# Sonde Instrumentation for Upper Air Weather Monitoring System

Raymart B. Balakit [1], Febus Reidj G. Cruz [1,2], May Anne C. Valencia [1]
[1] *School of Graduate Studies, Mapua University, Manila, Philippines*
[2] *School of Electrical Electronics and Computer Engineering, Mapua University, Manila, Philippines*
frgcruz@mapua.edu.ph

*Abstract*— **Today, weather balloons are one of the emerging technologies used to monitor the weather. Even so, problems related to the cost of implementation, tracking of the device and weight of payload have limited innovators to cover a larger area to monitor atmospheric data. With this in mind, the present work has designed a sonde instrument using temperature sensor, humidity sensor, barometric pressure sensor, GPS and microcontroller. Actual balloon flights were conducted to gather upper-air measurements and laboratory experiments were carried out to determine the overall performance of the proposed device compared to the existing devices. The measurements taken were sent to a ground station using a radio frequency transceiver module and were saved in a database file. Results were tabulated and interpreted using statistical analysis. Laboratory tests showed that there was a high correlation between the measurements made by the proposed device and the existing devices. Field experiment was carried out using a 150 g hydrogen-filled balloon to lift the proposed device into the atmosphere. Z-scores for the two experiments done showed that there was no significant difference in the mean of the observations done by the two devices.**

***Keywords***—— ***Upper air, atmospheric pressure, temperature, relative humidity, radiosonde***

## I. Introduction

Upper-air observation is a meteorological observation made either directly or indirectly in the free atmosphere [1]. In other words, it is the process of monitoring meteorological variables (temperature, pressure, relative humidity, etc.) in the atmosphere to determine and/or predict the weather condition. Weather condition plays a vital role in various fields, including agriculture, transportation, energy sector, communication, and disaster management. The International Telecommunications Union (ITU) stated that between 1970 and 2015, more than 12 000 natural disasters worldwide took the lives of over 3.5 million people and produced economic losses estimated at over 2.7 trillion US dollars. Ninety percent of these natural disasters, more than 60% of casualties and 70% of economic losses were caused by weather-, climate- and water-related hazards, such as droughts, floods, severe storms, and tropical cyclones as well as by health epidemics and insect infestations directly linked to meteorological and hydrological conditions. These extreme events are intensifying with climate change, the "defining challenge of our time", and will continue to do so if it is left unaddressed. There is indeed overwhelming scientific evidence that climate change will threaten economic growth, long term prosperity and social welfare of practically all countries, as well as the very survival of the most vulnerable populations [2]. For this reason, timely and accurate weather observation is a must to ensure public health and safety as weather affects human activity.

Various methods are explored to design an effective and accurate weather monitoring system. For instance, weather balloons are now used in several countries to perform upper-air sounding. These balloons have radiosondes which are equipped with devices to measure one or several meteorological variables and are provided with a radio transmitter for sending meteorological information to an observing station [1]. Sankar and Norman developed an embedded system to observe the atmospheric weather conditions using hydrogen balloons. The measured values were sent to the ground station by means of radio frequency (RF) communication [3]. In the same way, Gaurav et al. deployed a GSM-based low-cost weather monitoring system that is lightweight and floatable with a hydrogen balloon. The said system, however, was made to predict whether or not a place is suitable for solar power plant and wind energy generation and not as the main tool for monitoring weather [4]. Noordin et al. focused on the design of a weather monitoring system that is low cost and displays the temperature, relative humidity and atmospheric pressure [5]. Similarly, Krishnamurthi et al. made an investigation about an Arduino-based weather monitoring system. Humidity, temperature, pressure, light intensity and altitude sensors are integrated into the system. The gathered data is serially fed into a computer and is stored in a text file which, if desired, can be exported into an excel file [6].

Above-mentioned systems have things in common a microcontroller is utilized to process weather data and sensors are embedded to monitor each of the different weather parameters. Yet, the complexity of the implementation becomes a problem specifically for upper-air weather observation. This is because a huge size of the balloon is needed to lift a device that is used to make an observation in the upper-air. Aside from the cost and weight, the capability to track the location of the device and accuracy are issues that are also needed to be solved. Further calibration of the sensors is required and time logging capability must be established as well [3].

The main objective of this study is to design sonde instrumentation which can be used for upper-air weather monitoring system, in particular, with weather balloons. Specifically, it aims to design and to evaluate the accuracy of the sensors for upper-air observation of meteorological variables; to determine the volume of a weather balloon based on the required rate of ascent, and to conduct actual weather balloon flight and to gather upper-air measurements.

The proposed system will be significant to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA) since they can use it as an alternative to the existing methods/devices they used to monitor the weather. Likewise, this study will be of great help to the Filipino community as it will raise awareness or it will serve as an alert system on the current weather condition in the event of heavy rainfall or super typhoon. The results of this study will be equally important to the shipping industry in

978-1-7281-3044-6/19/$31.00 ©2019 IEEE

planning courses and taking necessary precautions. Farmers as well will benefit from this proposed system for it will help them make sound decisions regarding the timing for planting and harvesting of crops. Finally, the attempt of using low-cost devices in the system will also open new opportunities for future researchers to develop a more effective device for weather monitoring applications.

## II. Materials and Methods

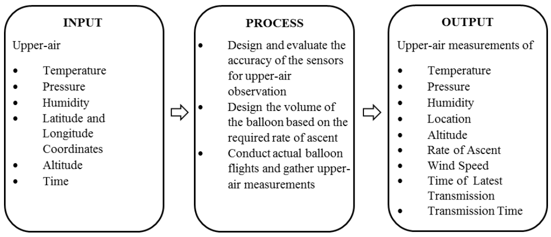


Fig. 1. Conceptual framework of the designed weather monitoring system

The proposed weather monitoring system is designed as depicted in Figure 1. The input to the system was the upper-air meteorological variables, which include the temperature, pressure, and humidity, location using the latitude and longitude coordinates, altitude and time of latest transmission. Then, several experimental trials were performed to evaluate the sensor module and to determine the volume of a balloon required to achieve the rate of ascent. The output was upper-air weather measurements of temperature, pressure, humidity, location, altitude, rate of ascent, wind speed, time of latest transmission and transmission time.

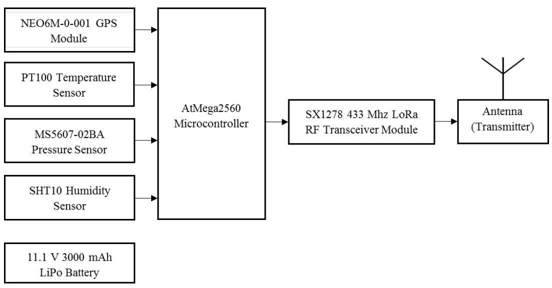


Fig. 2. Transmitter of designed weather monitoring device

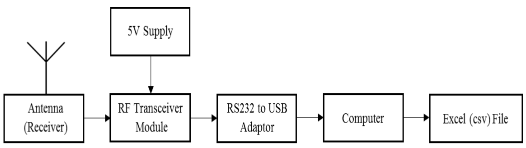


Fig. 3. Receiver of designed weather monitoring device

Figures 2 and 3 demonstrate the block diagram of the proposed upper-air weather monitoring device. For this research, the system was divided into three parts, namely, the sensor circuit, the data-logging circuit, and the time-keeping circuit. The sensor circuit was comprised of the humidity sensor (SHT10), pressure sensor (MS5607-02BA), temperature sensor (PT100 RTD) and GPS module (NEO6M-0-001) that were interfaced to the microcontroller. The microcontroller (AtMega 2560), which was supplied by a battery (11.1 V 3000mAh Lithium Polymer), processed the data gathered by the sensors. The measurements taken were forwarded to the ground station using RF communication, displayed on a GUI and can be stored in a CSV file.

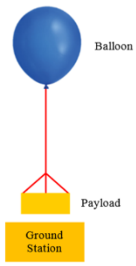


Fig. 4. Model of the proposed weather balloon system

Figure 4 shows the model of the proposed upper-air weather monitoring system. The payload contains the sensors that gather upper-air measurements.

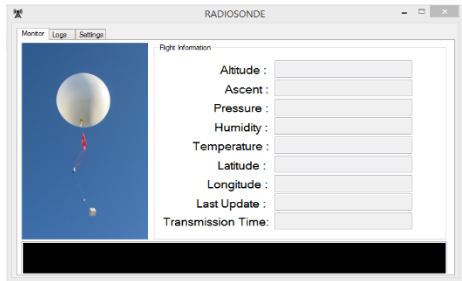


Fig. 5. User interface of weather monitoring device

The graphical user interface on Figure 5 below displays the output of the proposed system. Under the logs tab, all the observations made and saved in the computer can be accessed. In the settings tab, the user can choose the folder where he wants to save the observations.

There were two set-ups done to test the accuracy, reliability, and sensitivity of the proposed device. The first set-up was accomplished in a laboratory and the second will be on an open field. For the first set-up, the proposed device was tested on a closed chamber and subjected to a temperature range of -30 to +30°C and humidity of 45 to 88%. A separate chamber for pressure testing was also utilized to determine if the device can accurately function under extreme pressure conditions. The controlled pressure ranges from 700 to 1050 hPa. Conversely, field experiments involved not only performing actual balloon flight but also varying the volume of the balloons to achieve the required rate of ascent. Finally, the performance of the balloon using the gathered data was evaluated using statistical methods (mean, standard deviation and z-test).

## III. Result and Discussion

Balloon experiments were performed to design the volume of a balloon based on the required rate of ascent while battery test was accomplished to determine if the device can support continuous observations of up to two hours. Moreover, there are two experimental trials that were performed to test the performance of the designed weather monitoring system.

TABLE I. The Average Ascent of Three Balloons With Different Volumes

| Radius 1 (cm) | Radius 2 (cm) | Balloon Volume (cu.cm) | Payload (g) | Altitude (cm) | Average Time (s) | Average Rate of Ascent (cm/s) |
|---|---|---|---|---|---|---|
| 14.35 | 13.95 | **12032.80** | 2 g | 500 | 5.38 | **93.40** |
| 14.55 | 13.74 | **12184.32** | 2 g | 500 | 5.27 | **95.27** |
| 20.41 | 19.00 | **33151.67** | 2 g | 500 | 1.86 | **269.30** |

Table 1 summarizes the results of the repeated trials using different balloon sizes. It can be seen that the greater the volume of the balloon, the higher is its rate of ascent provided that the same weight of the payload is used.

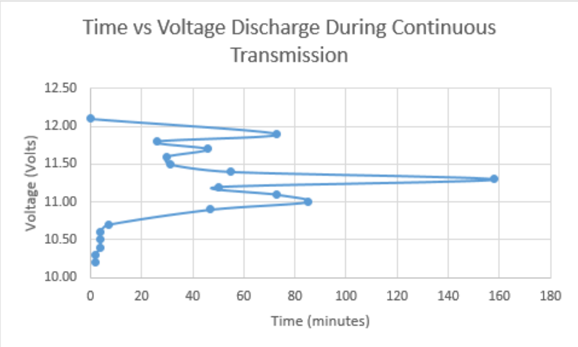


Fig. 6. Bateery discharge voltage during continuous transmission

Figure 6 shows the graph of the voltage discharge of the battery during continuous transmission. Based on the graph, the rate of discharge differs from time to time. Once the battery's voltage reaches 11 V, the discharge rate becomes rapid up to the allowable minimum value of 10.2V. For this test, it took 697 minutes (11.62 hours) for the battery to drop its value from 12.1 V to 10.2 V. As such, it was proven that the battery can support upper-air observation.

$$y = 1.1173x - 2.5676 \qquad (1)$$

$$y = 1.3126x - 5.6355 \qquad (2)$$

For this experimentation, it was found out that the system was able to function as designed. The sensors were able to measure the parameters specified while the microcontroller was able to process it. The gathered measurements were also transmitted successfully using RF communication. Moreover, equations for the calibration model (see Equations 1 and 2) were also derived for temperature and humidity measurements. These equations were inserted on the program and the prototype was tested again.

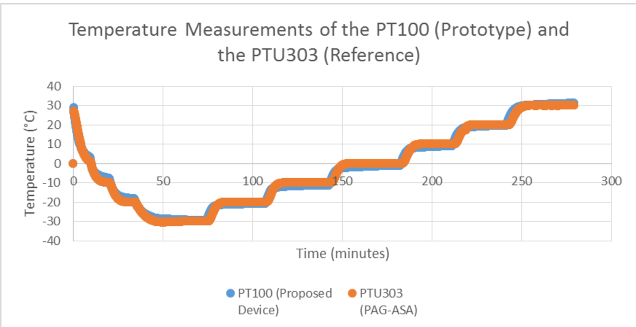


Fig. 7. Temperature measurements of the two devices after the implementation of the calibration model

Figure 7 shows the graph of the observations after the implementation of the calibration model. In relation to this, results revealed that on the average the device obtained an accuracy of 83.66%.

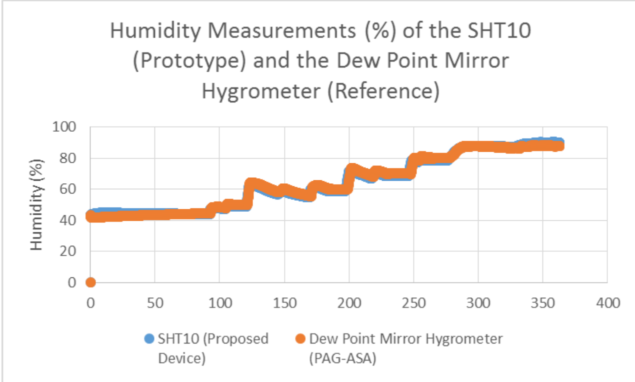


Fig. 8. Humidity measurements of the two devices after the implementation of the calibration model

Figure 8 shows the graph of the humidity observations where the proposed device obtained an accuracy of 98.64%.

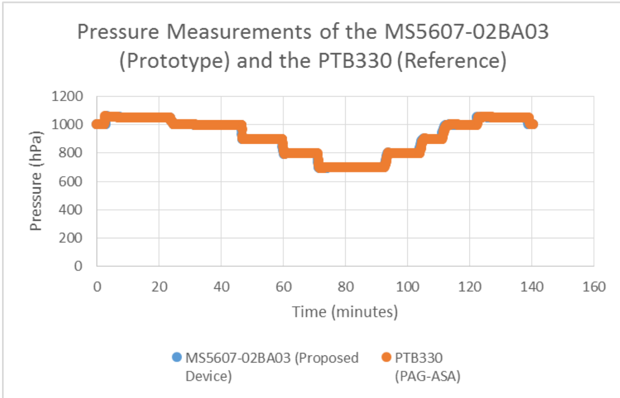


Fig. 9. Pressure measurements of the two devices during a laboratory test

On the other hand, Figure 9 illustrates the comparison between the performances of the MS5607-02BA03 Barometric Pressure and the chamber with controlled pressure. The average accuracy of the proposed device calculated was 99.97%.

A balloon filled with hydrogen gas with a diameter 150 cm was used to lift the payload which weighs 515 g.

$$d = \{cos[\sin(A)\sin(B) + \cos(A)\cos(B)\cos(D - C)]\}\times R \qquad (3)$$

The launch started at 11:31 am and the weather balloon reached an altitude of 21.92 km for a period of 1 hour and 38 minutes. Accordingly, the shortest distance of the balloon from the synoptic station is calculated to be about 25.59 km. The formula used to find for the distance traveled is shown in Equation 3: where A is the coordinate of latitude 1, B is the coordinate of latitude 2, C is the coordinate of longitude 1, D is the coordinate of longitude 2 and R is the earth radius which in this case is 3, 443.89849 km. The average processing time required for the MCU and the transmitter to output one string of data is about 2 seconds while the highest ascent of 6.48 m/s was obtained at an altitude range of 9.32 to 9.36 km. Highest wind speed of 1260.30 m/s was recorded at a distance of 24.62 km from the starting point.

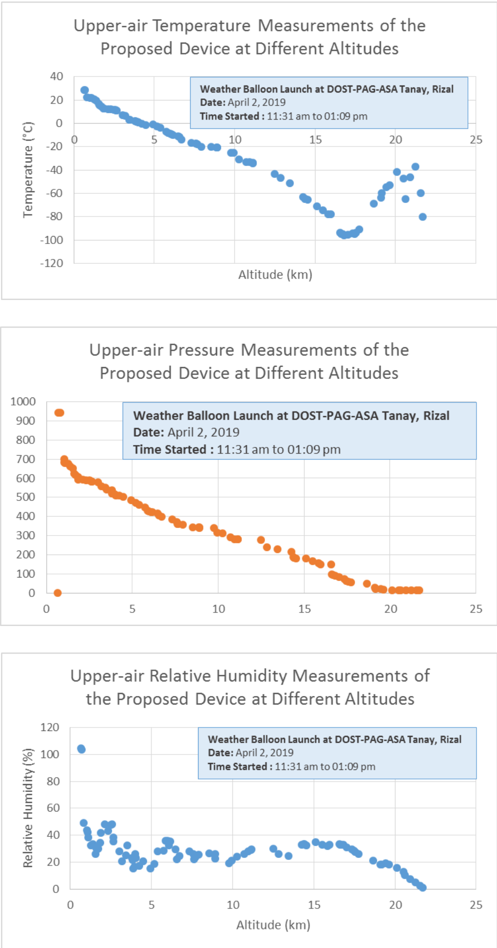


Fig. 10. Upper-air measurements of proposed device at different altitudes

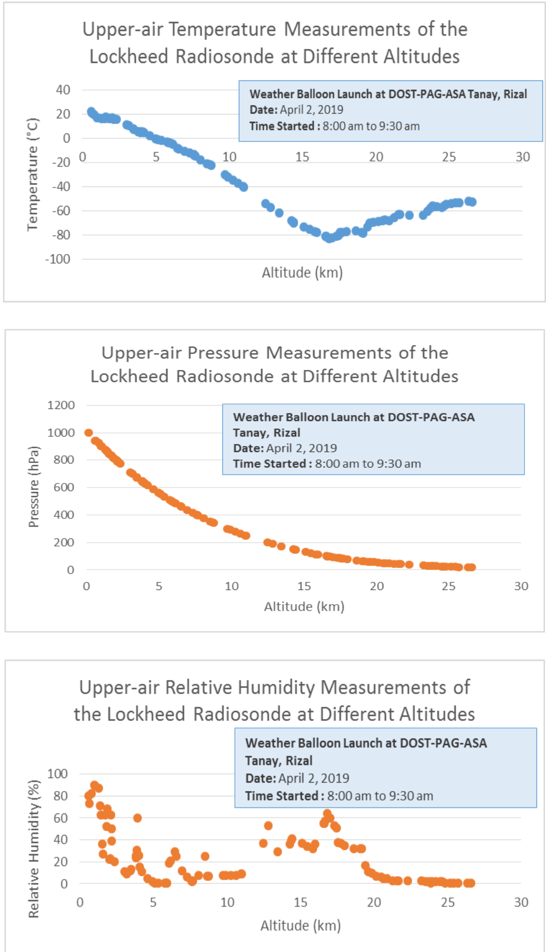


Fig. 11. Upper-air measurements of commercial device at different altitudes

Upper-air observations obtained from the two different launches using the proposed device and the commercial radiosonde were also plotted and demonstrated. Figures 10 illustrate the upper-air measurements of the proposed device during its launch last April 2, 2019 at PAG-ASA Synoptic Station Tanay Rizal.

In the same manner, the measurements made by the commercial radiosonde (currently being utilized by PAG-ASA for its weather balloon) are shown on Figure 11. It can be inferred from the graphs that for most of the points, the trend of the measurements is the same for the two devices.

In connection with the laboratory and field experimentations done, z-test was employed to determine if there is a significant difference between the measurements of the proposed device and the existing radiosonde. The null hypothesis ($H_o$) which says, "There is no significant difference between the means of the observations of the two devices." was established. For the laboratory tests, the computed values of z at a confidence level of 10% were $-8.3\times10^{-5}$, $4.84\times10^{-4}$ and -0.01 for the temperature, relative humidity, and pressure observations respectively. These z-scores fall within the acceptance. Hence, the null hypothesis was accepted and it was concluded that there was no significant difference in the mean of the observations made by the two devices. In addition, the computed values of z at a confidence level of 10% for the field experimentations were 0.03, 0.01 and $2.52\times10^{-4}$ for the temperature, relative humidity, and pressure observations respectively.

Again, the null hypothesis was accepted since the z-score falls within the acceptance region and as a conclusion - there was no significant difference in the observations mean made by the two devices.

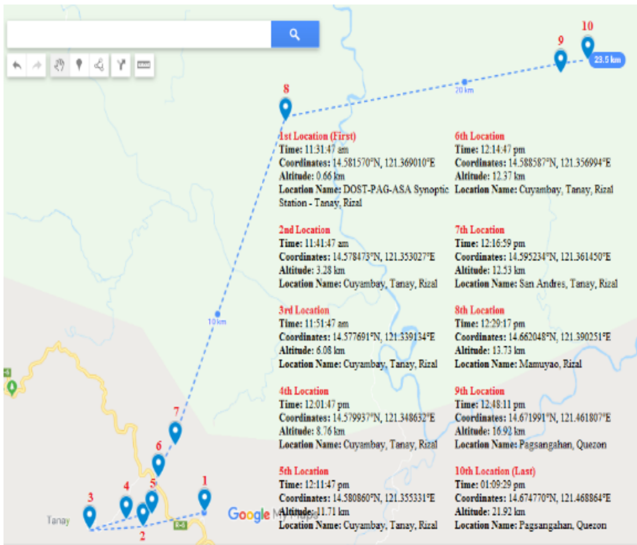


Fig. 12. Map of balloon trajectory

Lastly, Figure 12 demonstrates the mapping of the actual locations traveled by the weather balloon during its flight.

## IV. Conclusion and Future Work

A sonde instrument was designed using temperature sensor, humidity sensor, barometric pressure sensor, GPS and microcontroller to gather upper-air weather data. By performing experimental trials and applying statistical analysis, the sensors used in the study showed a high accuracy of measurement and are found to be reliable. Z-scores of the laboratory tests and field experiments revealed that there was no significant difference in the mean of the observations made by the two devices. From the graphs, it can be concluded that there is a correlation between observations at temperatures ranging from 30 °C to -40 °C. This is supported by the fact that the operating temperatures of the sensors are up to -40 °C only. Time of weather balloon launch must also be considered in interpreting the results since weather condition differs from time to time. The weather balloon with the commercial radiosonde was launched at 8:00 in the morning while that of the proposed device was at 11:31 am. The results of the experiment on the variation of the balloon volume implied that the volume of the balloon to be launched is dependent on the weight of the payload. The heavier the payload, the larger is the volume needed.

To further enhance the functionality of the proposed device, it is hereby recommended that an enhancement of the graphical user interface be done to include graph or plot of the real-time monitoring of the path of balloon trajectory (location). A neural network may be designed as well to determine the possibility of rainfall and/or give weather forecast on a particular area based on the results gathered by the device. As such, additional sensors should be incorporated to be able to measure additional weather parameters like dew point, solar intensity, and other relevant parameters.

## Acknowledgment

The authors would like to express sincere gratitude to the Department of Science and Technology – Engineering Research and Development for Technology (DOST-ERDT) program for the scholarship and research funding for Raymart B. Balakit, and to the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (DOST-PAG-ASA) for the weather balloon and hydrogen gas used during the actual flight test.

## References

[1] World Meteorological Organization (2017). *Chapter 12. Measurement of upper-air pressure, temperature, and humidity*. Guide to Meteorological Instruments and Methods of Observation, 7 bis, avenue de la Paix, P.O. Box 2300, CH 1211 Geneva 2, Switzerland, 347-419.

[2] International Telecommunication Union (2017). Handbook on Use of Radio Spectrum for Meteorology: Weather, Water, and Climate Monitoring and Prediction. *Place des Nations 1211 Geneva 20 Switzerland*, iv.

[3] Sankar, P. and S.R. Norman (2009, June, 4-5). Embedded system for monitoring atmospheric weather conditions using weather balloon. *International Conference on Control, Automation, Communication and Energy Conservation – 2009*, 1-4.

[4] Gaurav, D., et al. (2011). A GSM-based low-cost weather monitoring system for solar and wind energy generation. *School of Computing Science and Engineering (SCSE) VIT University, Vellore*, *India*, 1-6.

[5] Noordin, K. A., C. C. Onn and M. F. Ismail (2006). A low-cost microcontroller-based weather monitoring system. *CMU*, Volume **5** (1), 33-38.

[6] Krishnamurthi, K., S. Thapa, L. Kothari and A. Prakash (2015). Arduino based weather monitoring system. *International Journal of Engineering Research and General Science*, Volume **3** (2), 452-458.