Micro-weather Station System for Small Geographical Coverage in the Philippines

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Abstract. Drastic changes in the climate occur globally, and here in the Philippines, typhoons and storms are experienced all year round. According to the state weather bureau PAGASA, the Philippines visited by at least 8 to 9 tropical cyclones every year and more than million worth of crops and properties are being destroyed. To reduce the risk and danger due to extreme rainfall and strong winds caused by these disasters, early warning broadcast is necessary. In this article an Arduino-based weather data acquisition device was designed, tested, and installed. It measures temperature, relative humidity, and amount of rainfall to serve as a baseline data for studying the trend and its relationships on the occurrence of natural calamities to small geographical coverage in the Philippines. This also served as a warning system and source of information in the studies of weather patterns in the specific areas. It stored actual measurement of rainfall, temperature, and humidity to the database that can be printed or downloaded from the web page. The device alarmed the locals for incoming flood using GSM communications network. Test results revealed that the system gave an accuracy of 96.28%, with an efficiency of 97.06%, and effectiveness of 99.95%. The calculated Overall Equipment Effectiveness (OEE) of the whole device is 93.4%.

1. Introduction

Natural disaster such as earthquakes, flooding, volcanic eruption, landslide, hurricanes etc., are getting worst. Scientist from Intergovernmental Panel on Climate Change (IPCC) stated that global temperatures will continue to rise for decades to come, largely due to greenhouse gases produced by human activities. The IPCC also forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century. This temperature rise will change the precipitation patterns, frequency of droughts and heat waves. The Hurricanes will become stronger and intense, and the sea level will rise 1-4 feet by 2100 [1]. The worst is that, this rising temperatures would cause some regions to experience more extreme heat while others may cool slightly. Due to this, flooding, drought, intense summer heat, violent storms and other extreme weather events would become stronger [2].

Due to stronger natural disasters, there is a need to study its relationship to the climate parameters which we can measure, gather, or monitor, and make the prediction. Today, meteorologist uses temperature, humidity, precipitation, atmospheric pressure, solar radiation and wind, in predicting the weather. If we can find a connection between these parameters and the increasing occurrences of the natural disasters, then we can make prediction of it. There are already studies that found a relation between these parameters and the occurrence of natural disasters like the preliminary study conducted

for the Northern areas of Pakistan by Muhammad Usman. That study shows a positive correlation between the temperature increase, due to global warming, and the earthquake frequencies. The study leads to a finding that an increase in earthquake frequency is connected to the temperature increase. The increase in temperature causes the glaciers to melt and thereby releasing pressure on the Earth. The earthquake is caused by the rebounding of the earth [3]. There are also a study that proves the relationship of humidity and temperature in the formation of storms [4].

The effects of climate change on the natural disaster are already felt in the world. On January 12, 2010, an earthquake with a magnitude of 7.0 and a depth of 8.1 miles hits Haiti [5]. This earthquake killed over 200,000, leave 2 million homeless and 3 million wounded. Another earthquake killed at least 225 people in Mexico City on September 19, 2017, and a week after another massive earthquake killed at least 96 people and 2.5 million people in need of aid [6].174 people were killed by a landslide in Democratic Republic of the Congo on August 2017. In Sierra Leone, Africa more than 500 people were dead and hundreds of people are still missing (Madison Park, 2017). Also on August 24, 2017, a landslide hits Switzerland causing a forced evacuation of over 100 people; according to the report, 8 people were missing after the landslide [7]. Severe rains and cyclones killed 117 people and thousand people were left homeless in Zimbabwe on October 2016 [6]. In Pakistan, sixteen people died from flash flooding caused by monsoons [8]. And on August 31, 2017, more than 1,200 people were dead, 40 Million was affected and 18,000 schools were shut down in India, Nepal and Bangladesh from the flood caused by Heavy monsoon rains [9]. An earthquake in Nepal, there was over 5 million people affected, over 8,000 people were dead and estimated $85 billion damage [Infographic, 2016]. In India, Flood caused an estimated $16 billion on 2014 [10]. In Japan, there were 19,846 deaths with estimated $210 billion damage from Earthquakes and tsunami on 2011. In china, there were at least 114 people were killed by severe floods and destroyed 31,000 homes since January of 2017.

In the Philippines, Filipinos experience strong rainfalls in the past years. The monsoons are getting stronger especially the southwest monsoon that causes floods in some parts of the country. According to the Global Climate Risk Index 2015, the Philippines is the number one in the most affected country by climate change. Philippines is surrounded by bodies of water the reasons why it is more affected when the ocean's surface temperature increases. And this additional heat in the ocean and air can lead to stronger and more frequent storms [11]. Philippines has an average of 8 to 9 tropical cyclones each year [12]. But on the past years, the frequency of storms in the Philippines exceeds the average. On 2013 there were 13 destructive tropical cyclones recorded, 11 on 2014 and 10 on 2015 [13]. On part of the earthquake, there were 4 recorded earthquakes in 2017. One of this has a 6.5 magnitude in Leyte which killed 4 people and left 100 injured.

Bataan is located in the southwest of Luzon, the northern part of the Philippines. It experience mostly by floods and storms. On August 20, 2013, Bataan is placed under state of calamity due to the heavy rain from the southwest monsoon enhanced by Tropical Storm Maring. Figure 1 showed the year 2013 trend line data source from Weather Underground and Typhoon information form PAGASA that hit the province of Bataan.
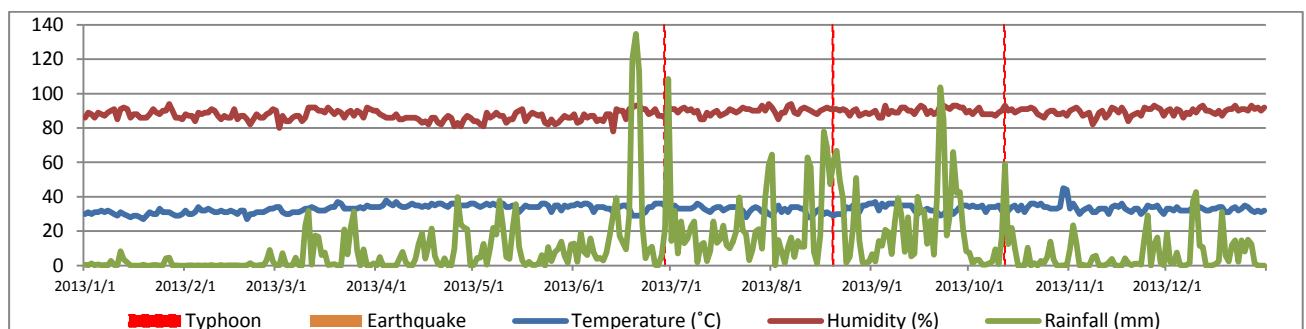

Figure 1. Year 2013 climate trend line with the occurrence of typhoon in Bataan

On August 13, 2016, Flash floods hit the 6 towns of Bataan; there were 3 villages in Dinalupihan, 8 in Hermosa, 4 in Orani, 3 in Samal, 2 in Abucay and 4 in Orion. Three Bataan towns were flooded due to

heavy rains on July 10, 2016. According to the report, there were 15 villages in the towns of Hermosa, Orani and Samal that are affected by the flood [14]. Figure 2 shows the year 2016 trend line data source from Weather Underground and Typhoon information form PAGASA that hit the province of Bataan.
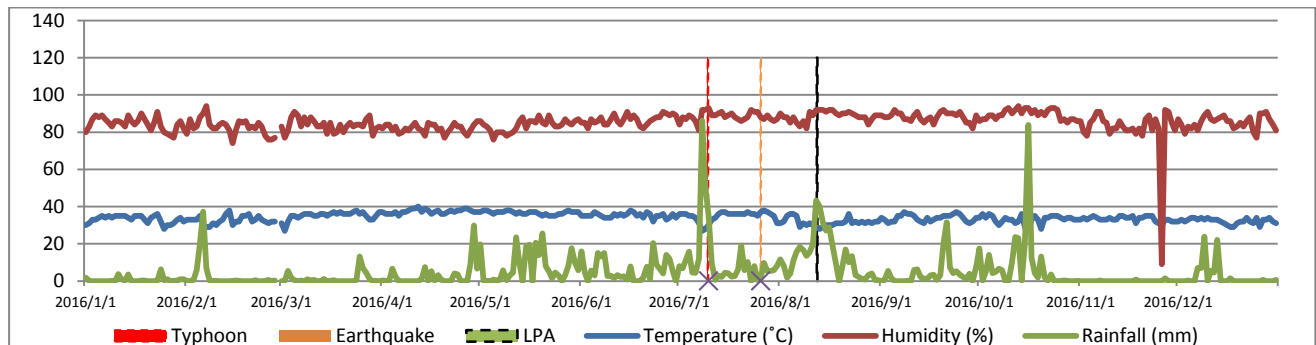

Figure 2. Year 2016 climate trend line with the occurrence of typhoon in Bataan

Climate change worsens the economic situation and food security among others of the Filipino people [15]. There is already a weather forecasting department in the Philippines which is called PAGASA (Philippines Atmospheric Geophysical and Astronomical Services Administration) which daily reports the condition of weather in the Philippines and there is also the Project NOAH which is the primary disaster risk reduction and management program of the Philippines. Though, PAGASA covers cities and regions in the Philippines but does not include the small municipalities and barangay. The Project NOAH is not enough to monitor a municipality. The government should also check the status of the municipalities since the conditions of its climate changed, where there are different rainfall, flood, etc., in a single district or municipality.

Looking to the figures 1 and 2, there is no much significant observations in the trend line of weather data and the occurrence of the calamities. One reason is the distant location of the actual sensors to the location of the concerned area. Based from the findings, the sensor is located in Subic Bay, Philippines which is approximately 33.77 kilometers from the City of Balanga. This study leads to create a system of localized micro-weather station system for small geographical coverage. It has data acquisition of three parameters, the temperature, rainfall, and humidity. The device has three possible outputs through the LCD, text messages, and the web. The transmission and display of outputs are shown every hour during stable weather, and a continuous reading depending on the weather in the vicinity when worse. The output is directed to the mobile phone of the locales and to the officer in charge from the municipality or barangay level. The web page is incorporated so the user can also monitor the weather in the vicinity when there is a presence of network access. Trend of historical data are saved and used for further study.

2. Significance of the study

Filipino local citizens mostly live near the sea or rivers have experience flooding and other natural calamities. A late dissemination of information may lead to fatal casualties and destruction of properties. Having a faster and precise weather condition reports on small municipalities can help the citizen to prepare for possible evacuations in case of occurrence of strong typhoons or other natural calamities. They can be aware about the status of the flood level especially when there is continuous heavy rainfall. The developed system is a self-monitoring device that tells whether to evacuate or not. In addition to this, the municipality will also be able to cancel or suspend classes ahead of time. Even those in agriculture sector can make necessary preparations. The data collected can be used in studying weather patterns in terms of humidity, rainfall and temperature.

One of the agencies that can benefit to this system is the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). This project can help monitor the weather condition and forecast problems on smaller scale like barangays with accurate data. These data are supplemental information in their operational decision making. Agricultural agencies both public and private with concerns in weather related conditions can make good use of this device and all of its

features by implementing this technology in areas of their concern. They can conserve time, money and effort through this device.

3. Methodology

The major components of the system are divided into three stages. These are designing and building the system unit, gathering and analyzing the weather condition, and dissemination of analyzed data to the locales. Figure 3 shows the basic framework of the system which describes the interrelations of each subsystem. The parameters needed to assess the weather condition are the relative humidity, temperature and amount of rainfall. The input parameters will be transmitted to a computer database. Data is analyzed and provide an output to disseminate through text in the residence within the locality.
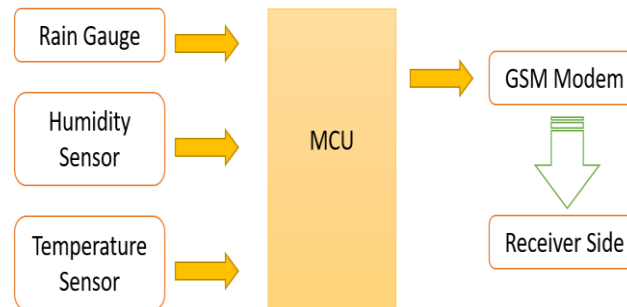

Figure 3. Framework of the micro weather station

3.1. Testing the accuracy of the device

Prior to the actual deployment of the device in the field to gather reliable data measurements, adjustment and calibrations were done under controlled environment which was setup in the laboratory.

3.1.1. Laboratory testing

During the laboratory testing, sensors' readings were compared and adjusted to make it almost similar with the accepted standard calibrated sensor. Mechanical adjustments and software numerical calibrations were implemented in this phase.

3.1.1.1. DHT22 temperature accuracy

Temperature sensor reading is compared with a calibrated room thermometer placed near the sensor. A thermoelectric cooler using peltier module is used in the controlled environment to test the temperature accuracy. There are at least 1095 sample trials (n = 3 samples/day x 365days/year) for each temperature in the range of lowest to highest temperature recorded in the Philippines [16].

3.1.1.2. DHT22 humidity accuracy

Four plastic containers having dimension of 22.8cm x 10.7cm x 13.2cm with different salt solution contents is used as a replacement for a climatic chamber for economic reasons. For these set-ups, the following proportions were used [18]:

Table 1. Salt Solutions for Testing Humidity

Container	Salt	Salt Content (g)	Water Content (g)	Expected relative humidity
1	NaCl	53.33	27.28	75%
2	LiCl	53.33	43.64	11%
3	$MgCl_2$	53.33	5.46	93%
4	K_2SO_4	53.33	18.19	97%

The prepared salt solutions in each container are left undisturbed for 24 hours for the salt solution to stabilize. The calibrated hygrometer sensor and DHT22 sensor are placed in the container without affecting the internal environment, the hole or opening for passing the wiring has to be sealed. A waiting time of 2 hours is necessary to allow the sensors to stabilize and start taking the measurements. Measurements were conducted every hour for five days.

3.1.1.3. Accuracy of the debounce circuit (tipping bucket)

A tipping bucket rain gauge as shown in Figure 4 has several components that allow it to accurately measure rainfall. As rain falls, it lands in the funnel of a tipping bucket rain gauge. The rain travels down the funnel and drips into one of two very carefully calibrated buckets balanced on a pivot.

Figure 4. Tipping Bucket design for rain gauge measuring device

For the accuracy of the tipping bucket, three set ups were done which are based from PAGASA's category for rainfall. Light, Moderate, and Heavy rainfall simulations were done. Specific volume for each category was set. Light, Moderate, and Heavy rainfall are expected to be in the ranges of 30mL, 60mL, and 120mL respectively. The tips were counted when the volume of water has poured to the tipping bucket. Then the accuracy of the system was checked. The accuracy of each category was determined by identifying true values or false values. If the counted value is the same with the expected value, it will fall under true values, otherwise, false value.

$$Accuracy = \frac{Truevalue}{Truevalue + Falsevalue} x100\% \qquad (1)$$

3.1.2 Field testing

The system was installed in an open field to measure the parameters. A comparison of the results in the laboratory test and the field test was done.
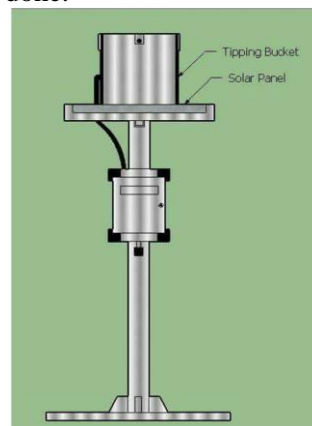

Figure 5. Front View with the Device Installed

Figure 5 shows the illustration of front view of the actual micro-weather data acquisition device. A tipping bucket was installed at the top most portion of the system with its base on the level of the solar panel. The solar panel serves as main source of power to the system. The circuit box which consists of the main board, battery, and sensor interconnection is located directly below the solar panel. The whole system is being framed in a round tubular tube with a solid metal plate.

3.2. Checking the device's efficiency

Efficiency is determined by the ratio of output over input. Mathematically, efficiency is defined as

$$\eta = \frac{average\ measured\ value}{average\ actual\ value} x100\% \qquad (2)$$

3.3. Measuring device's effectiveness

For the effectiveness of the device, the time delay of SMS sending in each trial was measured. The time difference when the message was sent and the time received is measured. There are at least 1095 sample (n=3samples/day x 365days/year) readings. The same procedure was done to compare the time sent by the GSM module and the time received by the web where outputs are saved into database. The effectiveness of the communication system is calculated with the use of the formula stated as:

$$\text{Effectiveness} = \left(\text{accepted time delay} - \frac{total\ measure\ of\ time\ delay}{no.of\ trials} \right) x100\% \qquad (3)$$

3.4. Calculating overall equipment effectiveness

Based from analysis earlier, the accuracy, efficiency, and effectiveness were identified. And to identify the overall equipment effectiveness for the reliability of the entire system is.

$$\text{OEE = Accuracy x Efficiency x Effectiveness x 100\%} \qquad (4)$$

4. Test results

4.1. Experimental setup

Three experiments were conducted for the calculation of accuracy, efficiency and effectiveness of the system. The standard used in this setup is according to the state weather bureau PAGASA in categorizing rainfall

Table 2 shows the data in simulation of light rain using a pressure sprayer done in a close environment that last up to 5 minutes.

Table 2. Tabulated data for Light Rain setup

No. of tips	Volume (mL)	Height (mm / 5min)	Height (mm / hr)
2	23	0.71	8.50
2	25	0.77	9.24
2	26	0.80	9.60
2	22	0.68	0.18
2	30	0.93	11.16
2	27	0.83	9.96
2	31	0.96	11.52
2	28	0.86	10.32
2	28	0.86	10.32
2	29	0.89	10.68

Average Volume: 26.9 mL

Average Flood Height per hour: 9.93mm/hr

Figure 6 is the graph that shows acceptable response of the tipping bucket of 2 tips for light rain in the range of 7~15 mm/hr of water rate.
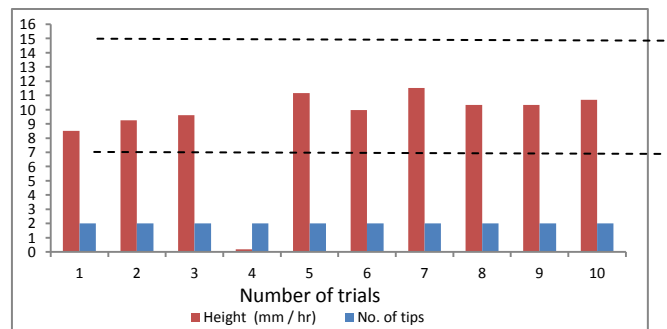

Figure 6. Comparison of number of tips and rain volume for light rain set up

Table 3 shows simulation of moderate rain using the same method in Table 2 but with increased water.

Table 3. Tabulated data for Moderate Rain setup

No. of tips	Volume (mL)	Height (mm / 5min)	Height (mm / hr)
3	45	1.39	16.65
3	43	1.33	15.91
3	43	1.33	15.91
3	51	1.57	18.87
4	56	1.73	20.72
3	42	1.30	15.54
5	66	2.04	24.42
5	71	2.19	26.27
5	73	2.25	27.01
6	81	2.50	29.97

Average Volume: 57.1 mL

Average Flood Height per hour: 21.13 mm/hr

Figure 7 is the graph that shows acceptable response of the tipping bucket of 4 tips for moderate rain in the range of 15~30 mm/hr of water rate.
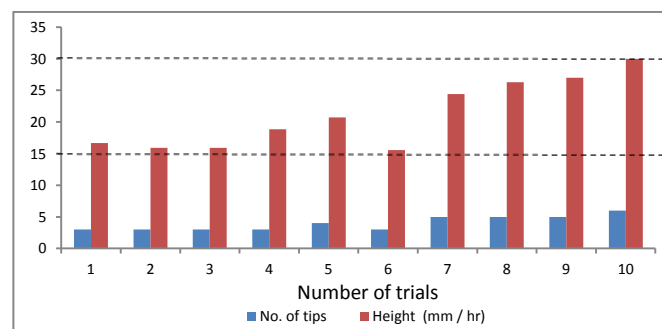

Figure 7 Comparison of number of tips and rain volume for moderate rain set up

Table 4 shows the possible height for flood during heavy rain using the same method as the latter.

Table 4 Tabulated data for Heavy Rain setup

No. of tips	Volume (mL)	Height (mm / 5min)	Height (mm / hr)
7	100	3.0836	37.000
7	100	3.0836	37.000
9	115	3.5461	42.500
8	110	3.3920	40.704
7	110	3.3920	40.704
8	110	3.3920	40.704
9	120	3.7004	44.404
8	110	3.3920	40.704
7	100	3.0836	37.000
8	115	3.5461	42.500

Average Volume: 109 mL

Average Flood Height per hour: 40.33 mm/hr

Figure 8 is the graph that shows acceptable response of the tipping bucket of 7~8 tips for heavy rain in the range of 30 mm/hr and above of water rate.
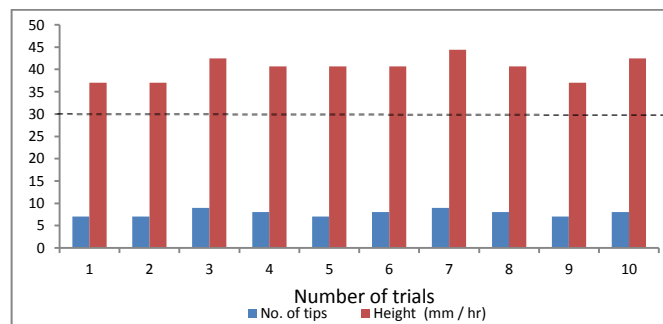
Figure 8 Comparison of number of tips and rain volume for heavy rain set up

DHT22 sensor was used in the system for the temperature and humidity measurement. It has 0~100% humidity range with an accuracy of ±2-5%, and -40~80°C temperature range with accuracy of ±0.5°C. It is better over a slightly larger range, smaller, and cheaper. Sim800L has a dimension of 17.6x15.7x2.3mm which is used in the system considering the cheaper price.

4.1.1 Checking the DHT22 temperature accuracy

In a controlled environment, the sensor is tested from the range of 6°C~42°C. In each temperature, there are 1095 samples. The average difference between the two readings is 0.2°C and the calculated accuracy of the sensor for the laboratory testing is 99.32%. During the field testing, where the device is placed in an open field, the accuracy drops to 92.97%. The average difference of the two sensors is 0.4 °C which coincide within the set accuracy for DHT22 temperature readings of ±0.5 °C.

4.1.2. Checking the DHT22 humidity accuracy

For DHT22 humidity readings, the sensors are tested in 11%, 33%, 75%, and 97% of relative humidity inside a controlled environment with 1095 sample of measurements. The average difference between the two readings is 0.8%. The accuracy for the DHT22 Humidity Sensor is 100% because all of its readings fall within the set accuracy of DHT22 for humidity of ±5%. The results of field testing for the DHT22 humidity sensor were also tested for 1095 samples. The average difference drops to 2.5% and all of its reading still falls within ±5%.

4.1.3. To observe sending time delay of the GSM shield (sim800L)

The optimum distances of transmission within 1km range are 300m and 800m for the specific location where the system was installed. There can be different results if the experiment will be done in different location because the speed of transmission depends on the strength of signal in every location. In locations where the signal strength is weak you will probably get a higher time delay. The delay for each designated distance falls within the accepted time delay which is 1 second. The average delay in the final testing is 0.549 seconds. This result is still within the acceptable time delay of 1 second. The average time delay for initial testing is 0.575 second while the average time delay for final testing is 0.557 second. Both results from two testing falls within the accepted time delay of 1 second.

4.1.4. Calculating device's overall equipment effectiveness

Accuracy:

    DHT22 Temperature Accuracy = 92.97%

    DHT22 Humidity Accuracy = 100%

Average DHT22 Accuracy = (Temperature Accuracy + Humidity Accuracy)/2

            Average DHT22 Accuracy = 96.49%

Table 5. Tipping Bucket before Adjustment

Rain level	No. of True Values	No. of False Values
Light rain	934	161
Moderate rain	908	187
Heavy rain	902	193
Total	2744	541

Table 6 shows the results after adjusting the tipping bucket. The total number of true value became 3156 which is greater than 2744 that can be seen in Table 5. The accuracy of the tipping bucket got higher, from 83.53% to 96.07%. Computations can be seen below.

Table 6. Tipping Bucket after Adjustment

Rain level	No. of True Values	No. of False Values
Light rain	1057	38
Moderate rain	1053	42
Heavy rain	1046	49
Total	3156	129

The system accuracy is calculated using equation (1) and shown below.

$$Accuracy_{Initial\ test} = 83.53\%$$
$$Accuracy_{Final\ test} = 96.07\%$$

$$System\ Accuracy = \frac{(DHT\ Accuracy + Tipping\ Bucket\ Accuracy)}{2} = 96.28\%$$

Moreover, the efficiency of the tipping bucket is calculated using equation (2).

$$\eta_{light\ rain} = 98.52\%$$
$$\eta_{moderate\ rain} = 99.01\%$$
$$\eta_{heavy\ rain} = 99.50\%$$
$$\eta = \eta L\ x\ \eta M\ x\ \eta H\ x\ 100\% = 97.06\%$$

Both the effectiveness of the mobile phone and the modem is calculated using equation (3).

$$Effectiveness_{mobile\ phone} = \left(Accepted\ time\ Delay - \frac{Total\ Measure\ of\ Time\ Delay}{No.of\ Trials}\right) x\ 100\% = 99.95\%$$

$$Effectiveness_{modem} = \left(Accepted\ time\ Delay - \frac{Total\ Measure\ of\ Time\ Delay}{No.of\ Trials}\right) x\ 100\% = 99.95\%$$

$$System\ Effectiveness = \frac{Effectiveness_{mobile\ phone} + Effectiveness_{modem}}{2} = 99.95\%$$

The overall equipment effectiveness (OEE) is calculated using equation (4).

$$OEE = 93.04\%$$

4.2. Creation of a web page that display data.
The webpage where the data are stored can be seen by the public. Separate tables for temperature, humidity, and rainfall readings are provided and graphs for temperature, humidity, and rainfall readings are shown. These data can be used as baseline information in the study of its effect to natural calamities. For this purpose, the webpage created can also download or print the stored data.
Table 7 shows the stored information about the natural calamities that occurred in Bataan. These information can also be used as base line data for determining the relationship of temperature, humidity and rainfall in the occurrence of natural calamities.

Table 7. Sample data of Natural Calamities that hit Bataan stored on the system

Date	Temperature (^{o}C)	Humidity (%)	Rainfall (mm)	Calamity
2009-05-06	29	88	48	Typhoon Emong
2009-06-25	26	82	7	Tropical Depression Feria
2009-09-23	28	79	38	Typhoon Ondoy
2009-10-30	27	74	44	Typhoon Santi

Table 8. Past 14 days data before the typhoon Ondoy hits Bataan

Date	Temperature (^{o}C)	Humidity (%)	Rainfall (mm)
2009-09-09	26	87	38
2009-09-10	28	78	0
2009-09-11	26	82	13
2009-09-12	26	86	12
2009-09-13	27	81	5
2009-09-14	30	78	0
2009-09-15	32	71	0
2009-09-16	32	75	6
2009-09-17	31	76	27
2009-09-18	30	76	0
2009-09-19	30	75	0
2009-09-20	31	74	9
2009-09-21	32	46	15
2009-09-22	28	79	0

Table 8 shows the past 14 days sample data that can be seen in the database before the typhoon Ondoy hits Bataan. The user can choose the range of days to be viewed in the web page. It will show the temperature, humidity and rainfall of the past days picked by the user.

5. Conclusion

The microweather system station developed is significant for small geographical coverage areas. This collect more precise information of the conditions in the area of concerned for better decision making and early warning applications. It is a device that determined the calculated height of flood due to amount of rainfall measured by the tipping bucket. It sent real time rainfall data to the community via GSM network within the acceptable delay time of 1 second in less than 1km range then displayed data via LCD. With the use of a solar panel, the system can reliably operate in times of its intended purpose. The overall equipment effectiveness of the system reached up to 93.36%. An incorporated database connected via network is established in the system. And lastly, the information stored can be printed or downloaded for use as a baseline data to the study of its relationships on natural calamities.

6. Appendices

6.1. Actual installation of the micro weather system station

(a)   (b)

Figure 9. Testing Overall System with sensors for comparing the temperature, humidity and amount of rainfall (a) daytime and (b) night time

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