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Development and Implementation of an IoT-Based Early Flood Detection and Monitoring System Utilizing Time Series Forecasting for Real-Time Alerts in Resource-Constrained Environments

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ABSTRACT

Flooding is a recurrent natural catastrophe in Malaysia, demanding excellent early warning and monitoring systems to reduce the impact on those affected. Traditional flood monitoring systems have severe limitations, including reliance on human data gathering, a lack of real-time capabilities, expensive prices, and slow response times, particularly in developing countries. To solve these issues, this research aims to design an Early Flood Detection and Monitoring System that uses Internet of Things (IoT) technology to provide a cost-effective, efficient, and real-time solution for detecting increasing water levels and sending early alerts. The system uses commonly accessible components such as NodeMCU ESP8266, HC-SRO4 Ultrasonic Sensors, and MAX7219 Dot Matrix Displays to build a sensor network in flood-prone locations. These sensors continually send data to a central processing unit for analysis, and a machine learning model based on Time Series forecasting is used for predictive analysis in the ThingSpeak platform, which is available via an internet dashboard for real-time monitoring. Testing revealed that the system efficiently monitors water levels and sends timely alerts, hence increasing flood readiness and response. Its real-time monitoring capacity guarantees communities receive early information, allowing for proactive flood risk mitigation actions. This study presents a scalable and sustainable solution for improving flood monitoring efficiency and reliability, addressing the limitations of traditional systems and significantly advancing flood preparedness and resilience, thereby supporting effective flood mitigation in resource-constrained environments.

1. INTRODUCTION

Flooding is one of the most common natural disasters worldwide, including in Malaysia. Monsoon floods, which usually occur from October to March owing to the northeast monsoon, are the most serious natural catastrophe danger to Malaysia, notably the east coast, northern Sabah, and southern Sarawak due to the heavy rainfall pattern in Malaysia and how it is influenced by two monsoons as shown in Figure 1. Malaysia, being near the equator, endures regular and severe monsoonal floods, resulting in significant loss of life, property destruction, and infrastructure disruption. According to Hassan et al. [1] , a particularly disastrous flood outbreak in 2014-2015 hit Kelantan, Perak, and Johor, displacing over 200,000 people and killing 21 individuals. This tragedy caused severe damage to buildings, schools, transportation networks, and hospitals, as well as communication interruptions and power outages, with an estimated recovery cost of more over RM1 billion. Furthermore, rapidly expanding metropolitan areas, such as Kuala Lumpur, are also prone to floods due to poor drainage infrastructure. According to Hadi et al. [2], 2009 research projected that roughly 29,800 km², or 9% of Malaysia's total territory, is at danger of floods. This affects nearly 4.85 million people (22% of the population). Over 28% of Malaysians

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blamed the country's inadequate drainage system for the majority of flooding.

To mitigate the impact of floods, early warning and monitoring systems are crucial for providing timely alerts to residents in flood-prone areas. Leveraging IoT technology, this system can deliver accurate real-time flood status by detecting and calculating the water levels rise rate. Additionally, a robust flood detection system was engineered, incorporating a machine learning model to predict floods based on gathered data. This system utilizes an online dashboard for real-time flood monitoring and early warning. A Time Series forecasting machine learning method was employed for predictive purposes. This method involves collecting data, cleaning it, and utilizing relevant information to solve the problem. Flood monitoring and prediction models are essential for risk assessment and management, demonstrating efficiency, reliability, and quick prediction capabilities.

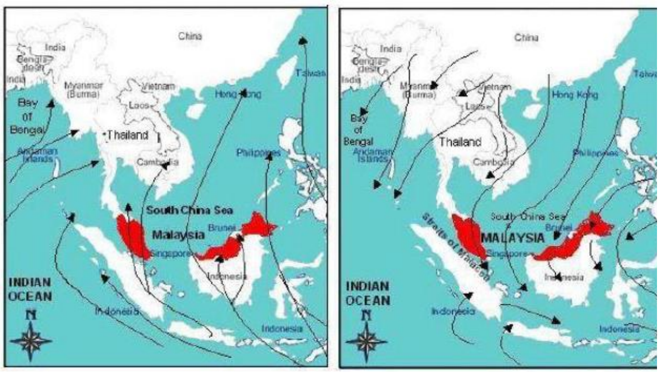

Fig. 1. The rainfall pattern in Malaysia and how it is influenced by two monsoon that are southeast west and northeast monsoon. [1].

Traditional early flood monitoring systems face numerous limitations that significantly reduce their effectiveness. These systems often rely on manual monitoring and data collection, which can be time-consuming and prone to human error, resulting in delayed detection and response times. They typically lack real-time capabilities and depend heavily on historical data, which may not accurately predict future events due to changing climate conditions. The infrastructure required for these systems is costly to install and maintain, particularly in developing regions where resources and technical expertise are limited. Furthermore, traditional systems often lack automated alert mechanisms, leading to slow and ineffective communication during emergencies. Geographical limitations mean that remote or hard-to-reach areas may be inadequately monitored. Data inaccuracies, high operational costs, and inadequate community involvement further impede the effectiveness of traditional systems. Additionally, the limited integration with modern technologies such as the Internet of Things (IoT), machine learning, and real-time data analytics restricts their ability to provide accurate and timely insights. Addressing these limitations is crucial for enhancing flood preparedness and response.

To address this critical issue, the research focuses on developing an Early Flood Detection and Monitoring System that leverages Internet of Things (IoT) technology to offer a cost-effective, efficient, and real-time solution for detecting rising water levels and issuing early warnings. This research introduces an advanced early flood detection system leveraging the Internet of Things (IoT) to revolutionize flood management practices. The proposed system integrates readily available components such as NodeMCU ESP8266, Ultrasonic Sensor, and MAX7219 Dot Matrix Displays to create a robust network of water level monitors. These sensors, strategically placed in flood-prone areas, continuously transmit data to a central processing unit, which analyses the information and triggers alerts when predetermined thresholds are surpassed. This real-time monitoring capability ensures that communities receive timely notifications, allowing for proactive measures to mitigate flood risks.

The Early Flood Detection and Monitoring System aims to revolutionize traditional flood monitoring by leveraging IoT technology to provide real-time, accurate, and automated flood detection. Unlike manual and error-prone traditional methods, this system integrates a network of sensors for continuous monitoring and rapid alert dissemination, ensuring timely and reliable responses to flood threats. Utilizing cost-effective components and a user-friendly dashboard, it is accessible and maintainable in resource-constrained environments. This innovation enhances flood monitoring efficiency, promotes community engagement, and supports skill development. By addressing the limitations of traditional systems, this work significantly advances flood preparedness and resilience, offering a scalable and sustainable solution for effective flood mitigation.

Therefore, this work uses a structured method to investigate the development of an early flood detection and monitoring system. Section 1 outlines the system's background, concept, and objectives. Section 2 examines existing research and methodologies to flood anticipation, monitoring, and forecasting. Section 3 describes the proposed methodology and technique, which includes the system's design, hardware modelling, prediction analysis, real time monitoring and PCB implementation. Section 4 details the proposed system's testing and outcomes. Finally, Section 5 highlights key results and conclusions, adding to scholarly discussion on early flood detection and monitoring systems.

2. Literature Review

Various research has focused on the development and implementation of computer approaches for successfully predicting, monitoring, and forecasting flood events. This substantial component of study has focused on the essential element of early flood detection, investigating a wide variety of detection parameters, devices, systems and their potential contributions to accurate and timely flood warnings. Key areas of focus include the hardware modelling of the flood detection system, the detection method applied in the research, and the monitoring system used to display, issue alert warnings, and anticipate future flood events.

2.1 Hardware Modelling

The use of IoT-based systems has garnered significant attention for their ability to collect and transmit data autonomously. For instance, [2] demonstrated a system using the NodeMCU ESP8266 as the computing core, coupled with an Ultrasonic sensor (DFR 3280) for water level monitoring and GPS Neo-6M for precise geolocation. This system enabled real-time flood data collection and alerts in vulnerable areas. Similarly, [3] proposed an Arduino Nano-based design integrated with a LoRa wireless sensor network for data transfer, utilizing an ultrasonic sensor (HC-SR04) for water level detection and a dissolved oxygen sensor to analyse water quality.

In a unique approach, [4] developed an SMS-based monitoring system using an Arduino Uno and GSM module for communication. This design incorporated an ultrasonic sensor for real-time water level measurements and a barometric pressure sensor (SM5100B) to detect atmospheric pressure changes, which provided early indicators of potential rainfall and flooding. By monitoring these changes, the system enhanced predictive capabilities for timely flood response.

While most studies focused on water level monitoring, [5] added a soil moisture sensor to detect water saturation, an early sign of flooding. This addition improved prediction accuracy and supported proactive management strategies. Additionally, [6] integrated rainfall and water flow sensors with a NodeMCU microcontroller to assess hydrological conditions comprehensively. Rainfall sensors captured precipitation rates to predict runoff, while water flow sensors measured the volume and speed of water entering reservoirs, offering critical insights for upstream flood management.

2.2 Detection Method

Flood detection systems often utilize sound wave-based methods, relying on ultrasonic sensors primarily the HC-SR04. These sensors emit high-frequency sound waves and measure the time taken for the echoes to return, enabling accurate determination of water levels. By continuously monitoring water depth and transmitting data via GSM modules, this approach facilitates real-time flood detection and early warnings, aiding timely responses [1][7].

Pressure sensors are another widely used method, measuring hydrostatic pressure exerted by water. For example, [8] employed a WL400 water level sensor integrated with an ATmega microcontroller and GSM module. The WL400 converts water pressure into electrical signals, providing accurate water depth readings that are transmitted to central monitoring systems for immediate analysis and alerts.

Image processing algorithms offer an alternative by analyzing visual data from cameras or satellites to identify and map flooded areas. [9] developed an image-based flood alarm (IFA) system comprising a module to segment images into foreground (water) and background (landscapes or structures) and a detection module to assess flood severity and issue alerts. Similarly, [10] utilized image comparison techniques such as Scale Invariant Feature Transform (SIFT) and Binary Robust Independent Elementary Features (BRIEF) to enhance object detection and flood monitoring accuracy.

Machine learning is increasingly used to enhance flood detection and forecasting capabilities. Models trained on historical flood data and weather patterns enable reliable predictions of flood events. [11] explored machine learning techniques, including Artificial Neural Networks (ANN), Long Short-Term Memory (LSTM), and Gated Recurrent Units (GRU), using six years of precipitation and flow data from gauging stations. These methods identified patterns indicative of potential flood events, improving forecasting accuracy and decision-making.

2.3 Monitoring System

Reliable monitoring systems are essential for flood prevention, providing real-time data and timely notifications that enable proactive measures to mitigate flood risks. Cloud-based platforms have become a cornerstone of these systems due to their scalability, dependability, and advanced analytics capabilities. These platforms facilitate the storage, processing, and analysis of large volumes of sensor data, while also enabling collaboration among flood management stakeholders [12].

IoT platforms such as Blynk offer user-friendly interfaces for monitoring devices, displaying real-time water level data, setting alarms, and creating customizable dashboards. Studies have demonstrated the use of Blynk to remotely monitor flood conditions and send alerts based on preset thresholds [2][5]. Similarly, [13] utilized the ThingSpeak platform for data collection, storage, and visualization. By integrating ThingSpeak with Twitter, researchers broadcast flood warnings to a wider audience. Other implementations, as per mentioned in [14], paired ThingSpeak with a custom Android application to monitor environmental parameters and send SMS notifications to users.

Alternative tools such as PLX DAQ allow for real-time data collection and analysis from various sensors. When combined with websites, PLX DAQ enables the development of comprehensive flood monitoring systems, providing users with updates on water levels, rainfall intensity, and other critical parameters [15].

3. MATERIAL AND METHODS

The IoT-enabled early flood detection and monitoring system integrates a flood prediction feature using time series analysis. Figure 2 below is the flowchart of the whole system, while Figure 3 briefly shows the system's basic principle. The entire system begins with an ultrasonic sensor that continually analyses water levels and growth rates. The system then uses the ESP8266 NodeMCU as its principal microcontroller, which links all sensors via Wi-Fi. The alarm system contains a buzzer and LEDs (red for high water levels and green for safe levels). The data is transmitted to ThingSpeak for analysis. The circuit diagrams of the proposed systems illustrate the physical arrangement of electrical components, shown in Figure 4.

3.1 Hardware Modelling

Hardware implementation of the early flood detection and monitoring system includes an HC-SR04 ultrasonic sensor to measure water levels, an ESP8266 NodeMCU for data processing and transmission, and alert components (LEDs and buzzer). When water levels are at safe level, the green LED activate, and the display module shows "Normal" as shown in Figure 5 (a). Meanwhile, the HC-SR04 ultrasonic sensor assists in the continuous monitoring of water level and growth rate since the sensor is based on the sonar principle and is used to determine the distance between the water and the sensor, shown in Figure 5 (b).

ESP8266 NODEMCU was selected to be used in the role of the microcontroller which is an open-source microcontroller board. ESP8266 NODEMCU is an open-source platform based on the ESP8266 that allows things to be connected and data to be transferred using the Wi-Fi protocol.

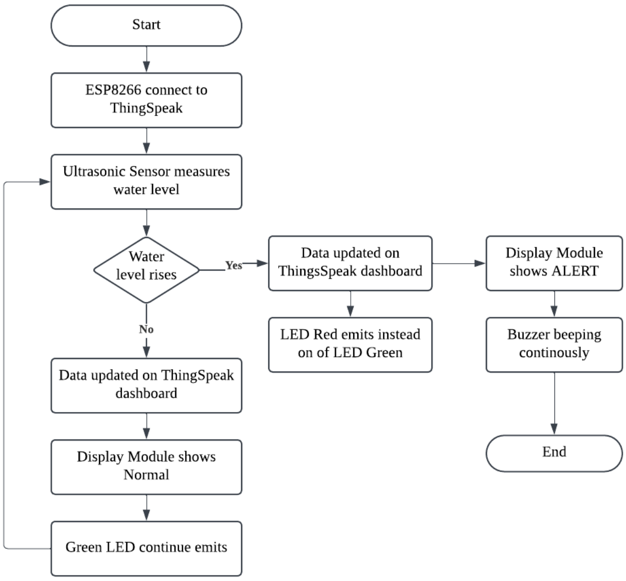

Fig. 2. Flowchart of the system.

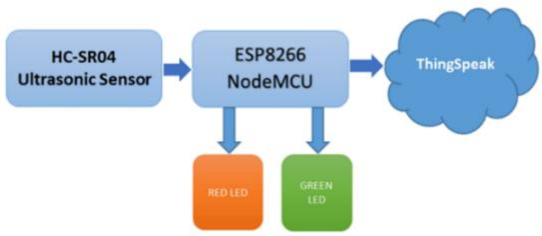

Fig. 3. Block diagram of the system.

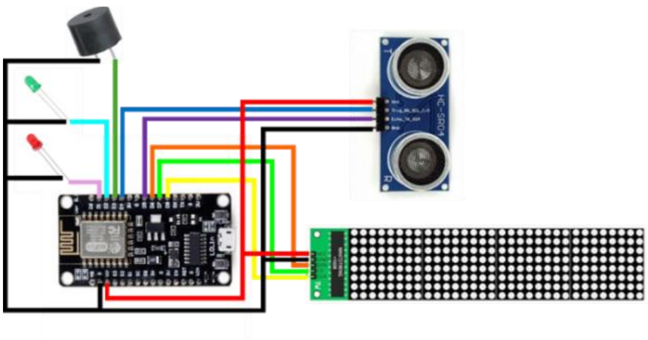

Fig. 4. Circuit diagram of the system

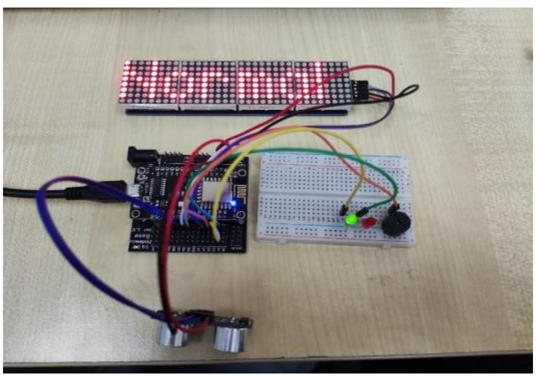

Fig. 5(a). Hardware implementation of the system.

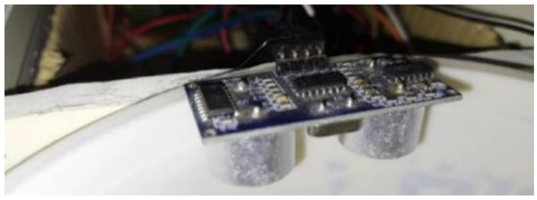

Fig. 5(b). Implementation of ultrasonic sensor in the system.

The board has some digital and analog input/output pins that can be used to connect to expansion boards and other devices. This alert system consists of a Buzzer, one red and one green LED. When the measurements of sensors are at a predetermined point and the LED lights turn on and the buzzer starts to beep. The device has a two-step alert system. The alert systems depend on the measurements of the sensors. If the device senses that the water level is increasing, then the green LED light turns on. If the device senses nearing water and the output of ultrasonic sensor measurement is over 20 cm (in this case), the Buzzer starts to make a sound, and the red LED light turns on. The outputs are shown in the Dot Matrix Display Module.

3.2 Prediction Analysis

In the work, time series forecasting, a machine learning technique is implemented to forecast or predict future flood events based on the runtime data. To analyse, the prediction model uses data in the form of a dataset to forecast flood risk. MATLAB was utilized to do time series analysis on runtime data for prediction. The time series forecasting model records data points at fixed intervals over a set length of time rather than intermittently or arbitrarily. The Linear Parametric model was specifically used as the time series model. It estimates parameters in structures such as autoregressive models and state-space models. A linear time series model might be polynomial (poly), state-space (less), or greyscale (grey). The recognized models can be used to anticipate model output at the command line, in the app, or Simulink®. Users can also forecast model outputs beyond the temporal range of the measured data from the command line. A machine learning output has created MATLAB. For predicting flood events, MATLAB was used to learn from a large number of flood detection-related runtime data from the device. At first, MATLAB reads data from the Thing speak server where the flood detection systems data are stored. Data includes water level, rain, temperature, humidity, and water increase rate. Output data obtained from certain 15 days were taken from the server.

For water level prediction, x axis was set as data time and y axis was set as water level to set up a curve. The polyfit MATLAB function was used to compute a least-squares polynomial for a given set of data. It generates the coefficients of the polynomial, which is used to model a curve to fit the data. The input is used to predict the next data flow represented by a curve. In the next step, the future deadline for flood working on or prediction was fixed. In this case, prediction on the next 10 days flood situation was warranted. Forecasting is done through polyval function.

Polyval computes the value of a polynomial for a given collection of x values. As a result, Polyval constructs a curve to fit the data based on the coefficients discovered by polyfit. That curve will represent the high and low of water level work on the next few days selected previously based on past runtime data. Then, the curve figure is plotted over future time and forecasted value. Hold on functions are used to retain plots in the current axes so that new plots added to the axes do not delete previously existing plots. Now, the figure is set as hold off functions used to set the hold state to off so that new plots are added to the axes that clear existing plots resetting all axe's properties. Label was set as 'cm' as it represents water level on the horizontal axis and y as 'date' as it represents the time flow on a vertical axis. Similarly, time series analysis was tested to implement rainfall forecast, humidity forecast, temperature forecast, and water increase rate forecast based on the previously gathered runtime data. The labels were set to necessary and related values to plot the output curve. Lastly, the output of the model for respective fields was obtained which were curve representations of data points such as humidity, temperature, water level, and others at fixed intervals over a set length of time which is the runtime duration. Sensor data and prediction results are updated on the ThingSpeak server.com server, where all the data is stored

3.3 *Real Time Monitoring*

This work requires stable internet connection. Once the microcontroller successfully connects to Wi-Fi, it facilitates the transmission of sensor data to the ThingSpeak platform as shown in Figure 6. This real-time data transmission is integral for monitoring and analysing flood conditions, ensuring timely alerts and interventions. Hence, the ability of the system to connect to Wi-Fi and communicate its status via the Dot Matrix Module.

Next are the operational mechanics and alerting system of the Early Flood Detection System, specifically focusing on the real-time distance measurements recorded by the ultrasonic sensor. These measurements are crucial for the system's ability to monitor water levels and anticipate potential flooding.

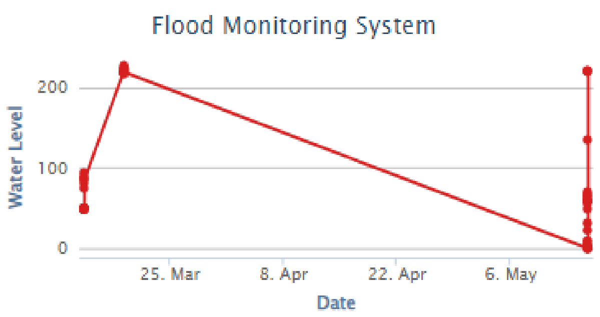

Fig. 6. Displayed Water Level in ThingSpeak dashboard.

The ultrasonic sensor continually captures distance data, which is then displayed in real-time. The primary objective of the system is to use these distance measurements to assess the risk of flooding. When the sensor records a distance greater than the predefined threshold set in the code, it signifies a safe condition. In this state, the water level is sufficiently low, posing no immediate threat of flooding. However, when the distance measured by the sensor falls below the specified threshold, it signals a potential risk. The system is programmed to respond immediately to this condition by triggering an alert. This alert system is designed to be both visual and auditory to ensure that it captures attention promptly. The buzzer sounds an alarm, and simultaneously, the Red LED will show the "ALERT" sign, both serving as clear indicators of a potential flood situation

3.4 *PCB Implementation*

In addition to the prototype using breadboards and jumper wires, a printed circuit board (PCB) version of the work was also developed to enhance the reliability and robustness of the system. The transition from a breadboard-based prototype to a PCB-based design addresses several critical aspects of the work.

The PCB design integrates all components into a single board, which simplifies assembly and reduces the potential for loose connections. This integration ensures that all connections are solid and minimizes the risk of disconnections that could occur with breadboards and jumper wires.

The PCB layout was created using Eagle, a CAD software by Autodesk. The design process involved creating schematic diagrams, laying out the PCB, and routing connections between components. The CAD software provided precise control over the placement of components and the routing of electrical connections, ensuring an optimal design for both functionality and manufacturability.

The PCB was fabricated using standard industry processes, including copper etching, drilling, and applying solder masks. Components were then soldered manually or through automated assembly for consistent and reliable connections compared to breadboards. Rigorous testing followed to verify sensor readings and ensure LEDs and buzzers responded correctly to water level changes. Any issues identified were addressed through iterative refinements.

The PCB design enhances system durability and suitability for real-world environments. Its robust construction withstands environmental factors better than prototypes and allows for protective enclosures, making it ideal for outdoor deployment. The compact layout supports scalability and mass production, ensuring consistent quality and reliable performance across multiple units for large-scale flood monitoring.

4. EXPERIMENTAL RESULT

A display module is used to display all of the warnings throughout the environment, mainly regarding the water level increase rate. When the sensor measures a distance below the set threshold, it signals a potential flood risk. The system responds immediately with visual and auditory alerts: the buzzer sounds, and the red LED displays an "ALERT" sign, effectively notifying users of the danger as shown in Figure 7.

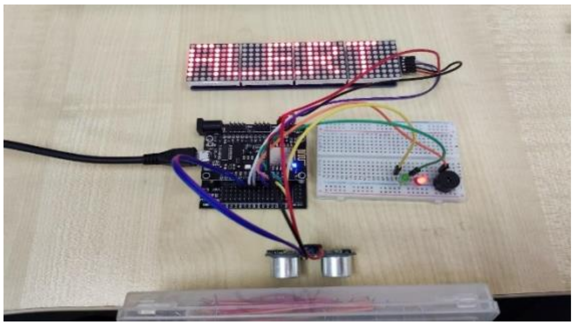

Fig. 7. System detects near object which indicates the functionality of the ultrasonic sensor.

4.1 Flood Detection Results

Leveraging IoT technology in the system, real-time water level data was acquired at specified intervals using specific sensors and wirelessly communicated to a ThingSpeak cloud platform for centralized storage and administration. The corresponding time-series dataset, shown in Figure 8, gives a detailed record of water level variations across the monitoring period.

Fig. 8. Uploaded detection results of water level in the thingspeak.com server.

4.2 Prediction Results From MATLAB

The time series forecasting model utilized historical water level data collected at fixed intervals. This data, represented as a curve, served as input to predict future water level fluctuations. The model aimed to identify high and low water levels for the coming days based on the analysed historical patterns. The predicted water level data, along with the sensor measurements, were continuously updated and stored on the ThingSpeak server for further analysis.

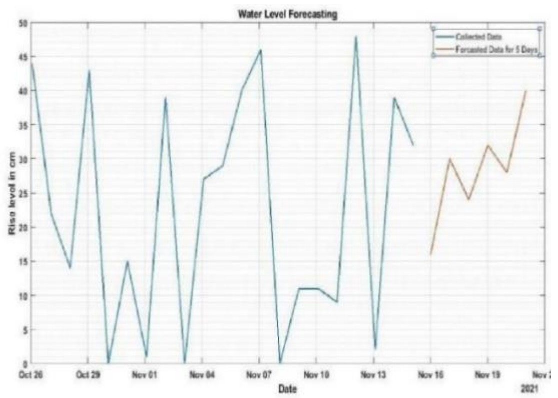

Figure 9. Output result of water level prediction.

As shown in Figure 9 of water level prediction curve output from MATLAB's Time Series Forecasting model, the green curve shows ThingSpeak sensor runtime statistics of collected data and the red curve is the predicted water level by the model. Water level and humidity are on "x", and time is on "y." The curve shows the expected humidity and water level on November 19: 80% and 35 cm, respectively. That means there is a high chance of flooding in that area.

5. Conclusion

In conclusion, this work presents a cost-effective and scalable IoT-based early flood detection and monitoring system that combines real-time water level monitoring with predictive analysis using time series forecasting. The system addresses critical gaps in traditional flood monitoring systems, such as delayed alerts and limited real-time capabilities, making it highly suitable for resource-constrained environments. By providing timely and reliable alerts, this system enables proactive decision-making and reduces the risk of flood-related damages.

The findings have significant implications for flood management practices. The adoption of such systems can enhance community resilience by improving preparedness and response times. Furthermore, its cost-effectiveness and scalability make it feasible for widespread deployment, particularly in rural and economically disadvantaged regions where advanced flood detection systems are often inaccessible.

To further enhance the system, future research could explore such as implementing advanced prediction models and multi hazard detections to provide comprehensive risk assessments. These detections may vary on multiple environmental parameters, such as rainfall intensity, soil saturation, and wind speeds.

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