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Design and Implementation of Tipping-Bucket Rain Gauge

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***Abstract*—This paper describes the design and implementation of rain gauge by using tipping-bucket method, and then called tipping-bucket rain gauge (TBR). The function of the TBR is to measure the amount of rainwater that falls on a certain surface of the earth with a certain time range as well. The amount of rainfall is generally measured using units of mm per time. To measure the intensity of rainfall in urban hydrology the most common instrument used is TBR. Because of the measurement principle, the intensity of rainfall and bucket size are parameters that affect the time resolution. TBR has been successfully designed and built. The rain gauge has been tested in the laboratory and in the field (BMKG Bandung). Testing is done by building a system-based microcontroller, and with a program specifically created for these purposes. This system is able to display of measurement and record data rainfall for 24 hours using database. The reading results of TBR are successfully measured, stored in the database, and to be sent and displayed on the Web.**

***Keywords*—design and implementation; tipping-bucket; rain gauge; rainfall**

I. INTRODUCTION

Indonesia which is a tropical country certainly cannot be separated from two alternating climates, namely summer and rainy season. The rainfall monitoring instrument is one of the most important instruments for the purposes of rainfall information, for example agriculture, early warning of flood or drought, and so on. Therefore, it takes a rainfall monitoring instrument, which in addition to reliable, also the price is cheaper. Until now, the instrumentation system used in Indonesia is still a lot that comes from imported products, which has implications for strategic factors, economic factors, and national independence factors.

From the background above, then comes a thought to design and implement a system that is able to measure rainfall that is inexpensive, also expected reliable. This designed instrument, called tipping-bucket rain gauge. This instrument is suitable for use in rural or remote areas throughout Indonesia.

The goal to be achieved from this designed system, is to measure rainfall in the surrounding environment either in seconds, minutes or hours. In addition, the instrument is expected to be implemented in a microcontroller-based system, to be able to display rainfall data for 24 hours.

The method used in this study is system design and development. The design and development of the instruments is based on the results of theoretical studies of various literatures. The stages in this work are literature review, field visit (interview) in BMKG (Badan Metereologi, Klimatologi dan Geofisika) Bandung, instrument design, and system testing.

Over the past few years, in many countries there have been many proposed and implemented rainfall station projects, which in addition to cheap are also portable. Precipitation measurement has been proposed by Conti et al [1]; The weather radar system used is X-band. The field of high-resolution precipitation in space and time is monitored by radar. In addition, they are supported by a rain gauge network of 18 bucket gauges that glide over the observed area, a weight rain gauge, an optical disdrometer, and a weather station. The system used requires a very complicated and expensive setup. While we propose is a system that allows measurement of rainfall parameters with low cost and portable system. Later by Rajiv Kumar Das et al [2] has been also proposed tipping-bucket rain gauge design for rainfall measurements and snow precipitation. The rainfall monitoring system developed have a similar system like ours but did not integrated to web page. In a study conducted by A. S. Al-Wagdany [3], he conducted a rainfall evaluation using dual TBR. Obviously, this way is not efficient. In the study, they installed a tipping-bucket rain gauge station in the arid region of western Saudi Arabia. The difference between the two rain gauges installed is the gauge collector size. Whereas by Jess Christopher B. Lopez et al [4] has been proposed a low-cost weather monitoring system with online data visualization. Their system unfortunately does not explain clearly about the TBR sensor used by them, as well as the building materials.

II. THE STUDY AREA

The main objective of the present project is to design TBR instrument which is low cost portable rainfall station. As well as the system capable to monitoring rainfall at remote area by using web page. In this project, a prototype integrated rainfall monitoring system is proposed in the latest rainfall monitoring system. The size of conventional rainfall stations is larger and the installation costs very high, which is a burdensome factor for developing countries. The goal of this project is to

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introduce an inexpensive system that supports flexibility, portability, and easy operation.

Although there have been many rainfall gauges in Indonesia, but most of them are imported instruments. For the purpose of providing simple and inexpensive rainfall gauges, we have designed and developed this type of rain gauge to support a reduction of dependence on imports. The project aims to design and implement a portable TBR, and which is cost-effective in measuring rainfall. The design of this rain gauge is what can be made from materials other than cheap, it must be ascertained the material is available locally. The results of rainfall measurements other than displayed on the instrument, can also be uploaded to the web server and monitored through the user's web page.

III. LITERATURE REVIEW

The amount of rainfall that passes through a particular area is a dynamic process; of course, this changes its shape and intensity. Many studies have been conducted to understand the rain, because water is a vital resource. The measurement and sensing of the amount and type of rain helps us develop a description of rain physically and dynamically. So, a better understanding of our environment and preparing for possible environmental disasters such as droughts or floods, we can get. Although, local characteristics and rainfall variability make it difficult to understand and model physical parameters and behavior. Parameters describing the types of rainfall include total amount of rainfall, rainfall rate, drop size distribution, and rainfall intensity. In meteorology and hydrology, it is a measurement that has a wide range of applications. Examples of measurement techniques include mechanical recording sensor (float-operated recorders, weight-operated recorders), electric rain gauge sensors (tipping bucket, capacitance gauge sensors), and drop-counting gauge sensor (vibration based disdrometers, optical-based disdrometers) [5].

The main component of the water cycle is precipitation and is responsible for the deposition of freshwater on Earth. Precipitation provides water for everyday purposes, agricultural purposes, and industrial purposes, as well as aquatic and non-aquatic ecosystems, and their measurements are the most important part of hydrology. The characterization of precipitation and adequate measurement is one of several factors of the basic form of effective water resources management. Thus, precipitation sensors for point measurements with various operating mechanisms have been widely developed, for example: optical sensors, acoustic sensors, impact sensors, and TBR instruments; The last one that is widely used around the world is the rain collector. [6].

The term rainfall is a term used to describe the precipitation of a water droplet of a size greater than 0.5 mm, which is the principal form of precipitation in India. The maximum rain drop size is about 6 mm. Any droplets larger than this tend to break into smaller size drops during the fall of the cloud. Based on the intensity, rainfall is grouped into three types: (1) Light rain (intensity: Trace to 2.5 mm / h); (2) Moderate rain (intensity: 2.5 mm/h to 7.5 mm/h); (3) Heavy rain (intensity:> 7.5 mm /h).

The depth at which rainwater will be in an area if all collected on it is an expression of a precipitation. Thus, every 1 cm of precipitation water over a 1 km^2 water catchment is equal to 10^4 m^3 of water volume. Rain gauge sensors are used for collecting precipitation measurements. For the case of snowfall, the equivalent water depth is used as the depth of precipitation. Sometimes it is also used to designate raingauge, for example for terms such as pluviometer, ombrometer and hyetometer. The classification of raingauge can be broadly divided into two categories as (i) nonrecording raingauges, and (ii) recording raingauges [7].

To measure the intensity of rainfall in urban hydrology the most common instrument used is TBR. Because of the measurement principle, the intensity of rainfall and bucket size are parameters that affect the time resolution [8]. The rain gauge systems consist of three types: capacitance, weighing, and tipping-bucket [9]. Rain is a hydrometeor that falls in the form of water particles having a diameter of 0.5 mm or more. Hydrometeor that fell to the ground is called rain, while those not reaching to the ground are called Virga. The rain that reaches the soil surface can be measured by measuring the height of the rainfall by the volume of rainfall per unit area. The result of the measurement is called rainfall. Rainfall is one of the weather elements whose data is obtained by measuring it using a rain gauge, so it can be known in millimeter (mm). 1 mm rainfall is the amount of rainwater that falls on the surface per unit area (m2) with no record that evaporates, absorbs or flows. Thus, rainfall of 1 mm is equivalent to 1 liter/m2 [10].

The operating principle of tipping-bucket rain gauge is by counting the pulses per unit of time, determined from the amount of water entering the funnel. From these pulses can be known the amount of rainfall per area unit per time unit. Rain water is accommodated in a tipping container.

Some types of rainfall gauges that have been developed include the type of weighing, capacitance, TBR, optics, and others [11]. However, Tipping-bucket rainfall gauges are more commonly used for precipitation measurements because they are simple and durable, can be installed in remote areas, can be linked to various monitoring and recorder devices (data), and they are relatively cheap.

IV. SYSTEM DESIGN

The design of the system built is covering the design of hardware and software. On the hardware part, has built a sensor to measure rainfall from the type of tipping-bucket rain gauge. The sensor design consists of mechanical parts and electromechanical parts. The design incorporates sensors and equipment to assess precipitation, presence of rain.

A. Mechanical and Electromechanical Design

Fig.1. shows a sketch of the mechanical design of the TBR that has been made. Inside the box is equipped with two reed switches. The mechanical design shown in Figure 3.1 is made of aluminum material with size: 25 cm long, 25 cm wide and 16 cm high. Inside the mechanical building there is a reed

switch that is placed on the conical hole with a diameter of 10 cm. This cone hole serves as a channel of rain water entry, and this cone hole becomes the reference value of conversion for rainfall units. The instrument box is made of a relatively cheap acrylic material. TBR sensors used are the type of reed switches, reed switch including relatively inexpensive materials (see Fig.3)

Illustration of Fig.1 for each number is given below:

- ① **Cone**. Cone is the entrance of rain water. Peak cone has a small hole of 2 mm. This hole serves to remove raindrops to tipping-bucket.
- ② **Tipping Bucket.** Tipping-bucket serves as a rain dropper, until it reaches a certain value. If the value has been met, then tipping-bucket will be tipped alternately
- ③ **Calibrator**. Calibrator serves to calibrate the weight of rainwater that is accommodated in tipping-bucket
- ④ **Drainage A, rainwater disposal.** The measured rainwater will be discharged through this channel
- ⑤ **Drainage B, rainwater disposal.** The measured rainwater will be discharged through this channel
- ⑥ **Reed Switch**. When tipping-bucket has reached a certain value, tipping-bucket will be tipped. Every time the bucket is tipped it causes the reed switch to become active. This generates the pulse signal as its output.

Reed switch is an electric switch operated by a magnetic field. This device has two pins which are pin and ground pin data. In other words this sensor can be used by using one digital pin from microcontroller. Fig.2 shows an example of the physical image of the reed switch.

- ⑦ **Magnet**. Magnet serves to trigger reed switches on.

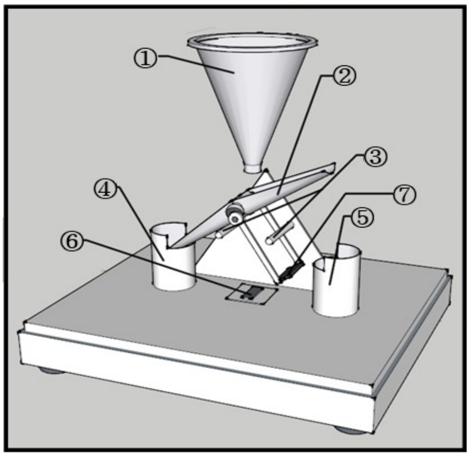

Fig. 1. Sketch of mechanical design of the TBR

Fig. 2. Physical images of reed switches

The operation of the instrument system is, firstly, rain falling to earth is collected on a tipping vessel. When water enters into a vessel is equivalent to a 0.2 mm rainfall, it will be tipped and water discharged. There are two vessels that alternate to accommodate rain water. In each vessel tipped mechanically, it will be recorded through the counter. The number of counts multiplied by 0.2 mm is the height of the rain that occurs. Rainfall below 0.2 mm is not recorded.

Photo of the designated TBR sensor can be seen in Fig. 3. This photo was taken when testing TBR instrument in BMKG Bandung.

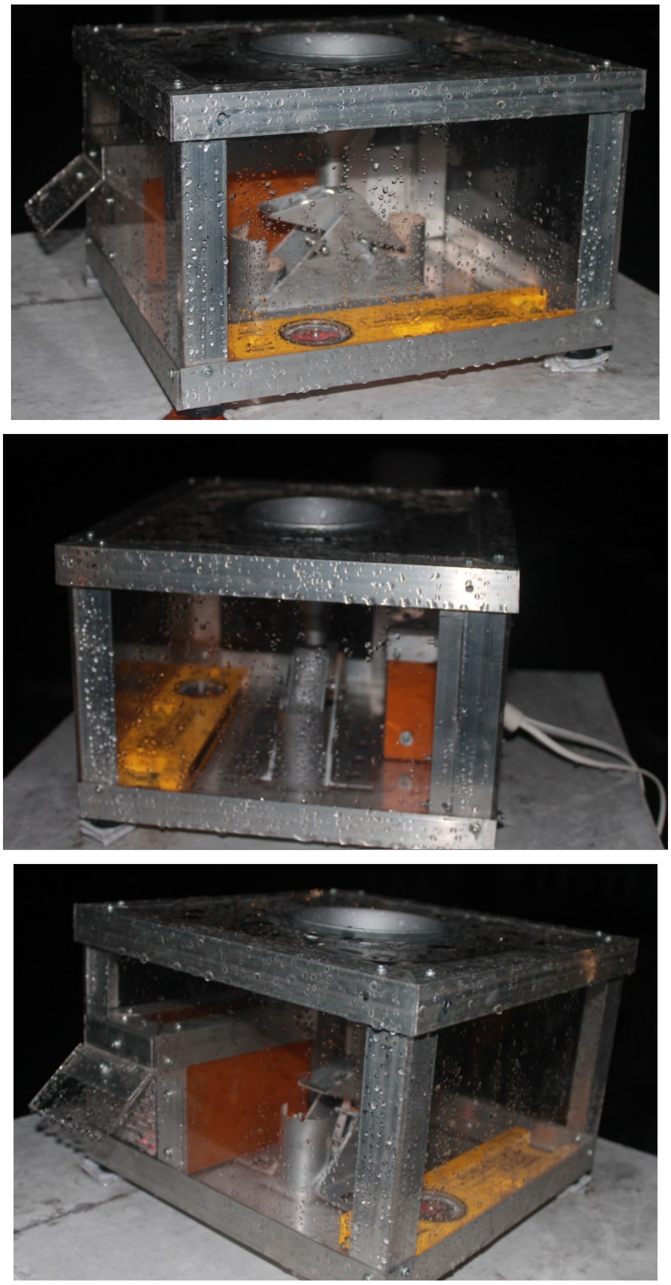

Fig. 3. Photo when testing TBR instrument in BMKG Bandung

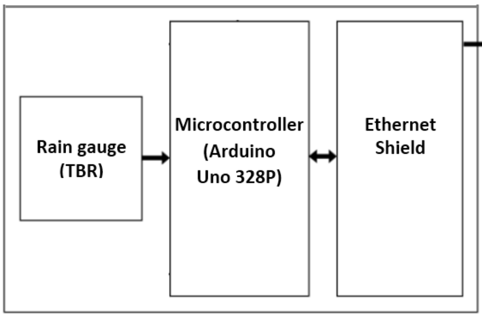

Fig. 4. Diagram block of the system hardware

B. *General Description of the Reed Switch*

ORD213 is one commonly used reed switch with magnetic principle. In it is a small single contact designed for general control of low loads of less than 24 V. To maintain contact reliability, ORD213 reed contacts are sealed in glass tubes with inert gas.

The features of the reed switch are as follows:

- Reed contacts are tightly sealed in a glass tube with inert gas and protected from external atmospheric environmental influences.
- The response to the signal is very fast.
- The structure consists of operating parts and electrical circuits with a coaxial arrangement. The Reed switch is suitable for applications in radio frequency operation.
- The Reed switch has a compact and lightweight structure.
- Having a long life and contact wear resistance ensures stable switch operation due to superior corrosion resistance
- Reed switch is economically and easily becomes a proximity switch because there is a permanent magnet. [12]

C. *Control System Design*

The hardware that has been built consists of a microcontroller connected to TBR. The hardware block diagram shown in Fig. 4. TBR is connected through any input port of the microcontroller and the processing results are connected to any output port.

It can be seen that the main controller in the design of this system is Arduino Uno 328P. Arduino Uno 328P is a microcontroller used as a tipping-bucket controller. The I/O pin number used on Arduino Uno 328P for data processing and controlling is pin 3.

Ethernet shield is a board that serves as an interface between the microcontroller with the Internet network. Ethernet shield has 14 pin digital input / output. In addition, ethernet shield has a card reader from microSD that can be used to store data. Arduino ethernet shield is different from other board because it does not have USB driver chip to serial, but has a Wiznet Ethernet interface. The Ethernet Shield specifications used in this design are given below:

Hardware interface	: Arduino Ethernet Shield
Voltage operation	: 5Volt
Input voltage	: recommended 7-12Volt
Input voltage ranges	: 6-20Volt
Pin I/O Digital	: 14 (6 allowed for PWM)
Arduino Pins Reserved	: 10 To 13 used for SPI
Pin Analog	: 6
DC current I/O	: 40ma
DC current when 3.3V	: 50ma
Flash Memory	: 32 KB and 0,5 KB using bootloader
SRAM	: 2 KB (Atmega328)
EEPROM	: 1 KB (Atmega328)
Clock speed	: 16 MHz

Fig. 5 shows the installation configuration for the TBR sensor. The TBR sensor is made up of reed switches. Reed switch is an electric switch operated by a magnetic field, this sensor has two pins that is one pin for ground and one pin for data. In other words, this sensor can use one port on digital Arduino Uno 328P. From the picture can be seen TBR sensor connected with port 3 on microcontroller of Arduino Uno 328P.

D. *Software Design*

The software design is described in the flowchart as shown in Fig. 6. A more detailed flow chart explanation is given in Table I.

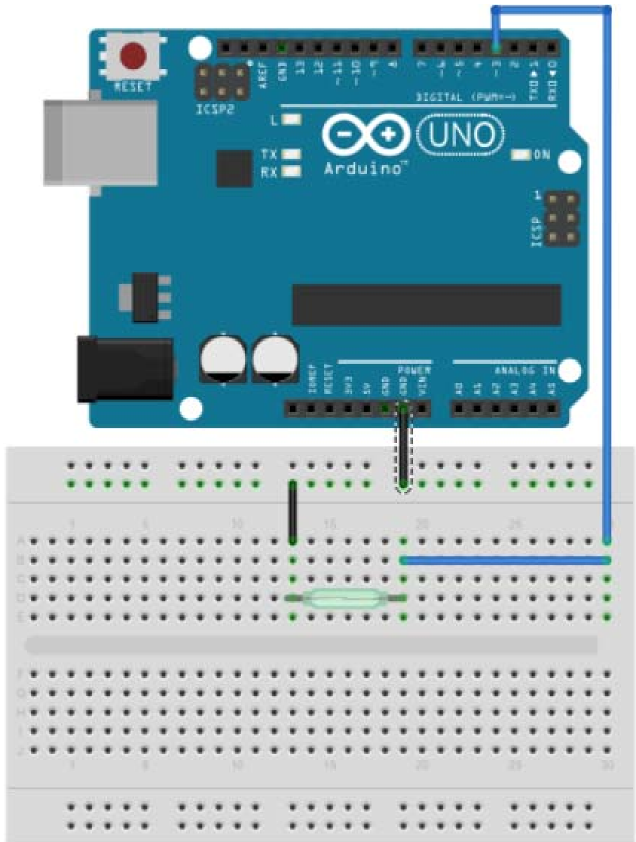

Fig. 5. Connection of reed switch sensor on Arduino board

TABLE I. EXPLANATION OF THE FLOWCHART CONTAINED IN FIGURE 6

Sub-flowchart	Explanation
Start	The program starts running
Setting of Mac Address	is enabled to make it easier for router and other network devices to uniquely identify each type of device connected to the network. In this case the set is the mac address of ethernet shield.
Setting of IP address	enabled to provide IP address on ethernet shield to be identified in the internet network.
Create a client connection	In this section is to create a client connection, which aims to ethernet shield connected in the internet as a client.
Initialization of Hardware interface	This part is the initialization pin, where every pin connected with Arduino will be initialized, whether as input or output.
Read data from TBR	This section will read data from rainfall sensor.
Display data on the web	Displays data obtained to the web page.

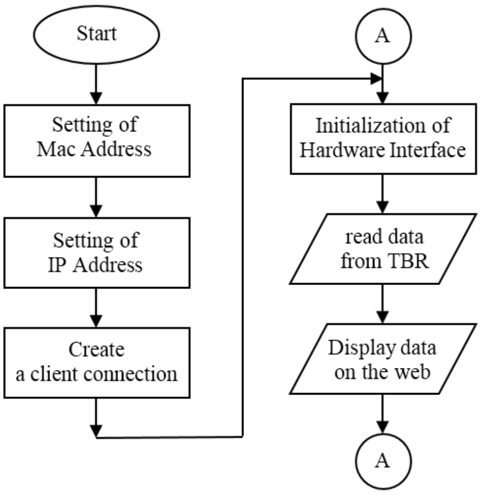

Fig. 6. Flowchart of the software design

V. TESTING AND DISCUSSION

Testing is done by: one tipping (1 click) is converted to 0.2 (mm unit). 10 mm equivalent to 10 liters/m². TBR input and system output using high-active, it is possible because the sensor is just a reed switch or like an on-off switch in general. Table II is the comparison of test results between TBR (design results) and BMKG instrument. The rain gauge with reed switch is using the principle of division between the volume of rainwater divided by the cross-sectional area of the container.

Field comparison of operational tipping-bucket raingauges was conducted at BMKG in the periods of 19 June 2016 to 23 June 2016 to assess their performances in rainfall intensity

TABLE II. COMPARISON OF TESTING BETWEEN TBR AND BMKG INSTRUMENT

No	Measurement duration (hour)	BMKG's instrument (mm)	TBR (mm)	Difference (mm)
1	2	3.0	2.8	0.2
2	2	3.6	4.0	0.4

measurements. When measured rainfall on the first measurement (June 19, 2016) obtained 2.8 mm. Catchment area ± 1 km2, shows the amount of rainwater that falls from the clouds and up to the earth as much as: 1 km2 x 2.8 mm = 2800. This means rainfall that occurs for 2 hours is 2.8 mm, meaning equivalent to 2800 liters within a radius of 1 km. The second measurement (June 23, 2016) obtained 4.0 mm. This means rainfall that occur for 1 hour is 4.0, meaning equivalent to 4000 liters within a radius of 1 km.

Measurements are made every 24 hours once. The measurement results are not accurate yet. Although it can be seen that the measurement difference is not more than 1 mm. Testing is only done twice in June 2016. Of course, the frequency of the test (the number of tests) cannot be said to be adequate, because at the time of testing, there are constraints of rain fall time, the coming of the rain is unpredictable. And also access permission to do direct testing with tools in BMKG is limited.

The type of instrument used by BMKG is the rainfall gauge of the weighing type or Hellman type. While the rainfall meter we have made is the type of TBR. Both devices have differences in the method of measurement. So, the comparison of measurement results in table III above clearly cannot be made or claimed as calibration result. The purpose of this test is simply to check whether the test results of the instruments we designed have been able to provide rainfall measurement results.

The benefits of the TBR instruments we make are relatively cheaper compared to BMKG instruments. This is based on the price comparison of both. BMKG's rainfall gauge is equipment imported from outside countries. While the TBR that we make only comes from materials that are cheap and easy to obtain. In addition, the advantages of the TBR instruments we have made are smaller, lightweight, practical and portable, so it is suitable for rainfall measurements placed in remote areas. Fig 6 shows a photo both of rainfall recorder of the Hellman type (BMKG's instrument, and TBR type (our design instrument). From this photo can be seen that size of BMKG instrument is larger than the instrument of our design. This means the design of our instrument is portable, which is certainly an advantage.

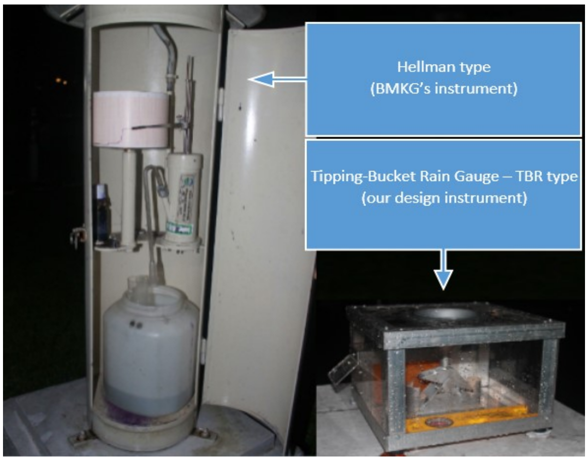

Fig. 7. Comparison of TBR type instrument rather than Hellman type.

Fig. 8. Monitoring parameters on the web page

The next research is how to calibrate the TBR so that the measurements are acceptable.

Next is given the test results of the web page. This test is intended to verify whether the data from the microcontroller has been successfully received by the web or not. Testing is done by using internet modem network. After several rainfall measurement experiments, it was found that these parameters can already be displayed on the web with 1-hour update time interval. But the length of the status on the web changes depending on the quality of service from the network itself. Fig.8 is the status display on the web page with each parameter status.

VI. CONCLUSION

A tipping-bucket rain gauge has been designed and field tested with encouraging results. Reed switches on tipping-buckets can operate well and are quite sensitive. This rain gauge can detect when the bucket is tipped.

The rainfall data parameters, which are transmitted from the microcontroller to the web can be done well. Rainfall parameters can be monitored well on the web display.

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