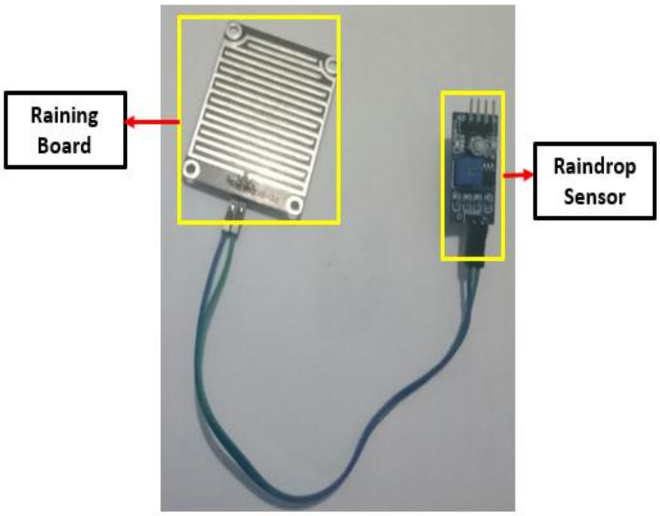


Fig. 3. Randrop Sensor

Raindrop sensor has analog and digital output values. For the digital raindrop the sensor will give the logic "1" if there are drops of rain and provide a logic "0" vice versa . For analog, the numbers range from 0 to 1024. In the research, digital output was used as a switch for tipping bucket sensor to calculate rainfall. If the raindrop sensor detects droplets, the rainfall calculation device will be ON and if not the rainfall calculation device will be OFF.

C. Design of Tipping Bucket Sensor

Sensor is a device that used to convert a physical quantity into an electrical quantity so that the output produced can be processed both electrical circuits and digital systems[13] Tipping bucket sensors is a sensors that use plates which tipped alternately to measure rainfall values [4] [11]. Accuracy of rainfall values is obtained by performing a calibration on the tipping bucket [3] [6] [8] [12]. The level of accuracy is measured using a measuring cup to determine the volume that can be accommodated in the tipping bucket [14]. The method used in tipping bucket calibration is to compare 1 mm rainfall with the volume of water that should be accommodated in the tipping bucket [8] [14] as shown in Figure 4.

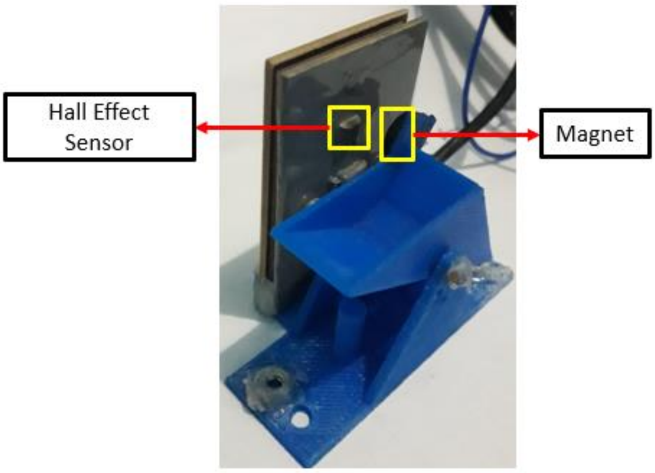


Fig. 4. Tipping Bucket Sensor

The tipping bucket works when in rain conditions, the rainwater will enter into the funnel then it will be accommodated in the tipping bucket. If one side of the tilt is full, there will be a tilt on the other side so that the collected water will spill and change to the other side of the tipping to hold the water [4] [10] [11]. Tipping buckets uses the Hall effect sensor to record the number of somersaults during rainfall measurements and to provide digital input to the microcontroller [10] [12]. If the Hall effect sensor approached by a magnet which attached to the tipping side of the bucket, then the flowing current will approach the side affected by the magnet [13].

The calibration performed on the sensor tipping bucket was to compare the volume of tipping bucket per 1 mm rainfall. 1 mm rainfall was state that at 1 m2 equal as high as 1 mm or as much as 1 Liter of water [2] [3].

$$\text{Volume}(V_1)=\text{Large}(A_1)\text{xTinggi} \quad (1)$$

$$= 1 \text{ m2 x } 1 \text{ mm}$$

$$= 1 \text{ m2 x } 0.001 \text{ m}$$

$$= 0.001 \text{ m3 / } 1 \text{ Liter}$$

Funnels in Tipping Buckets has a rectangular shape with a length of 5.3 cm and a width of 3.6 cm. So that the Tipping Bucket surface area can be calculate by eq.2 below.

Large(A_2)= length (5.3 cm) x width (3.6 cm) = 19.08 cm^2(2)

Tipping bucket volume can be calculate where A_1 = 1 m^2 / 10.000 cm^2, V_1 = 1 Liter / 1000 mL, then A_2 = 19.08 cm^2 . So that, *tipping bucket volume* (V_2) can be calculate :

$$\frac{V_1}{A_1} = \frac{V_2}{A_2} \quad (3)$$

$$V_2 = \frac{A_2}{A_1}\, x\, V_1$$

$$V_2 = \frac{19{,}08\ cm^2}{10.000\ cm^2} \times 1000\ mL$$

$$V_2 = 1{,}908\ \mathrm{m}L$$

So that it could be seen that 1 mm of rainfall was equal to 1,908 mL in the Tipping Bucket Sensor for one tilt on this device.

IV. REALIZATION AND MEASUREMENT

Hardware design uses acrylic boxes with dimensions of 24 cm x 26 cm x 6.5 cm according to the layout

Published by: The Mattingley Publishing Co., Inc.

March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

design that has been made. The box was used as a casing to store NodeMCU and hardware components. as shown in Figure 5.

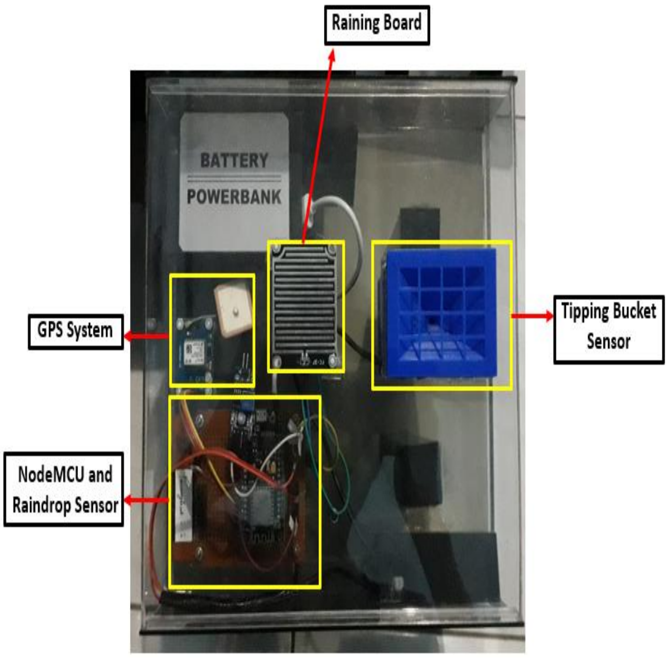


Fig. 5. Hardware Measurements

A. Measurement of Functionality

In this testing, each sensor was tested by conducting an experiment 5 times for each sensor to see the success of data transmiting to Firebase in Realtime[15] which obtained on the Arduino IDE Serial Monitor. Testing the accuracy of sensor data such as Table 1 below.

TABLE I. Functionality Testing

Conditi-on	Data on Serial Monitor	Data on Firebase	Status	Information
Long	107.6287	107.6287	Match	GPS
Lat	-6.972014	-6.972014	Match	GPS
Rain	1	1	Match	Raindrop
Rain	1.46	1.46	Match	T-Bucket
Not Rain	0	0	Match	Raindrop

B. Measurement Volume at Tipping Bucket and Raindrop Sensor

Testing the volume value of water per tip in the Tipping Bucket Sensor was aim to determine the volume of water that could be accommodated in the Tipping Bucket Sensor for each tip on the tilt. The Tipping Bucket sensor has been connected to NodeMCU ESP8266. The test was carried out using a measuring cup aid with a resolution of 0.1 mL and starting from 0.5 mL with an addition of 0.1 mL to produce one tilt. The value "0" indicates there was no tilt and the value "1" indicates a tilt. The results of water volume measurement on the tipping bucket as seen in Table.2 below.

TABLE II. Volume at Tipping Bucket

Volume on Measuring Cup (mL)	Tip	Volume on Measuring Cup (mL)	Tip
1.9	0	2.5	0
2.0	0	2.6	0
2.1	0	2.7	0
2.2	0	2.8	1
2.3	0	2.9	1
2.4	0	3.0	1

Based on Table 2 for water volume measurement on the Tipping Bucket produce a volume of 2.8 mL for each tilt. The calculation for 1 tilt was equal to 1,908 mL by comparing the volume that could be accommodated on the tipping bucket with 1 mm rainfall volume. So, the resolution obtained on Tipping Bucket Sensors in eq.4.

$$Resolution = \frac{2{,}8\,mL}{1{,}908\,mL} \times 1\,mm = 1{,}46\,mm \tag{4}$$

So, if there is 1 tilt with a volume of water of 2.8 mL in the Tipping Bucket then it is equivalent to 1.46 mm. Same as measurement on tipping bucket, the measurement also conducted on raindrop sensor. As result can be seen in Tabel .3.

Published by: The Mattingley Publishing Co., Inc.

March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

TABLE III. Volume Testing On Raindrop Sensor

Volume on Measuring Cup (mL)	Status
0.5	1
0.6	1
0.7	1
0.8	1
0.9	1

Based on Table 3 shows the value of the volume of water in a measuring cup of 0.5 mL has been detected in the Serial Monitor with the condition of Rain on the Logic "1". In this test, the water that has been spilled on the Raindrop board must be in a condition where there is a movement to get the logic "1". If there is no movement, the status will be at "0" logic with no rain conditions. Another test on raindrop sensor was carried out to determine the accuracy in detecting water or rain droplets .The testing had been done by pouring 0.5 mL of water into the Raining Board, then the data which received by NodeMCUESP8266 would be displayed via Serial Monitor and sent the status to Firebase in real time [16]. Raindrop sensor error testing shown in Table 4.

TABLE IV. Accuracy of Raindrop Sensor

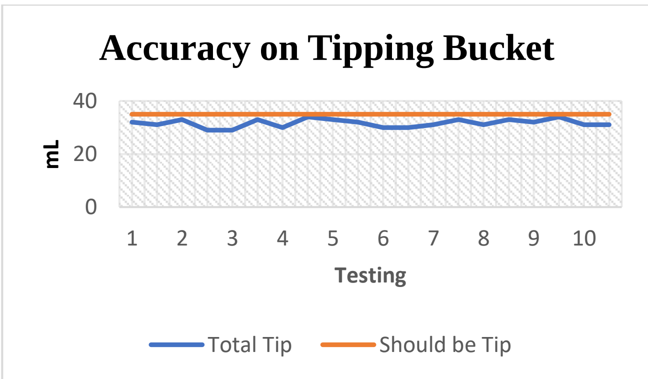
Measuring Cup (mL)	Data on Serial Monitor	Data on Firebase	Result
0.5	1	1	Match
0	0	0	Match
0.5	1	1	Match
0	0	0	Match
0.5	1	1	Match
0	0	0	Match
0.5	1	1	Match
0	0	0	Match

Fig. 6. Accuracy Testing "0.5 mL" on Raindrop Sensor

Fig.7 Accuracy Testing "0 mL" on Raindrop Sensor

The results based on Table 4 the testing, accuracy of the Raindrop sensor were as expected. The data which sent to firebase as same as the data that displayed on the device. The Tipping Bucket sensor has been installed with ESP8266 NodeMCU. The test had done by spilling 100 mL of water into the sensor tipping bucket. The data which obtained by NodeMCU ESP8266 was send to the firebase database and displayed on the Serial Monitor. This was to determine that the Tipping Bucket Sensor could work according to the value of the water entering the sensor based on the value of the per-tip sensor. Data sent in each tilt was 1.46 mm. Thus, the number of tilts that should be obtained was 35 tips for each experiment. Testing of errors on the Tipping bucket sensor was done 5 times. The results is as shown in Graph 1.

Graph 1. Accuracy of tipping bucket



Published by: The Mattingley Publishing Co., Inc.

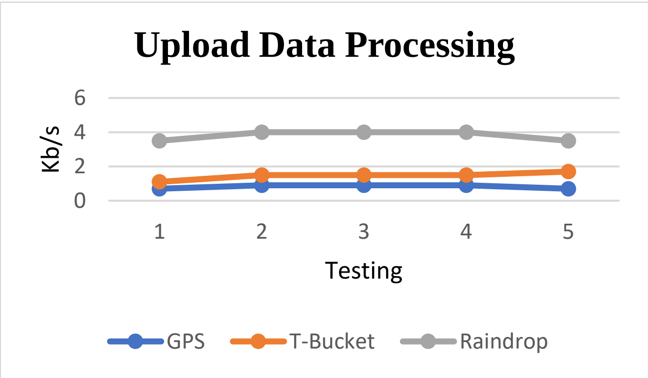
March-April 2020
ISSN: 0193-4120 Page No. 7712 - 7719

Based on Graph 1 testing accuracy on tipping bucket that system approach 91% of accuracy tipping bucket.

C. Upload Data Processing Test

Data upload testing had aim to determine the amount of data that used to sent from the device to the firebase in real time. Data upload testing was carried out 5 times as seen in Table. 5.

Graph II. Upload Data Processing



Based on Graph 2 testing data processing that has been done to sent rainfall data to Firebase in real time, the average data usage approach 10.13 Kb.

D. Application Raingauge

In this testing, hardware is implemented on April 28, 2019 by measuring rainfall. Hardware is placed on each corner of the square surface base. Length (P_L) of 20 m. Width (L_L) of 20 m. So the surface area can be calculated:

Large (A_L) Length(P_L)xWidth (L_L) (4)

= 20 m x 20 m

= 400 m^2

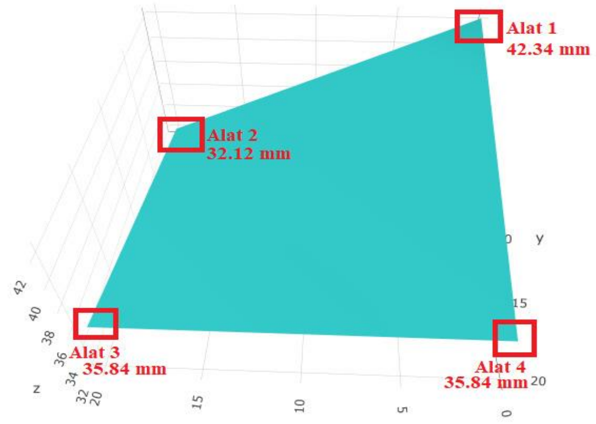
Test the rainfall as Table V below

TABLE V. Accuracy of Raindrop Sensor

Hardware	1	2	3	4	Total
Value (mm)	42.34	32.12	35.84	35.84	146.14
Average (Cr) (mm)					36.53

Then the results of rainfall measurements will be displayed with a 3D Graph to determine the volume of rain water as in Graph III below:

Graph III. Upload 3D GRAPH FOR



The average value of rainfall becomes a high value on the building. So the rainfall volume can be calculated:

Volume(Cr) =Large(AL)xAverage (Cr) (5)

$= 400\ m^2 \times 36.53\ mm$

$= 400\ m^2 \times 0.03653\ m$

$= 14.612\ m^3$

$= 14.612\ dm^3 / L$

The volume of rainwater is shown as Figure 8 below:

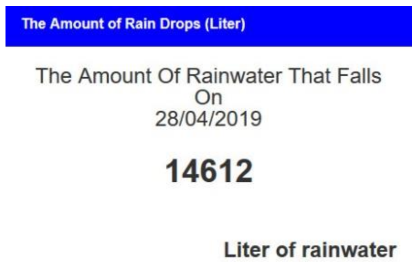


Fig.8 Display of Rainwater Volume

V. CONCLUSION

In this research had been proposed a system to measure rainfall based on data calculations which produced by sensors on device, the device also could

Published by: The Mattingley Publishing Co., Inc.

be used to detect rain conditions. The experimental shown that system approach 91 % of accuracy with resolution of device was obtained 1.46 mm. This resolution worked with a ratio of 1mm rainfall volume and tipping bucket volume. The rainfall measurement system also had done an experiment to test delay of system, life time of system, and total data, each parameter approach 6.25 of total delay, 69 hours of life time, and 10.13 Kb of data usage. This system also could send the data in real time to the firebase, so our future project will continue to make a conversion of rainfall data in the firebase to rainfall information that will be displayed on website as media information based IoT.

REFERENCES

[1]. Raghava, V., Wani, P., 2014, Internet Enabled Tipping Bucket Rain Gauge, International Conferences on Computer Communication and Informatics (ICCCI -2014), India.

[2]. Aldrian, Edwin., Karmini, Mimin., Budiman, 2011, Adaptasi dan Mitigasi Perubahan Iklim di Indonesia, Hal. 22. BMKG: Pusat Perubahan Iklim dan Kualitas Udara Kedeputian Bidangan Klimatologi, Jakarta.

[3]. All Weather Inc, National Drive, 2008, Tipping Bucket Rain Gauge Models 6011-A 6011-B. http://www.allweatherinc.com/wp-content/uploads/6011-0011.pdf. Diakses pada 17 April 2019.

[4]. Freeny, E., 1968, Statistical Treatment of Rain Gauge Calibration Data, Nokia Bell Labs.

[5]. Jeng Li, W., Yen, C., Lin, S., Tung, C., Huang, S., 2018, JustIoT Internet of Things based on the Firebase Real-time Database, IEEE.

[6]. Goldhirsh, J., Gebo, E., 1992, A Comparative Assessment of R.M. Young and Tipping Bucket Rain Gauges, The Johns Hopkins University, United States.

[7]. Deshmukh, S., Vanjale, B., 2018, IoT based Traffic Signal Control for Reducing Time Delay of an Emergency Vehicle using GPS, Bharati Vidyapeeth College of Engineering for Women, India.

[8]. Hardiharddaja, Joetata., 1997, Drainase Perkotaan, Penerbit Gunadarma, Jakarta.

[9]. Pastoriza, V., Machado, F., Marino, P., Fontan, P., 2014, Modelling Rain Rate by Means of Arrival Processes, The 8th European Conference on Antennas and Propagation (EuCAP 2014), Spain.

[10]. Badan Metereologi Klimatologi dan Geofisika, 2017, Buletin Analisis Hujan Bulan Agustus 2017 dan Prakiraan Hujan Bulan Oktober, November, dan Desember 2017 Provinsi Jawa Barat No.9, BMKG: Stasiun Klimatologi Bogor, Bogor.

[11]. Badan Metereologi Klimatoogi dan Geofisika, 2019, Stasiun dan UPT BMKG, https://www.bmkg.go.id/profil/stasiun-upt.bmkg. Diakses pada 15 April 2019.

[12]. Badan Metereologi Klimatoogi dan Geofisika,, Deskripsi Alat Rain Gauge Tipe Tipping Bucket: Data BMKG, http://data.bmkg.go.id/share/Dokumen/deskripsisensorlintek.pdf. Diakses Pada 14 April 2019.

[13]. Omoruyi, O., John, N., Chinonso, O., Robert, O., Adewale, A., Okokpujie, O., 2017, Wireless Sensor Network for Rainfall Measurement using a Tipping Bucket Rain Gauge Mechanism, 2017 International Conference on Computical Science and Computational Inteligence.

[14]. Sarkar, S., Gayen, S., Bilgaiyan, S., 2018, Android based Home Security Systems using Internet of Things (IoT) and Firebase, International Conference on Inventive Research in Computing Applications (ICIRCA 2018), ISBN:978-1-5386-2456-2.

[15]. Google Developer, Firebase Realtime Database, https://firebase.google.com/docs/database?hl=id. Diakses pada 17 April 2019.

[16]. Putra, Hadi, Riyan., Kusuma, Teja, Feri., Ramadan, Nur, Dadan., 2019, IOT: Smart Garbage Monitoring Usig Android and Real Time Database, Telkomnika, 2019.