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A NOVEL COST-EFFECTIVE PRESSURE SENSOR BASED FLOOD MONITORING SYSTEM WITH IOT

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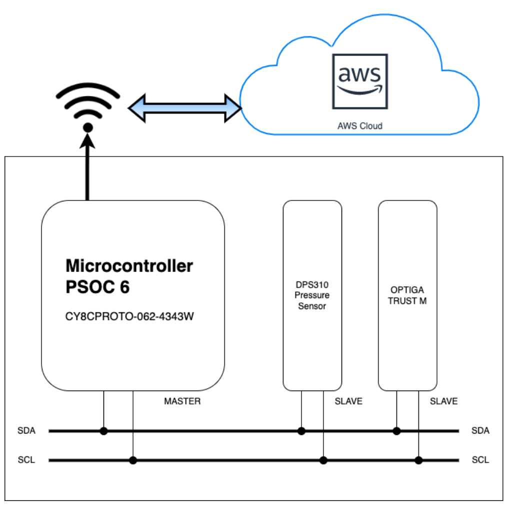
Graphical abstract



Abstract

Floods are one of the most frequent and destructive natural hazards in the world. Early warning and flood monitoring is beneficial in the response and preparedness for this hazard. This paper presents a novel, low-cost flood monitoring system for disaster prevention, based on a pressure sensor. The system comprises a state-of-the-art microcontroller, a pressure sensor, and a security element. It is connected to an Internet of Things (IoT) cloud service, allowing for further data processing, interaction, and storage. The sensor data is processed to provide real-time flood measurements. The calibration data obtained from the designed system demonstrates a linear correlation between the water level and the sensor output. Additionally, the system was able to provide flood level measurements with an average error of 4.08% using the calibration equation, whereas a 4.40% error was obtained when using theoretical equations to determine the flood height.

Keywords: Internet of Things (IoT), Wireless Sensor Networks, Flood Monitoring, Pressure Sensor, Microcontrollers

1.0 INTRODUCTION

Floods are one of the most frequent and destructive natural hazards in the world. Its impact has caused considerable damage to properties, livelihoods, and loss of human lives. Thus, early warning and flood monitoring systems would be beneficial in the response and preparedness for this hazard [1].

Developing countries such as the Philippines are one of the most flood-prone countries in the world, ranking fourth as the most vulnerable to natural hazards such as flash floods [2] [3]. With the country's growth and rapid urbanization, the risk of flooding and its undesired consequences has also increased. In the Philippines, most flooding data is collected manually by observers. However, due to the manual approach, the collected data is prone to incomplete and inaccurate information. This is caused by delays in transmitting raw data to the Central Office, lack of formal training for observers, failure to observe and read data during high floods, and lack of information management [4].

Opportunities for technological solutions to enhance flood response and preparedness are present. These solutions can help in detecting, forecasting, and monitoring floods. Examples of these systems include mobile applications, wireless sensor networks, crowdsourced data, artificial intelligence, and remote sensing.

Efforts are currently underway to incorporate new technological solutions and make these systems available to the wider public. Such systems provide people with access to real-time information on weather conditions in specific areas.

In recent years, the Internet of Things (IoT) has gained widespread usage across various industries, including early warning systems. IoT systems can be used to monitor hazards such as floods and provide early warnings to users. Hazard-prone countries would benefit from digital innovations, such as connected sensors and IoT, in monitoring hazards that have devastating impacts on local communities, such as floods and landslides [5]. Several systems [6, 7, 8, 9, 10, 11] that use IoT-based sensors to measure flood levels have been implemented.

Bączyk et al. compared different sensors for monitoring and measuring water levels [12]. They noted that automatic pressure transducers, rangefinders, and optical and radar sensors are the most commonly used in flood monitoring IoT systems. Pressure transducers are capable of measuring highly accurate water levels and are compatible with most controllers, allowing for real-time data logging and visualizations. However, they require correct calibration and are sensitive to any vertical displacement. Rangefinders, such as ultrasonic sensors, are low-cost sensors that also require calibration and are often non-submersible, making them prone to malfunctions during intensive flooding. Optical and radar sensors are used for monitoring using satellites.

Waleed et al. designed a water level monitoring system based on pressure transducers, using piezoelectric pressure sensors to measure the pressure exerted by water connected to a ZigBee device for data transmission [13]. Yuliza et al. developed a water level measurement system employing a commercial submersible pressure transducer [14]. The pressure sensor is connected to an ATmega 16 microcontroller for data logging, processing, and visualization. Their research concluded that the measurement results obtained using the pressure sensor showed a linear correlation between the water level and its sensor output.

Tolentino et al. implemented a real-time Flood Detection, Alarm, and Monitoring System [15]. Flood levels are calculated through image processing of a captured flood marker. Additionally, their developed system uses multiple linear regression to predict flood levels with inputs from image processing, a rain gauge, a float switch, and a flow rate meter sensor. Once a threshold of flooding risk is reached, users are alerted through a mobile application.

Another system is the Flood Monitoring and Early Warning System by Natividad et al., which uses ultrasonic sensing for real-time flood monitoring. Additionally, it implements an early warning system through web monitoring and SMS notifications [16]. Similarly, Purkovic et al. utilized a low-cost ultrasonic sensor that transmits data every 5 minutes and is capable of measuring water levels with a range of 10 meters and a resolution of 10 mm [17].

Garcia et al. have also developed a Real-Time Urban Flood Monitoring System that consists of a ground-based sensor and a rain gauge [18]. Data logging and telemetry are done using General Packet Radio Service (GPRS) networks, which are then received by a TCP server. The received data is processed to provide real-time information through a web and mobile application.

Canillo et al. has demonstrated the use of Information systems for floods [19]. In this study, it has shown that information systems are becoming vital for managing floods in urban areas providing capabilities such as monitoring and in prediction of flood risk areas.

Despite the rapid growth and proliferation of IoT systems, significant challenges are faced, such as security, reliability, privacy, cost, and complexity [20]. Common to these systems is that they consist of parts such as a sensor, a data processing unit, a transmission unit, and a receiving unit at a control center. The data is then saved in a database run by a computer server, enabling online access to the information. Cloud-based IoT has been surging as a popular and desirable solution to some of these challenges. Cloud and sensor integration solves the issue of storing and processing large volumes of data without increasing the cost of sensor networks and complexity on the part of a control center. However, Cloud IoT performance is limited based on processing capabilities, storage capacity, communication bandwidth, and energy available to sensor nodes [21].

This paper highlights key features of the proposed system, such as modularity, scalability, IoT cloud services capability, and the utilization of a cost-effective pressure sensor, controller and readily available off-the-shelf components to measure flood levels. The novel use of a pressure sensor to measure flood levels provides a new alternative to flood monitoring systems that often rely on more traditional methods like gauges or weather data. Furthermore, the affordability and scalability of this solution makes it a feasible option for a wider range of regions and communities. In addition, leveraging recent advances in IoT and sensing, provides a robust and reliable method for early warning and disaster preparedness. This approach significantly improves the system's ability to facilitate better disaster preparedness, and leading to more effective responses to flooding events, making it a valuable contribution in the field of flood monitoring and disaster management.

2.0 METHODOLOGY

This section describes the methodology employed in the development of the novel pressure sensor-based flood monitoring system. The underlying principles and concept of utilizing pressure measurement for flood level detection are discussed. Then, the implementation of the system through the integration of Internet of Things (IoT) technology is presented, along with the materials employed in the study.

The methodology followed the design procedure for creating a pressure-based flood monitoring system. Figure 1 shows the design and testing process of the design prototype.

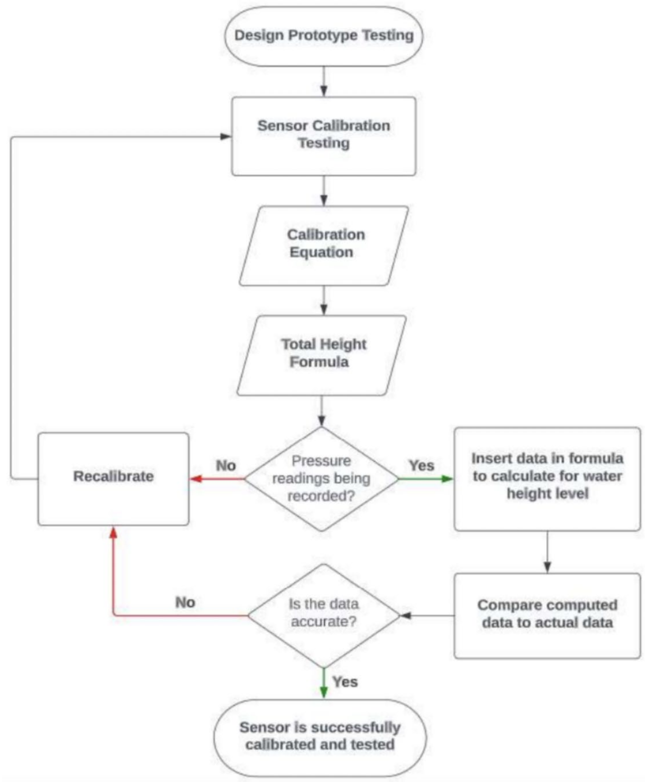


Figure 1 Process of design and testing of the prototype.

2.1 Pressure and Level Concept for Flood Monitoring

The flood monitoring system utilizes a barometric sensor to create an inverse barometer effect within a vessel as illustrated in Figure 2. The Total flood height h_T can be calculated by using Equation (1) below.

$$h_T = h_d + d2 + d3 \quad (1)$$

Where h_d is the difference between the height of the flood waters outside and the water inside the tube. The water inside the tube is represented as $d2$ which is the water from the bottom opening of the tube affected by air pressure. The height of the setup is considered by measuring from the bottom of the tube up to the ground level which is fixed during installation and is represented by $d3$. Using the Fluid Mechanics formula for an open-ended manometer, h_d can be solved by using equation 2.

$$h_d = \frac{P - P_{atm}}{\rho g} \quad (2)$$

where P is the compressed air inside the tube during the rise of flood waters. This is measured by the pressure sensor installed on top of the tube. The atmospheric pressure is represented by P_{atm} which can be obtained by measuring the air pressure before the initial flood water rises. The variables of ρ and g represented as density of water and force of gravity respectively.

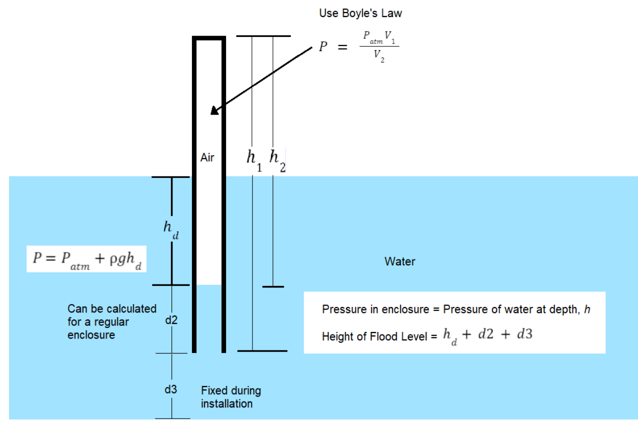


Figure 2 Flood Monitoring concept of water level and pressure

$$d2 = h1 - h2 \quad (3)$$

Where $d2$ is the height of the water inside the tube, h_1 is the height of the tube, and the height of the compressed air is h_2. To determine the height of the compressed air inside the tube, h_2, Boyle's law is used.

$$P_{atm} V_1 = P V_2 \quad (4)$$

P_{atm} is the atmospheric pressure and V_1 is the volume of air in the tube in atmospheric pressure which is the state without flood. P is the pressure of the compressed air inside the tube when the water rises, and its volume is represented as V_2.

Solve for h_2 using Equation (4).

$$h_2 = \frac{P_{atm} h_1}{P} \quad (5)$$

Substituting Equation (4) to Equation (3) to solve for $d2$.

$$d2 = h_1 - \frac{P_{atm} h_1}{P} \quad (6)$$

2.1.1 Formula for Total Height:

Substituting Equation (2) and (5), for Equation (1) to solve for Total flood height h_T.

$$h_T = \frac{P - Patm}{\rho g} + h_1 - \frac{P_{atm} h_1}{P} + d3 \quad (7)$$

As the flood water height increases, the atmospheric pressure outside the pipe remains constant, while the air pressure inside the pipe is compressed due to the rising water level at the bottom opening. This compression of air causes the water inside the tube to be pushed down, resulting in a lower water level inside the tube compared to the actual flood water height outside. This phenomenon is known as the inverted barometer effect.

Conversely, as the air pressure inside the pipe increases, the water level outside the tube rises. The actual height of the flood level can be determined by calculating the difference between the pressure reading obtained from the sensor and the installation dimensions of the system. By considering these factors, the system can accurately estimate the true height of the flood level.

2.2 System Design

The proposed IoT system, illustrated in Figure 3, utilizes the capabilities of the PSOC 6 Microcontroller to support IoT applications. IoT devices are typically designed to be portable, scalable, and power-efficient. In this design, direct cloud connectivity is enabled from the microcontroller itself.

The PSOC 6 Microcontroller is compatible with FreeRTOS, a real-time operating system that ensures secure and reliable integration with AWS cloud services. This compatibility allows for seamless communication between the microcontroller and the cloud, ensuring the efficient and secure transmission of data.

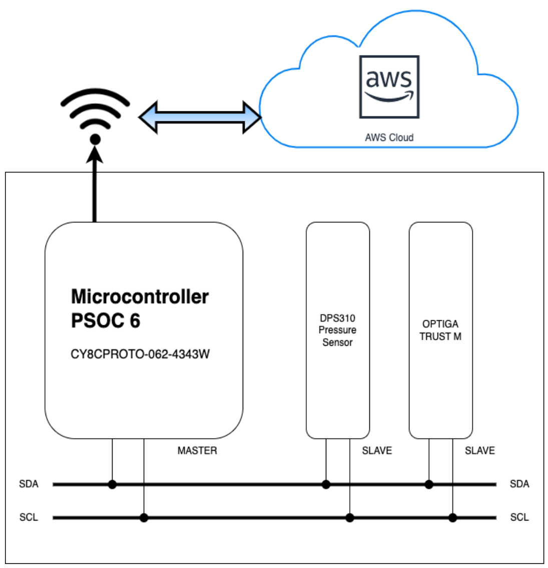


Figure 3 System Architecture of the Flood Monitoring System

Unlike conventional flood monitoring systems that require separate devices for data transmission and collection, the proposed system consolidates these functionalities into a single device. This consolidation simplifies the system architecture and enhances efficiency. The data collected from the DPS310 Pressure sensor and Optiga Trust M module is transmitted through an I2C serial communication bus, which offers low latency and improved efficiency.

Furthermore, the proposed design is scalable, allowing for the addition of additional sensors as needed. Security measures are implemented using the Optiga Trust-M secure element. Additionally, data visualization is achieved through the integration of Grafana with the cloud server, enabling users to visualize and analyze the collected data efficiently.

2.3 Materials

The system built in this research comprises a microcontroller and corresponding sensors to yield pressure-based flood level measurements. This system is designed to be an Internet of Things (IoT) node, connecting to the cloud and enabling real-time monitoring of flood levels. By integrating the microcontroller, sensors, and IoT capabilities, the system allows for continuous and remote monitoring of flood levels, providing valuable information for early warning and disaster management purposes. The overall system was designed to utilize cost-effective off the shelf components, which have the desired features. Table 1 shows the list of materials and their cost as part of the prototype.

Table 1 Cost of Materials

Item	Description	QTY	Cost (USD $)
1	DPS310 Digital Barometric Air Pressure Sensor	1 pc.	8.38
2	CY8CPROTO-062-4343W PSoC 6 Microcontroller	1 pc.	27.87
4	PVC Pipe (Length = 1m, Diameter = 2.54cm)	1 pc.	3.39
6	IP68 Controller Box	1 pc.	7.14
8	Accessories (PVC End Cap (Diameter = 2.54cm))and IP68 Connector Gland	1 set	1.10
9	Misc. consumable items (Teflon, Wires, Heat Shrink Tubing, Pipe clamp etc.)	1 set	23.20
		TOTAL	**71.08**

*Prices converted from Philippine Peso at 1 USD = 56 PHP.

2.3.1 PSOC 6

The main development kit used for the system is the CY8CPROTO-062-4343W (Figure 4). It is based on the PSoC 6 MCU architecture that provides ample processing performance needed by the group's desired IoT device application. he CY8CPROTO-062-4343W is a cost-effective hardware platform capable of supporting applications using FreeRTOS and integrating with Amazon Web Services (AWS) for cloud connectivity.

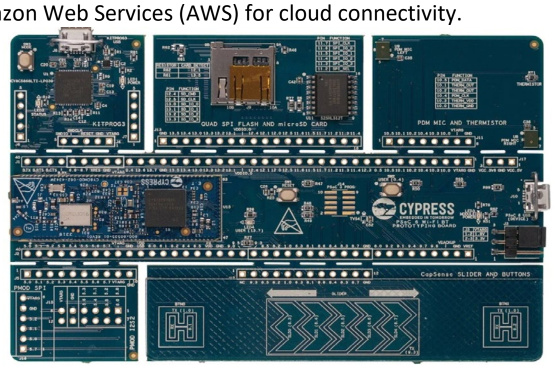


Figure 4 CY8CPROTO-062-4343W Microcontroller. [22]

The prototyping kit is equipped with various interfaces such as UART, I2C, and SPI, allowing easy connection of digital sensors like the DPS310 and other sensors chosen by the researchers. The future addition of features would also be possible due to the board's flexibility and scalability.

For wireless connectivity and communication with the cloud, the kit incorporates the on-board Murata LBEE5KL1DX module, providing Wi-Fi and Bluetooth connectivity. Additionally, the chosen board is designed for ultra-low power consumption, making it well-suited for IoT device applications. The CY8CPROTO-062-4343W development kit ensures a secure, efficient, and straightforward connection between the designed IoT device and cloud services, meeting the requirements of the research.

2.3.2 DPS310

The proposed system incorporates the Infineon DPS310 Digital Barometric Air Pressure Sensor, depicted in Figure 5, as the pressure sensor. This sensor is known for its high accuracy and power efficiency, making it suitable for the intended application. It operates within a range of 300-1200 hPa and offers a precision of ± 0.002 hPa, relative accuracy of ± 0.06 hPa, and absolute accuracy of ± 1 hPa.

Figure 5 DPS310 Digital Barometric Air Pressure Sensor. [23]

The DPS310 sensor is interfaced with the PSOC6 microcontroller using the I2C protocol, allowing for seamless communication between the sensor and the microcontroller. One of the notable advantages of this sensor is its flexibility in terms of measurement precision and rate, which can be adjusted according to the specific requirements of the application. This flexibility contributes to the energy efficiency of the overall system. The sensor provides precise and energy-efficient pressure measurements, which are crucial for accurate flood level monitoring.

2.4 Test Setup

The main test was conducted on March 23, 2023, in a simulated flood environment, with measurements taken at a range of 5 to 11 inches in height. The data sent by the device was recorded and compared to both the theoretical computation and the calibration of the flood height especially in different weather conditions exposed to direct sunlight, rain, and strong wind during the testing phase. The calibration of the pressure sensor was obtained in the prior testing conducted which involved multiple trials of pressure readings inside the laboratory for each increment of water level increase. The calibration curve obtained from these trials was used to determine the calibration of the setup which is used for the main outdoor testing. The accuracy of the formulated flood height formula and calibration equation was evaluated, and the setup was tested at various height levels to assess its impact on the data readings. Sensitivity and accuracy tests were also conducted for the system.

Figure 6 illustrates the outdoor experimental setup of the flood monitoring prototype. A PVC pipe measuring 1 meter in length and 1 inch in diameter was chosen for the calculations. The PVC pipe was securely fastened to a post using clamps, with the bottom part of the pipe in contact with the ground. To ensure precise measurements, a DPS310 sensor was positioned inside the top portion of the tube and connected to the PSOC6 microcontroller. A connector and endcap were installed to effectively seal the top portion of the pipe, ensuring airtightness and protection to the sensor. Figure 8 shows the actual implementation of the pipe.

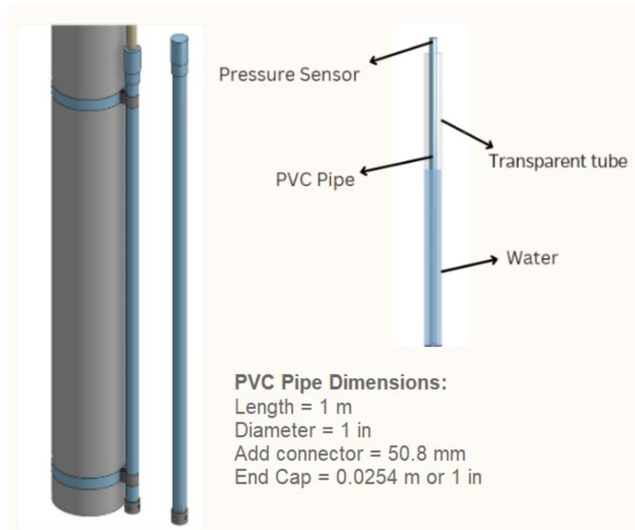


Figure 6. Design of the flood monitoring setup prototype during calibration.

Before conducting the main outdoor testing, a laboratory test with 5 trials was first conducted in order to determine the calibration of the setup. The calibration is necessary in order to determine the sensitivity which will be used to create a new equation for flood height measurement. The calibration was done with the use of transparent tubing with measurements in inches for water level measurement, conducted inside the laboratory to ensure controlled conditions. The transparency of the tube enabled clear visual observation and accurate measurements of the water level. The tube acted as a controlled environment where the PVC pipe could be fully submerged, simulating a flooded scenario. The tube acted as a controlled environment where the PVC pipe could be fully submerged, simulating a flooded scenario. The height of the pipe matched that of the prototype being examined. The experimental setup covered a measurement range from 0 to 30 inches in height, with precise 0.5-inch increments at each level. This systematic approach allowed for meticulous evaluation and analysis of the water level measurements, facilitating a comprehensive understanding of the prototype's performance in varying conditions.

The calibration process for the flood monitoring prototype involved establishing a relationship between the pressure readings (y variable) in millibars and the corresponding actual height of floodwater (x variable) measured in inches. A series of 5 trials as shown in Figure 8 were conducted to calibrate the prototype, with each trial spanning from 0 inches (representing atmospheric pressure) to 30 inches of total height, in increments of 0.5 inches. In total, 60 water levels were measured during the calibration process. For each level, the pressure sensor was given at least 10 seconds of soak time to stabilize the reading.

Figure 7. PVC pipe and pressure sensor setup

3.0 RESULTS AND DISCUSSION

By analyzing the collected data points after conducting 5 trials, a calibration equation was derived to accurately relate pressure readings to the actual height of the flood water. Figure 9 shows the line graph created from the average of the trials obtained from the calibration process. The equation y = 2.2227x + 1009.8 was obtained.

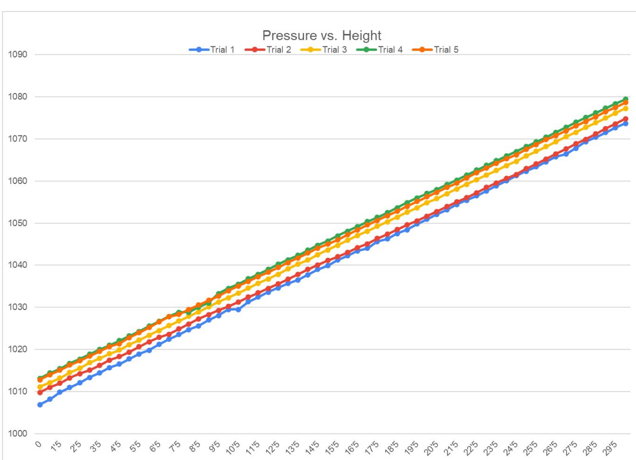


Figure 8 Calibration measurements of pressure vs. height obtained in 5 trials

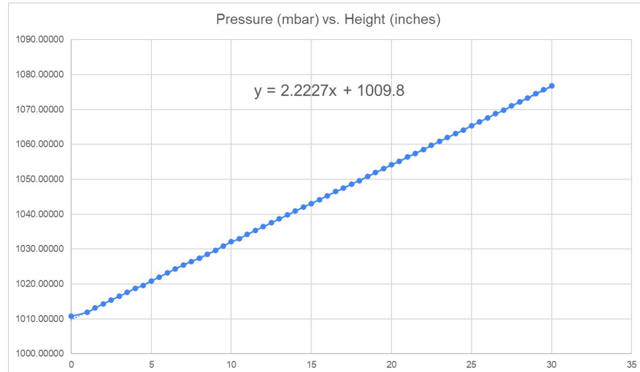


Figure 9 Calibration Curve from the average of 5 trials

The slope of the calibration, y = 2.2227x + 1009.8 is 2.2227 which is determined as the sensitivity of the 1-meter tube experimental setup. Therefore, for every additional inch of water level outside the tube, there is a corresponding increase in pressure of 2.2227 millibar. A new and simplified formula can be created using this sensitivity by finding the difference between the current pressure reading, P, and the current atmospheric pressure, P_{atm}, then dividing it by the sensitivity to solve for the flood height. This calibration equation is expressed as:

$$h = \frac{P - P_{atm}}{2.2227} \tag{8}$$

h = flood height (inches)
P = current pressure obtained from the sensor (millibar)
P_{atm} = atmospheric pressure

An actual setup exposed to the environment was done to assess the robustness and reliability of the prototype's design setup. The outdoor testing was done on March 23, 2023. This allowed for the prototype to be exposed to varying weather conditions such as direct sunlight, rainfall, and various wind speeds for the duration of the testing period. These factors during testing helped confirm that the sensor was able to obtain accurate readings despite the different environmental conditions. Figure 10 shows the entire setup installed into a post located along Taft Avenue, Manila.

Figure 11 displays the data obtained from the outdoor testing procedure which shows line graphs of pressure and water height. The topmost graph displays the pressure data obtained in millibars throughout the testing period which were used to obtain the calibrated and theoretical height. The bottom graph shows the actual, theoretical, and calibrated height for comparison. The actual water level inside the cylinder is represented by dark green text, while the computed value of the water level using the calibration equation was denoted by blue text. The computed value using the Total Flood Height Formula which is the theoretical equation was denoted by light green text. The line graph shows the difference between the values of the two equations as well as the accuracy of the data collected. The testing procedure began at 1:00 AM with 5 inches of water inside the tube. This water level remained constant for 12.5 hours until 1:30 PM. Despite the actual water level being 5 inches, the microcontroller computed the level to range between 5.0 and 6.02 inches for the calibration based on the collected pressure data while the total flood height or theoretical formula computed the level to range between 5.0 and 6.01 inches.

Figure 10. Image of the Overall Flood Monitoring system including the microcontroller box during field testing

For the continuation of the testing phase, random water level values were added every 30 minutes starting from 1:30 PM to 9:00 PM. An additional inch of water was added, and the sensor provided measurements for both the calibration and the total flood height formula. For a water level of 6 inches, the calibration yielded a measurement of 6.03 inches, while the flood height formula indicated 6.02 inches. Similarly, when the water level reached 6.5 inches, the calibration showed 6.39 inches, and the flood height formula indicated 6.38 inches. Additional observations revealed that a water level of 8.25 inches corresponded to a calibration measurement of 8.1 inches and a height formula measurement of 8.07 inches. At 9 inches, the calibration indicated 8.79 inches, while the theoretical formula yielded 8.80 inches. A water level of 9.5 inches resulted in 9.9 inches for both calibration and the theoretical flood height formula. Finally, at 10.5 inches, the calibration range was calculated as 10.58 to 11.25 inches, while the formula yielded a range of 10.53 to 11.2 inches.

At approximately 9:00 PM, the tube was drained, leaving around 6 inches of water for the sensor to measure. During this condition, the readings ranged from 6.26 to 5.67 inches for the calibration and a range of 5.66 to 6.25 inches were computed using the theoretical or flood height formula.

Based on the gathered data, the average percentage error for the calibration was determined to be 4.08% while the error for the total flood height formula was 4.40%. The findings provide crucial insights into the performance of the flood monitoring prototype and highlight the need for the calibration equation for better accuracy of the water level measurements.

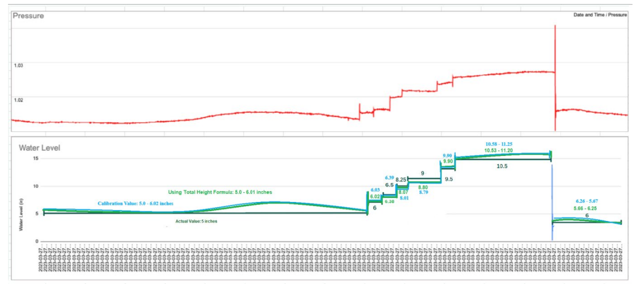


Figure 11 Data Curve gathered from Home Simulation

Grafana is configured with users and can show live data which refreshes every 20 seconds. The DPS310 is set to collect data and can be viewed via desktop or mobile devices.

Figure 12 shows the different graphs presented by the Grafana website in desktop view which are separated into three parts with the topmost presenting the current flood height calculation in inches using the calibration equation while the middle graph presents the current pressure reading in bars which were used to compute the height using the theoretical equation. Each pressure measurement has a corresponding temperature value in degrees Celsius which is presented in the bottom-most graph. This is measured using the DPS310 sensor. The measurements were acquired during the testing of the prototype in a specific location. The data presented by the Grafana website can also be presented in a mobile view as shown in Figure 13 which serves as an alternative to the desktop view.

Figure 12 Desktop View of Grafana Website

Figure 13 Mobile View of Grafana Website

The gathered data from the tests provided valuable insights into the performance and limitations of the flood monitoring system. While the project prioritized cost-effectiveness over absolute accuracy, the data comparisons and evaluations still demonstrated correlations between the obtained readings, theoretical measurements, and actual flood height. This indicates that the project was able to successfully measure the height of different water levels inside the tube using the data obtained from the pressure sensor.

4.0 CONCLUSION

This study developed a cost-effective IoT-based flood monitoring system that utilizes a pressure sensor. By utilizing and calibrating this pressure sensor, the system measured the water levels in real time and provided valuable data for flood monitoring. The integration of IoT has allowed the system to transmit data and be controlled and monitored remotely. Grafana was used as a data visualization tool that enables users to analyze and interpret the collected data. This allows for better understanding and more efficient visualization of flood patterns and trends. The researchers were able to gather data from the pressure sensor and transfer it to the cloud. The obtained data, which consisted of pressure readings, was used to calculate the water height level using calibration equation and theoretical formula, resulting in 4.08% and 4.40% average error respectively. The developed system has the potential to be implemented in different regions, providing valuable information and insights to flood monitoring authorities, emergency response teams, and communities at risk. Future studies to further develop the accuracy of the sensor system and IOT communication can expand upon these findings to further enhance the system's functionalities and capabilities to aid in flood monitoring and emergency response.

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References

[1] Asian Development Bank, 2022 “Nature-Based Solutions for Flood Risk Management: Revitalizing Philippine Rivers to Boost Climate Resilience and Enhance Environmental Sustainability,” [Online]. Available: https://www.adb.org/sites/default/files/publication/774721/revitalizing-philippine-rivers-climate-resilience.pdf [Accessed: January 2023]

[2] Republic of the Philippines and the Commonwealth of Australia (Geoscience Australia), 2014 “Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area: Summary Report,” [Online]. Available: https://ndrrmc.gov.ph/attachments/article/1509/Executive_Summary_of_RAP_Technical_Report.pdf [Accessed: January 2023]

[3] Eckstein D., Künzel V., and a Schäfer L., 2021. Global Climate Risk Index 2021: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2019 and 2000-2019, [Online]. Available: https://germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202021_1.pdf [Accessed: January 2023] https://doi.org/10.1038/s41586-018-0776-9

[4] Japan International Cooperation Agency (JICA), 2004 “The Study On Flood Control Project Implementation System For Principal Rivers In The Philippines,” [Online]. Available: https://openjicareport.jica.go.jp/pdf/11775665.pdf [Accessed: January 2023]

[5] GSMA, 2022 “Early Warning Systems in the Philippines: Building resilience through mobile and digital technologies,” [Online]. Available: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2022/06/PhilippinesEWS_R_Web.pdf [Accessed: January 2023]

[6] Thekkil, T. M., & Prabakaran, N. 2017. Real-time WSN based early flood detection and Control Monitoring System. *2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)*. https://doi.org/10.1109/icicict1.2017.8342828

[7] Prakash, C., Barthwal, A., & Acharya, D. 2023. Floodwall: A real-time flash flood monitoring and forecasting system using IOT. *IEEE Sensors Journal*, *23*(1): 787–799. https://doi.org/10.1109/jsen.2022.3223671

[8] Deowan, M. D. E., Haque, S., Islam, J., Hanjalayeamin, M., Islam, M. T., & Tabassum Meghla, R. 2022. Smart early flood monitoring system using IOT. *2022 14th Seminar on Power Electronics and Control (SEPOC)*. https://doi.org/10.1109/sepoc54972.2022.9976434

[9] Bande, S., & Shete, V. V. 2017. Smart flood disaster prediction system using IOT & Neural Networks. *2017 International Conference On Smart Technologies For Smart Nation (SmartTechCon)*. https://doi.org/10.1109/smarttechcon.2017.8358367

[10] Saravanan, L., Nancy, W., Chandran, K. P., Vijayanandh, D., Arunkumar, J. R., & Prabhu, R. T. 2022. A novel approach for a smart early flood detection and awareness system using IOT. *2022 8th International Conference on Smart Structures and Systems (ICSSS)*. https://doi.org/10.1109/icsss54381.2022.9782286

[11] Shankar, B. M., John, T. J., Karthick, S., Pattanaik, B., Pattnaik, M., & Karthikeyan, S. 2021. Internet of things based Smart Flood Forecasting and early warning system. *2021 5th International Conference on Computing Methodologies and Communication (ICCMC)*. https://doi.org/10.1109/iccmc51019.2021.9418331

[12] Arshad, B., Ogie, R., Barthelemy, J., Pradhan, B., Verstaevel, N., & Perez, P. 2019. Computer vision and IOT-based sensors in flood monitoring and mapping: A systematic review. *Sensors*, *19*(22): 5012. https://doi.org/10.3390/s19225012

[13] Al-Assadi, W. K., Gandla, S., Sedigh, S., & Dugganapally, I. P. 2009. Design of a flood prediction system. *2009 12th International IEEE Conference on Intelligent Transportation Systems*. https://doi.org/10.1109/itsc.2009.5309516

[14] Nurrahman, M. R., Cakti, A. G., Misrano, K., Yuliza, E., & Khairurrijal, and K. 2019. Realization of null-type bridge instrument to determine water level to anticipate flood using inquiry-based learning. *Journal of Physics: Conference Series*, *1204*: 012080. https://doi.org/10.1088/1742-6596/1204/1/012080

[15] Tolentino, L. K., Baron, R. E., Blacer, C. A., Aliswag, J. M., De Guzman, D. C., Fronda, J. B., Valeriano, R. C., Quijano, J. F., Padilla, M. V., Madrigal, G. A., Valenzuela, I., & Fernandez, E. 2023. Real time flood detection, alarm and monitoring system using image processing and multiple linear regression. *SSRN Electronic Journal.* 7(1):12-23. https://doi.org/10.2139/ssrn.4319789

[16] Natividad, J. G., & Mendez, J. M. 2018. Flood monitoring and early warning system using ultrasonic sensor. *IOP Conference Series: Materials Science and Engineering*, *325*: 012020. https://doi.org/10.1088/1757-899x/325/1/012020

[17] Purkovic, D., Coates, L., Honsch, M., Lumbeck, D., & Schmidt, F. 2019. Smart River Monitoring and early flood detection system in Japan developed with the EnOcean Long Range Sensor Technology. *2019 2nd International Colloquium on Smart Grid Metrology (SMAGRIMET)*. https://doi.org/10.23919/smagrimet.2019.8720390

[18] Garcia, F. C., Retamar, A. E., & Javier, J. C. 2015. A real time urban flood monitoring system for metro manila. *TENCON 2015 - 2015 IEEE Region 10 Conference*. https://doi.org/10.1109/tencon.2015.7372990

[19] Canillo, L. J., & Hernandez, A. A. 2021. Flood risk visualization and prediction information system: Case of city Manila, Philippines. 2021 IEEE 17th International Colloquium on Signal Processing & Its Applications (CSPA). https://doi.org/10.1109/cspa52141.2021.9377276

[20] Nunoo-Mensah, H., Boateng, K. O., & Gadze, J. D. 2017. Tamper-Aware authentication framework for Wireless Sensor Networks. *IET Wireless Sensor Systems*, *7*(3): 73–81. https://doi.org/10.1049/iet-wss.2015.0131

[21] Kumar, S., Tiwari, P., & Zymbler, M. 2019. Internet of things is a revolutionary approach for future technology enhancement: A Review.

Journal of Big Data, 6(1):111. https://doi.org/10.1186/s40537-019-0268-2

[22] Infineon Technologies. 2021. CY8CPROTO-062-4343W - Infineon Technologies.https://www.infineon.com/cms/en/product/evaluation-boards/cy8cproto-062-4343w/ [Accessed: January 2023]

[23] Infineon Technologies. 2018. S2GO PRESSURE DPS310 - Infineon Technologies.https://www.infineon.com/cms/en/product/evaluation-boards/s2go-pressure-dps310/[Accessed: January 2023]

[24] Infineon Technologies. 2020. S2GO SECURITY OPTIGA M - Infineon Technologies.https://www.infineon.com/cms/en/product/evaluation-boards/s2go-security-optiga-m /[Accessed: January 2023]