Empowering Communities in the Philippines with an IoT-based Localized Weather Monitoring and Early Warning System

ALBA, Erica A.
Electronics Engineering Department
Technological University of the Philippines

ATAS, Marjorie Cattlyn D.
Electronics Engineering Department
Technological University of the Philippines

BATARIO, Bianca Victoria T.
Electronics Engineering Department
Technological University of the Philippines

BROSO, Elian Justin P.
Electronics Engineering Department
Technological University of the Philippines

OCAMPO, Eliza Mae R.
Electronics Engineering Department
Technological University of the Philippines

***Abstract* — Weather monitoring and forecasting are crucial in areas vulnerable to climate change impacts. Localized monitoring provides specific readings for regions which enable communities to make informed decisions. Hence, the LIKAS system is developed which utilizes data from various sensors measuring temperature, humidity, wind, air pressure, and rainfall intensity. The system is solar-powered and operates on a lithium-ion battery. Data inputs are consolidated via Arduino Uno, and the LILYGO TTGO board. Long Range Wide Area Network (LoRaWAN) technology facilitates the wireless transmission of this data to end devices, enabling real-time data collection.**

The weather system exhibited low error metrics for the various parameters: temperature readings with 2.462 Root Mean Squared Error (RMSE) value, and 1.709 Mean Absolute Error (MAE) value, humidity with 8.772 RMSE value and 7.604 MAE value, and wind speed with 3.11 and 1.868 for RMSE and MAE value, respectively. With that, the LIKAS performed a strong accuracy in measuring temperature (99.4%), wind speed (99.2%), and rainfall measurements (100%). Humidity measurements, while still fairly accurate (75.458%), exhibited the highest RMSE (8.772) and MAE (7.604) values compared to other parameters, while pressure readings perform some deviations in results, it still exhibits high accuracy of 97.25%. Hence, the LIKAS system is recommended for adoption as a localized forecasting tool by Local Government Unit (LGUs) in the Philippines as it can significantly aids Local Disaster Risk Reduction and Management Offices (LDRRMOs) in addressing natural disaster challenges and mitigating impact.

Keywords* — *Early Warning System (EWS), Hydrometeorological Hazards, Localized, Real-Time, LoRaWAN, Wireless Sensor Network, Internet of Things, Disaster Risk Reduction and Management

I. INTRODUCTION

The Philippines' geographical location exposes it to a multitude of natural hazards, including frequent typhoons, floods, and earthquakes, with approximately 20 cyclones annually, eight of which typically make landfall. This susceptibility underscores the critical need for an effective early warning system (EWS) to mitigate disaster risks. While weather forecasting is extensive, covering wide regions, localized forecasting remains deficient, leaving communities vulnerable. Recognizing this gap, a research initiative aims to bolster disaster preparedness at the barangay level by leveraging Wireless Sensor Networks, Internet of Things, and LoRaWAN technology to develop real-time weather and flood monitoring systems. These systems will deliver local forecasting notifications through web-based applications, enabling timely evacuation alerts and providing users with optimal evacuation routes. By equipping government agencies and communities with these advanced tools, the initiative strives to enhance disaster preparedness, ultimately reducing the economic toll of natural disasters.

Efficient EWS implementation encompasses various stages, including risk assessment, forecasting, dissemination, and preparedness. The proposed initiative seeks to address these stages comprehensively, emphasizing the importance of localized forecasting for effective disaster management. By integrating technology-driven solutions, such as real-time monitoring and web-based applications, the initiative aims to bridge existing gaps in disaster preparedness, enabling prompt responses and minimizing loss of life and property. Ultimately, by empowering communities with accessible, localized EWS, the initiative endeavors to enhance resilience and mitigate the impact of natural disasters on the Philippines' vulnerable populations.

II. BACKGROUND OF THE STUDY

The Philippines is vulnerable to natural disasters such as earthquakes, floods, and typhoons due to its location in the Northwest Pacific Ocean. On average, the region encounters twenty typhoons each year, with eight of them making a landfall [1]. This increases the region's susceptibility to flooding caused by heavy rainfall. The need for an (EWS) is crucial to reduce the risks and dangers posed by tropical cyclones. Effective EWS is composed of monitoring, forecasting, and notification [2]. Hence, this study aims to enhance disaster preparedness by focusing on weather monitoring and forecasting systems utilizing Wireless Sensor Networks (WSN), Internet of Things (IoT), and LoRaWAN technology.

The current weather forecast in the country covers a wide regional scope, leaving a gap in localized forecasting. This research aims to fill this gap by developing a weather system at the barangay level to provide more accurate forecasts, facilitating efficient EWS. Effective EWS requires dissemination systems to inform people at risks; in addition, many sectors must be included [2]. Thus, the study developed a web-based application to alert the residents and the local government units regarding the weather conditions. Enhancing EWS must be employed at the root level to facilitate timely evacuation and minimize economic losses associated with natural disasters.

III. RESEARCH OBJECTIVES

To empower communities in the Philippines by developing and implementing a localized weather monitoring and early warning system aimed at enhancing disaster preparedness and resilience, this research aims:

1. To develop and implement a localized EWS utilizing LoRaWAN technology, and WSN at the barangay level in the Philippines.

2. To validate the effectiveness and reliability of the implemented EWS by comparing real-time weather data collected by the system with data from established meteorological sources.

IV. REVIEW OF RELATED LITERATURE

A. *Early Warning System*

According to the study in [3], typhoons impose significant threats to human lives and communities, among all the meteorological disasters. It is due not only because of their frequent occurrence and destructive power, but also due to other typhoon induced hazards, such as flooding caused by storm surge and heavy rainfalls. According to the assessment conducted by the study in [4], the typhoons that visited the Philippines during 2020 and the past years had brought serious damages and kill many Filipinos by floods and landslides. Hence, to better prepare the citizens for the mentioned disaster risks, the chances of these severe calamities must be predicted and forecasted to alert the citizens and communities. Thus, the need for early warning system based on weather forecasts must be implemented to address these disaster risks in the Philippines. With this, this study developed a weather monitoring system to gather and measure efficient weather parameters needed to establish an accurate weather forecast. These forecasts are used to provide timely alerts regarding the future possibilities and severity of rainfall and flood to the community.

B. *Hydrometeorological sensors*

The author in [5], presents an IoT-based weather monitoring system in which sensors are utilized to retrieved various weather parameters. The study uses different sensor to gather necessary parameters like humidity, temperature, pressure, and rain value. According to the study in [6], pressure, wind speed and direction, temperature, humidity, and rainfall are measured using weather instruments. These parameters and instruments are crucial to develop an effective and accurate weather monitoring and forecasting. Hence, utilizing efficient hydrometeorological sensors are required for effective weather forecasting and monitoring. With this, temperature and humidity sensors, anemometer, wind vane, rain gauge sensor, water level sensor, and barometric pressure sensor are utilized to this study to forecast and monitor weather conditions.

C. *Wireless Sensor Network*

The study in [7] focuses on the development of a weather monitoring system utilizing Wireless Sensor Networks (WSN). It allows real-time monitoring and detection through strategically deployed sensor hubs within the area. Leveraging sensors such as temperature, ultrasonic, and rain sensors, the system facilitates rapid data collection and transmission to microprocessors for further processing. Integration with LoRa (Long Range) modules enables seamless communication with cloud platforms, facilitating efficient data dissemination. Thus, this study applied the similar approach in developing the weather station to facilitate efficient data collection and transmission. Through this, the weather station can provide accurate real-time data and efficient early warning system to the communities.

D. *LoRaWAN Technology*

According to the study in [8], the integration of LoRa technology in the development of weather stations represents a significant advancement in wireless infrastructure within the realm of IoT systems. LoRa stands out as a formidable alternative to established wireless connectivity modules such as GSM, WiFi, and Bluetooth (BLE), offering an extended range of up to 5 kilometers while maintaining low power consumption. Hence, this study utilized LoRa in its prototype, aligning with the functionality showcased in the research. The integration of LoRa facilitates the transmission of various weather parameters, including temperature, humidity, air pressure, rain intensity, and wind speed and direction, utilizing sensors such as the DHT22, raindrop sensor, anemometer, wind vane, and BMP180 sensor. The inclusion of Arduino UNO, LoRa module, LoRa Gateway, and the utilization of ThingSpeak web application further enhance the functionality of the system. This study demonstrates the potential for scalability in rural settings which is crucial in establishing localized weather monitoring device. Through this integration, this study contributes to the advancement of IoT-based weather monitoring systems, facilitating efficient and effective weather monitoring device.

E. *Web-based Application*

The study in [9], presents the implementation of a weather monitoring system utilizing a transmitter and receiver system. The transmitter has a Wi-Fi module, microcontroller, and various sensors. The receiver includes the web server, router, and a website. Each sensor's output is accepted by the microcontroller and handled in compulsory format. Those values are transmitted from the nodes to the main server. Consequently, all the values of sensed data are maintained on the main server, routed, and showed continuously on the website with the refreshing rate of 10 seconds. Furthermore, the database is created using the MySQL query language. The dissemination and display of the measured data is crucial to make the weather station beneficial to the users. Hence, the integration of these methodologies highlights the significance of utilizing the transmitter-receiver systems to have a seamless transmission of data that it is continuously routed and displayed on the website. With this, this study also developed a web-based application to allow the dissemination and display of real-time data with updates occurring at regular intervals of 10 seconds. This study also utilized MySQL query language to processed and stored the data in a database to efficiently display data on a web, facilitating early warning updates.

V. METHODOLOGY

The weather system utilized different sensors for weather monitoring. This includes humidity, wind speed, temperature, air pressure, and rainfall sensors that is calibrated from the PAGASA Instrument Calibration Laboratory (PICL) for weather monitoring.

Moreover, the system provided web application which enables users to view weather forecasts in their area.

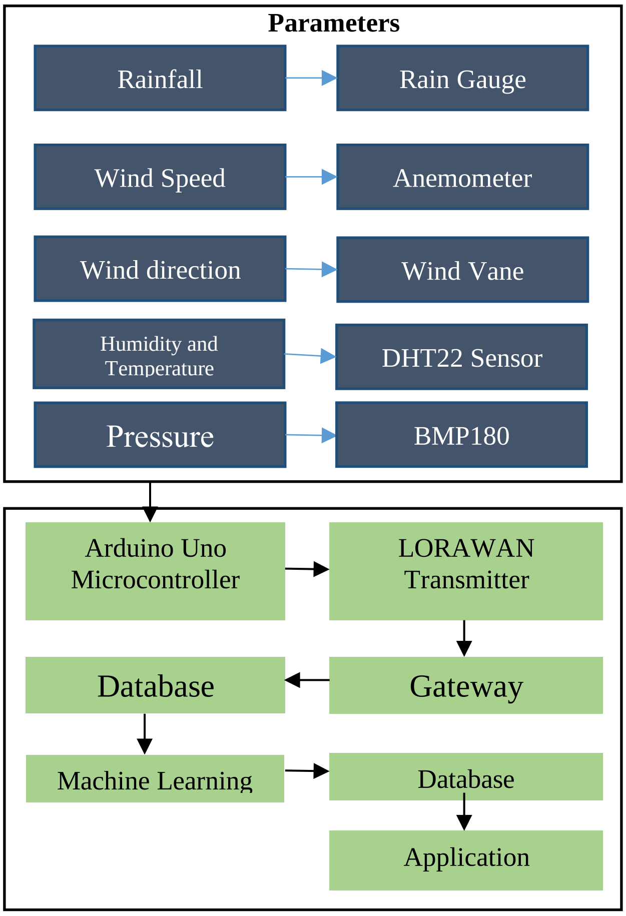

Fig. 1. Block Diagram of Weather System

Figure 1 depicts the block diagram of the weather system. The inputs comprise data gathered by IoT sensing nodes, which are then transmitted to an Arduino Uno. The process entails transmitting the accumulated data from the Arduino Uno to the system's database utilizing LoRaWAN technology. LoRaWAN, a long-range, low-power wireless communication protocol, facilitates the efficient transmission of data over long distances with minimal power consumption. This transmission method ensures reliable and robust communication between the IoT sensing nodes and the central database. Once the data reaches the database, a trained hybrid model processes it to generate accurate weather forecasts. Subsequently, the processed or predicted data stored in the database becomes accessible to users via web-based application, providing them with flexibility in accessing weather information. Through the application, users can obtain precise measurements of various weather parameters and access real-time weather data for informed decision-making.

This study centers on enhancing weather monitoring and early warning systems at the barangay level. The project aims to offer real-time weather alerts. The research adopts a Developmental Research design to innovate effective weather forecasting monitoring systems. Furthermore, a web-based application is developed for data visualization, forecasts, and early warnings. Evaluation via User Acceptance Testing involves officials from the Disaster Risk Reduction Management Office (DRRMO), barangay personnel, and residents to assess system functionality, reliability, and efficiency. This study also employs Descriptive Research Design to analyze and describe the weather-related phenomena and responses.

VI. RESULTS AND DISCUSSION

A. *Weather System Technical Description*

The system integrates a weather monitoring system following a standardized data collection process. The weather monitoring subsystem employs a variety of sensors: a DHT22 sensor for temperature and humidity, a barometric pressure sensor, an anemometer for wind speed, a wind vane for wind direction, and a rain gauge for rainfall intensity. Data from these sensors are transmitted via LoRaWAN technology to a central database, which then displays the information on web and mobile applications in real-time. The system also predicts weather conditions for the next five hours and displays these forecasts on the applications.

B. *Weather System Structure*

The weather monitoring system collects data on temperature, humidity, air pressure, wind speed, wind direction, and rainfall intensity. The figure below shows the weather system structure, which is composed of hydrometeorological sensors, battery management system, and the LoRa technology.

Fig. 2. Developed LIKAS Weather Monitoring System

C. *Signal Strength for LoRaWAN*

TABLE I
COLOR CODING OF SIGNAL STRENGTH

Color			Description
Green	RSSI > -70 dBm	SNR > 10 dB	Excellent connectivity or strong signal strength. Optimal performance and reliable communication.
Yellow	-90 dBm < RSSI ≤ -70 dBm	0 dB < SNR ≤ 10 dB	Moderate connectivity or moderate signal strength. Satisfactory performance.
Orange	-110 dBm < RSSI ≤ -90 dBm	-10 dB < SNR ≤ 0 dB	Fair connectivity or weak signal strength. Occasional connectivity issues. Requires improvement.
Red	RSSI ≤ -110 dBm	SNR ≤ -10 dB	Poor connectivity or very weak signal strength. Potential dead zones. Unreliable communication.
Gray or White	N/A	N/A	Areas where no data was collected or where coverage mapping was not performed.
Green	RSSI > -70 dBm	SNR > 10 dB	Excellent connectivity or strong signal strength. Optimal performance and reliable communication.

The table provides a clear and concise overview of the suggested color-coding scheme for representing different levels of connectivity or signal strength in coverage mapping.

D. Calibration of Sensors

The sensors used in the system undergo calibration at the PAGASA Instrument Calibration Laboratory. This ensures their accuracy and reliability in collecting data, which is crucial for effective monitoring and early warning systems in Bacoor City.

The figures below show the calibration results during the testing of the sensors at the PAGASA Instruments Calibration Laboratory to get accurate data for the forecasting of the weather system.

Calibration Results			
Reference Wind Speed, m/s	Observed Wind Speed, m/s	Correction, m/s	Uncertainty, ± m/s
2.0	1.8	0.2	0.01
5.0	4.0	1.0	0.03
10.1	9.0	1.1	0.05
20.1	19.5	0.6	0.59
25.1	24.0	1.1	0.13

Fig. 3. Calibration Result of Anemometer Sensor for Wind Speed

Calibration Results			
Reference Pressure, hPa	Observed Pressure, hPa	Correction, hPa	Expanded Uncertainty, ±hPa
979.96	980.84	-0.88	0.79
999.97	1000.81	-0.84	0.77
1020.02	1020.85	-0.83	0.80

Fig. 4. Calibration Result of BMP180 Sensor for Air Pressure

Calibration Results			
Reference Temperature, °C	Observed Temperature, °C	Correction, °C	Expanded Uncertainty, ±°C
19.9	19.8	0.1	1.1
29.9	30.2	-0.3	1.1
39.8	40.7	-0.9	1.5

Fig. 5. Calibration Result of DHT22 Sensor for Temperature

Calibration Results	
Simulated Rain Rate (mm/hr)	Percent Error (%)
121.73	-2.60

Fig. 6. Calibration Result of Rain Gauge Sensor for Rainfall Intensity

Calibration Results @ 20°C			
Reference Humidity, %RH	Observed Humidity, %RH	Correction, %RH	Uncertainty, ±%RH
11.5	8.8	2.7	0.88
29.4	33.5	-4.1	0.94
59.3	63.3	-4.0	1.1
91.2	94.0	-2.8	1.4

Fig. 7. Calibration Result of DHT22 Sensor for Relative Humidity

D. Real-time Performance of the Post-Deployment Data

TABLE 2
SUMMARY OF THE WEATHER NODE SYSTEM'S REAL-TIME PERFORMANCE

	Temperature	Humidity	Pressure	Wind Speed	Rainfall
Root Mean Squared Error (RMSE)	2.462	8.772	43.230	3.110	-
Mean Absolute Error (MAE)	1.709	7.604	4.321	1.868	-
Accuracy	99.451	75.458	97.253	99.267	100

The table highlighted the high accuracy of the weather node system, particularly in measuring Temperature (99.45%), Wind Speed (99.267%), Air Pressure (97.253%) and Rainfall with accuracy values close to or at 100%. Humidity measurements, while still fairly accurate, exhibited the highest RMSE (8.772) and MAE (7.604) values compared to other parameters.

The figures below show some gathered data for the comparison of real-time data of the parameters of the weather system at Bacoor City, Cavite and the Automatic Weather Station (AWS) of PAGASA in Science Garden, Quezon City.

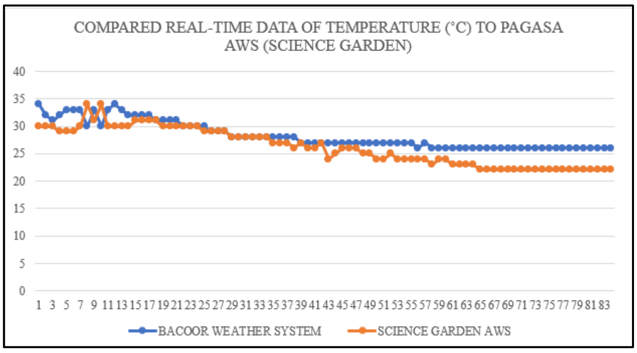

Fig. 8. Compared Real-Time Data of Temperature to PAGASA AWS

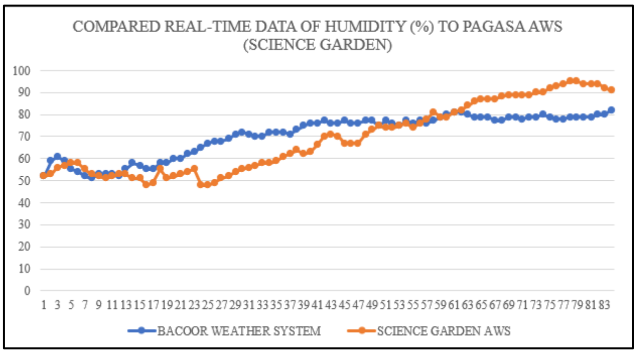

Fig. 9. Compared Real-Time Data of Humidity to PAGASA AWS

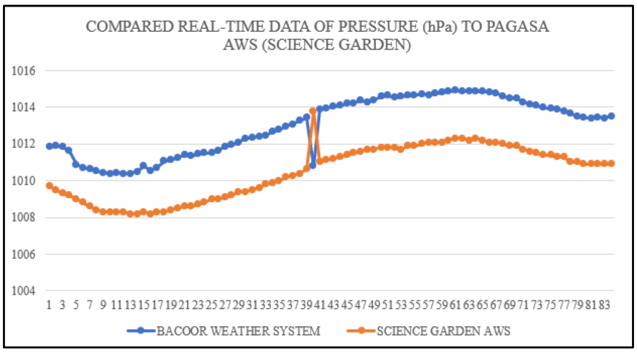

Fig. 10. Compared Real-Time Data of Air Pressure to PAGASA AWS

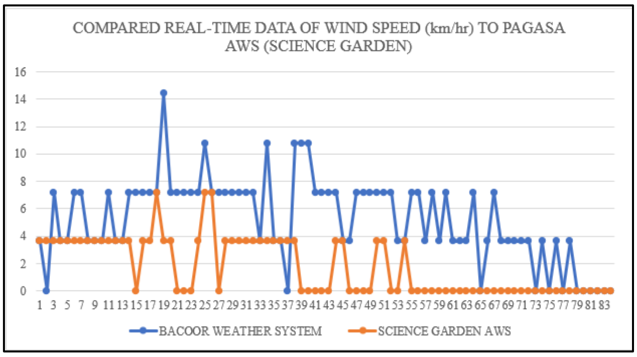

Fig. 11. Compared Real-Time Data of Wind Speed to PAGASA AWS

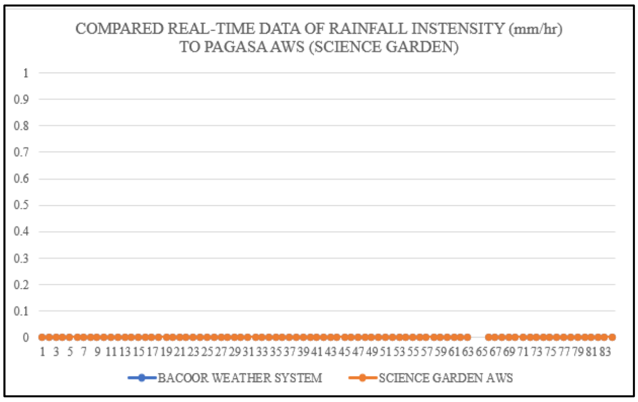

Fig. 12. Compared Real-Time Data of Rainfall Intensity to PAGASA AWS

VII. Conclusion

The goal of this study was to empower communities in the Philippines by developing and implementing a localized weather monitoring and early warning system (EWS) aimed at enhancing disaster preparedness and resilience. This study successfully achieved its objectives:

1. The system utilized LoRaWAN technology and Wireless Sensor Networks (WSN) at the barangay level to monitor critical weather parameters such as temperature, humidity, wind speed, wind direction, and rainfall. The integration of these technologies ensured comprehensive data collection and efficient transmission. The sensors were meticulously calibrated by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), guaranteeing high precision and reliability. This data was transmitted via LoRaWAN to a central database and displayed in real-time on web and mobile applications, providing communities with timely updates and predictions.

2. The system's performance was rigorously tested by comparing real-time weather data collected by the system with data from established meteorological sources. The real-time performance metrics revealed high accuracy and reliability for critical weather parameters. The system exhibited strong performance, particularly in temperature, wind speed, and rainfall measurements, achieving high accuracy rates within the set tolerance limits. Temperature performed 99.4% accuracy, Pressure provided 97.2% accuracy, and Wind speed performed 99.2% accuracy. However, humidity measurements displayed lower accuracy (75.4%), with a notable portion falling outside the ±10 tolerance. Pressure readings, while generally accurate, showed larger deviations in some instances despite most being within the ±3 tolerance. Nonetheless, the system's continuous 10-minute interval data collection ensured frequent updates, enhancing responsiveness and reliability.

Overall, this system's capability to deliver prompt alerts significantly improves disaster preparedness, thereby mitigating the economic and human impacts of natural disasters. Through the utilization of advanced technologies and precise sensor calibration, this localized EWS addresses critical gaps in disaster management, ultimately enhancing safety and resilience among vulnerable populations in the Philippines.

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