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An IoT-Enabled LoRa-Based Intelligent Flood Detection and Early Warning System Using Machine Learning

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Abstract: Floods cause extensive damage to life, property, and infrastructure, particularly in remote and rural regions where timely communication is limited. To address this challenge, this project presents an intelligent flood detection and early warning system that integrates the Internet of Things (IoT), LoRa-based communication, and machine learning technique RandomForest. The system employs multiple environmental sensors, including water-level, rainfall, soil moisture, and vibration sensors, interfaced with Arduino or ESP32 microcontrollers for real-time data acquisition. Sensor data are transmitted over long distances using low-power LoRa communication and forwarded to a cloud platform for storage and monitoring, with real-time visualization provided through an application developed using MIT App Inventor. Machine learning algorithm Random Forest analyze both historical and real-time data to predict flood risk at an early stage. During critical conditions, alerts are disseminated through a Telegram bot for public awareness and GSM-based emergency calls to authorized officials. The proposed system enhances disaster preparedness by ensuring accurate prediction, reliable communication, and timely.

Keywords: Flooding, Machine learning, Random Forest, Real-time monitoring, Environmental sensors, EWS, Disaster management, Arduino, Telegram Alert System.

I. INTRODUCTION

Flooding is one of the most severe natural disasters in terms of lives lost, damage done to homes and infrastructure, and destruction to economies around the world. Flooding has increased dramatically in frequency and severity due to the effects of global climate change and the growing unpredictability of weather patterns. Traditional flood monitoring systems have relied upon human observation to monitor flooding, along with static thresholds for when to issue a warning [1]. Therefore, they do not provide accurate or timely predictions about floods.

In recent years, new technologies, such as Internet of Things (IoT) devices, have made it possible to create intelligent automated systems that monitor the environment. IoT devices with built-in sensors enable continuous real-time collection of data on properties like temperature, humidity, rainfall intensity, water level, vibration, and soil moisture [2]. Machine learning can be applied to that data to discover more complex patterns than have been previously identified through conventional means and to produce more accurate flood predictions.

The objective of this research is to design a real-time flood warning system using IoT-based sensors, collecting environmental data, and applying a machine learning model for future forecasting [3]. The system collects data via an Arduino based sensor network that records environmental data and then sends it to the internet using serial communication. A random forest classification method will be used to analyze all collected data and classify flood risk levels. A labelled dataset served as the training dataset for this model. Evaluation of this model was performed using the standard evaluation metrics (accuracy, precision, and recall).

Additionally, the system implements a mechanism that provides real-time notifications/alerts using Telegram, allowing for immediate communication to those potentially affected by flooding conditions [4]. As with all aspects of this system, this communication method is meant to promote rapid response to floods and improve disaster preparedness. Compared to traditional methods of flood detection and reporting, the current research method is designed to be less expensive, more scalable, and provide consistent monitoring; therefore, it can serve both rural and urban locations.

Flooding is one of the most common and damaging natural disasters, affecting millions of people each year throughout the world. Flooding causes several severe effects, including loss of life, destruction of infrastructure, agricultural damage, and long-term economic impacts; however, developing nations are particularly susceptible to flood damage because most do not possess adequate drainage systems or have high concentrations of densely populated areas [5]. Extreme weather events (i.e., weather patterns influenced by global climate change) have recently increased the frequency of extreme weather events leading to increased importance of flood forecasting and early warning systems.

Traditional flood monitoring methods rely heavily on manual observation, historical data and analysis, and fixed thresholds for warning systems [6]. While such methods provide some information for flood preparedness, they do not typically provide timely information about changing environmental conditions. In many cases, late notification of imminent flood threats and/or poor response capability leads to damaging and less effective responses to flooding events.

II. LITERATURE SURVEY

Flood Prediction and Monitoring using IoT, ML and Real-time data systems is an Area of Significant Research Interest Given that the Number of Natural Disasters has Increased. Most Researchers have looked to use these technologies in order to Increase the Efficiency of the Early Warning System for Floods [7].

Flood Monitoring Systems have Improved using the IoT Environment (Based on Sensors, Such As Water Level Sensors, Temperature Sensors and Humidity Sensors). The Use of These types of Systems Provides Real-Time (Continuous) Monitoring, which makes Them Suitable for Many Areas Affected by Natural Disaster due to Their Cost Effectiveness (IoT-Based Flood Monitoring Systems). This also means that They are an Excellent Solution for The Real Time Detection and Management of Floods.

ML has been used to Predict Flooding as well. A Significant Amount of Literature has Examined the Application of ML-type Algorithms to Predict Flooding; There They continue to be the Most Widely Used ML Models. Some Examples of These Algorithms (Used to Perform Both Short- and Long-term Flood Predictions) Are Random Forests, Support Vector Machines, and Neural Networks [8]. Hybrid and/or Ensemble Models Demonstrated Improved Accuracy and Robustness as Compared to Previous Techniques.

Recent studies show that Random Forest (RF) performs better than many competing algorithms when predicting floods because of its ability to learn from complex and nonlinear environmental datasets [9]. Although few studies have directly compared the performance of Random Forest to that of other machine learning (ML) algorithms, comparative work has shown that Random Forest results in greater accuracy than other ML algorithms when predicting urban flooding.

The combination of the Internet of Things (IoT) and ML technology has allowed for the creation of intelligent flood-risk assessment systems that use real-time computer-generated data produced by sensors as input to ML models in order to dynamically produce predictions of potential flooding [10]. Parameters such as rainfall, river levels, soil moisture, and temperature are continuously monitored for use in generating real-time assessment predictions that greatly improve response times relative to that of historical systems.

More recent methods also utilize Geographic Information Systems (GIS), remote sensing, and big-data analytics integrated with IoT and ML technologies to enhance prediction accuracy and provide improved spatial analysis. Intelligent flood-risk assessment systems created using an integrated approach will both produce flood-risk mapping and aid decision-making for disaster management organizations.

More recent research has also focused on improving prediction performance by using deep learning and hybrid artificial intelligence (AI) models, such as long short-term memory (LSTM), fuzzy logic, and genetic algorithms [11]. Deep learning and hybrid AI models are particularly beneficial for modelling time-dependent patterns and environmental interactions that are complex with regard to flooding events.

The rapid advances in sensing technologies, data analytics, and intelligent algorithms have transformed flood prediction and warning systems significantly. Many researchers have explored many different types of models to predict floods, from traditional hydrological-based models to more modern data-driven models that utilize IoT and machine learning technology.

Early flood prediction systems relied on traditional hydrological and statistical methods using rainfall, river flow data, and historical flood history as inputs. Therefore, researchers used many common physical/analytical techniques (like regression analysis for statistical relationships between variables) and used techniques like time-series forecasting to analyze the historical data to develop flood prediction systems and understand how floods may develop. However, these early-stage hydrological models did not accurately represent how floods develop because they could not appropriately use nonlinear relationships and did not adjust for the real-time variances in physical and environmental conditions.

In recent years, many researchers have started to develop sensor-based IoT flood monitoring systems that use different types of sensors (like ultrasonic water level sensors, rain sensors, humidity sensors, and soil moisture sensors) to provide a continuous stream of real-time data to develop more accurate flood prediction systems while reducing the need for human involvement. However, due in part to limitations in the early stages of developing the technology and the lack of experience with the data generated by the sensors, many of the early-stage IoT flood monitoring systems only provided threshold-based alerts that could be issued as warning notifications when pre-set values were exceeded. Overall, this created a high number of false positive alerts and decreased the level of reliability of the system.

III. METHODOLOGY

The flood warning system will be an integrated flood alert system that creates a single platform for acquiring data from the environment (using IoT sensors), creating predictions of flood conditions using machine learning and then providing real-time alerts of flood conditions.

The overall flow of information through the system will consist of gathering data from environmental sensors, processing that data through a trained machine learning model, predicting based on that model whether a flood condition is available, and then sending out a flood alert.

A. IOT Sensor-Based Data Acquisition

The flood warning system will gather real-time environmental data through an Arduino-based network of environmental sensors. The sensors will measure many environmental characteristics, such as temperature, humidity, rainfall, water level, vibration and soil moisture. Each of these measurements will help to determine the true flood conditions.

The sensor data will be transmitted to the processing unit over serial communication in a structured manner [12]. Continuous monitoring of the sensors will provide the ability to obtain real-time data for analysis at any point in time, thus enabling rapid prediction based upon fluctuations in environmental conditions.

B. Data Cleaning/Preparation and Feature Creation

In order to be usable for machine learning models, the raw collected data will need to be cleaned/processed. To do this, the sensors will need to have their data formatted properly and converted from raw readings to numerical values that are usable in machine learning models. In addition, during the cleaning process, any missing or noisy data will be eliminated.

To perform feature selection, one considers only those parameters that will help to classify floods; therefore, features selected will be done so based on their relevance to a particular flood occurrence. Some examples of selected parameters are temperature, humidity, amount of rainfall, distance travelled, vibration, and soils moisture level. These features will be selected because they have a direct relationship with the classification of floods. The target variable of flood status will be transformed into numerical values according to the needs of the model.

C. LoRa Communication

LoRa (Long Range) communication is employed to facilitate reliable and energy-efficient data transmission from distributed IoT sensor nodes to a centralized monitoring station [13]. Owing to its low power consumption and extended communication range, LoRa is particularly well-suited for remote sensing applications where conventional wireless technologies may be constrained by limited coverage or high energy demands. In the proposed system, sensor nodes collect environmental or operational data and transmit it over LoRa networks, ensuring robust connectivity even in geographically dispersed or infrastructure-limited areas. This approach not only enhances scalability but also minimizes maintenance requirements by prolonging device battery life, thereby enabling continuous and real-time monitoring within the IoT framework.

D. Modelling the Data via Machine Learning

A Random Forest classifier will be the primary language model in order to take advantage of its accuracy, strength, and ability to model non-linear data. The data being used to create the model will be split into two subsets; one subset will be used to train and the other will be used to test the accuracy of the generated model. The Random Forest Algorithm builds a number of decision trees and produces a final prediction by combining the outputs of each of these decision trees into a single prediction. The ensemble approach taken with the Random Forest decreases overfitting and improves generalization.

Through training the model, patterns of historical environmental data will be identified by the Random Forest, and the model will be able to classify flood classifications of normal, moderate, and warning.

Metrics that will be used to evaluate the performance of a trained model include accuracy, precision, and recall [14]. Each of these metrics helps to estimate the accuracy of prediction (the overall success or failure of the prediction) and the effectiveness of the model at detecting flood conditions (precision and recall).

Fig 1. Workflow of the system

These metrics can also be used to assess the quality of the overall system and to ensure proper performance when challenged by different climates or environments. The use of bar charts as a form of visualization will help provide a better understanding of model performance.

The trained model has been deployed to perform real-time monitoring and prediction. Incoming sensor data will be constantly read via the serial interface and transformed into a structured data file. The trained model will be used to process the incoming sensor data and produce a flood status. The ability to perform real-time monitoring will allow for a rapid response to changes in the environment and therefore make this system an effective early warning system.

IV. PROPOSED SOLUTION

The intelligent and real-time flood warning system integrates IoT technology with machine learning algorithms to provide flood alerts. The system will be designed to monitor environmental conditions in real time and give early warning of potential floods to help reduce the effects of floods in a timely way [15]. The system will be built on top of an Arduino hardware platform, located in areas susceptible to flooding, and include various sensors to obtain key environmental parameters (such as temperature, humidity, rainfall amount/intensity, distance from the ground to water level, acceleration due to vibration, and soil moisture) that can help indicate whether an area may be flooding. The sensors will collect data on these parameters and send them to a central processing unit in real time, so they can be analyzed quickly.

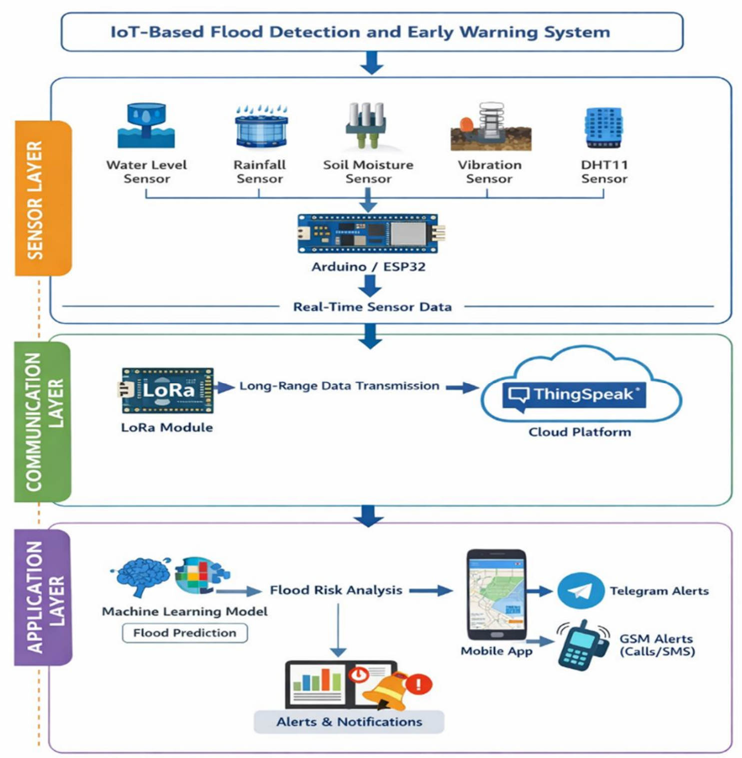

Fig 2. Design of proposed solution

Once the sensors collect data, the data will be sent via serial communication to a processing unit for structuring and analysis preparation. Data preprocessing is a critical component of this intelligent flood warning system. Without preprocessing, there would be no means of guaranteeing data integrity, thus, the data from each sensor will be preprocessed and cleaned up before being utilized for flood prediction [16]. Data preprocessing includes reducing noise, errors, and inconsistency that may have occurred when collecting the raw data. Thus, only the preprocessed (clean) data will be used in the prediction model. The preprocessed data will be sent to a machine learning model that has trained on historical environmental datasets. In the proposed solution, a Random Forest Classifier will be utilized as the prediction model due to its robustness, accuracy, and ability to identify complex non-linear relationships between many environmental characteristics.

The random forest model is built from many decision trees, each model predicting a result. The outputs from all of these trees are aggregated to provide a final prediction for a given observation. By combining multiple independent decision trees, the accuracy of the model improves significantly, and the likelihood of overfitting is minimized, which make it an appropriate model for use in real-time environmental monitoring systems. Incoming data is classified within the model into different levels of flood risk (e.g., normal, moderate, and warning) to assist with understanding the severity of a given situation and provide information to assist with timely decisions [17].

A major component of the system being proposed is its real-time monitoring capability. The sensors continuously provide data to the system and as soon as data are received, they are processed through the trained model providing timely identification of any environmental changes that occur suddenly. Because the system operates continuously, it is considered suitable for real-world use in areas prone to flooding.

In order to improve the real-world use of the system, an automated alert notification mechanism has been built into the system using the messaging service Telegram [18]. When the predicted flood risk becomes critical, the system will automatically send alert notifications to pre-defined users. By providing instant notification capabilities, it is possible for authorities or individual citizens to react by taking preventative actions such as evacuating or allocating resources more quickly and inexpensively than with traditional alert systems.

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V. RESULTS

IOT-based flood warning system was developed and tested with both historical datasets for training (historical) and real-time sensor data (current). The ability of the IOT-based flood warning system to forecast whether or not flooding conditions exist based on environmental parameters such as air temperature, humidity, rain level, distance to flood area (floodplain), vibrational data (ground shake), and soil moisture were evaluated using a Random Forest Classifier and demonstrated the ability to predict flooding conditions with high confidence.

During the training phase, the data set was divided into a training set and a test set so that there could be proper validation of the model. The Random Forest algorithm demonstrated high training accuracy (95.7%) and similar consistency of testing accuracy (95.1%). Therefore, the Random Forest algorithm learned the relationship of environmental parameters and the occurrence of floods without being overfitted; therefore confirming the robustness and generalization ability of a Random Forest algorithm to process multifactorial environmental parameter data.

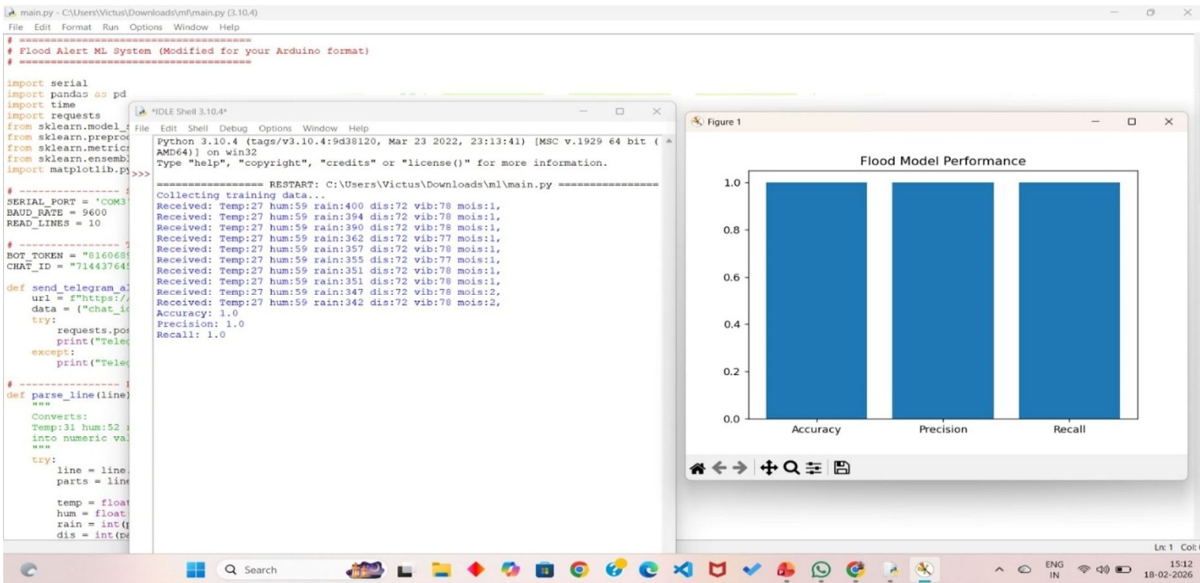

Fig3. Testcase 1 result

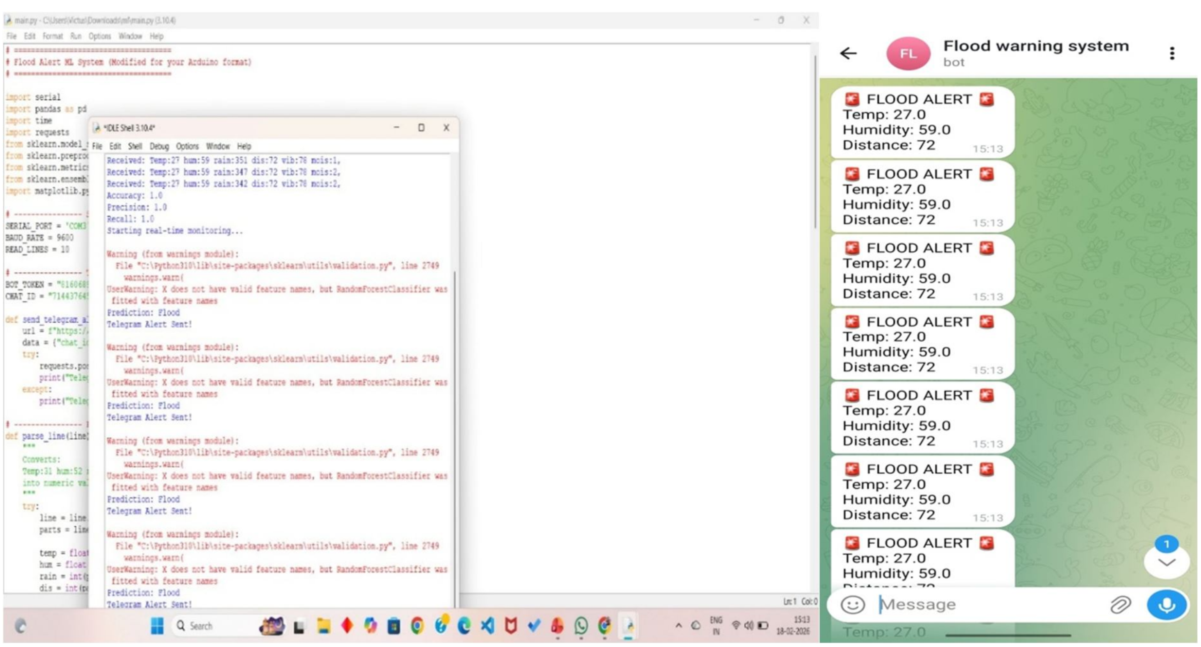

Fig4. TestCase 2 result

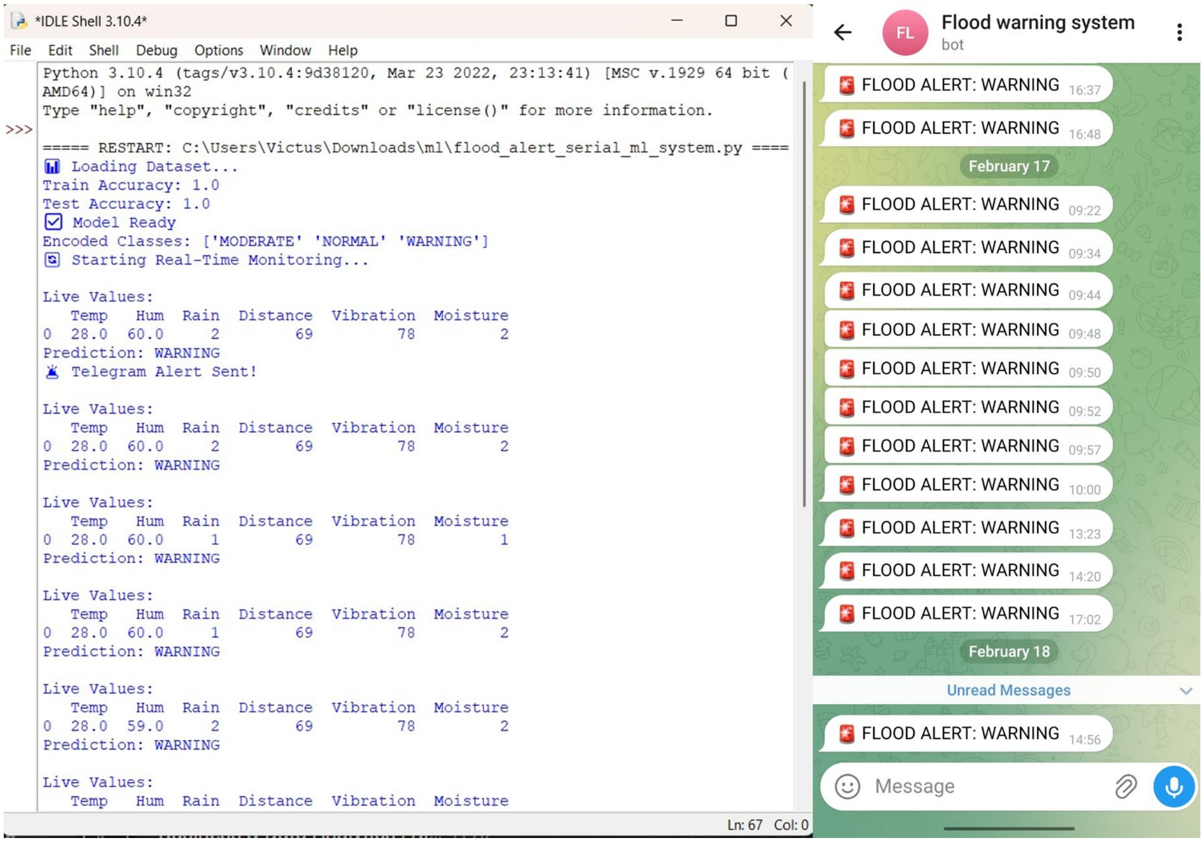

Fig5. Flood Warnings

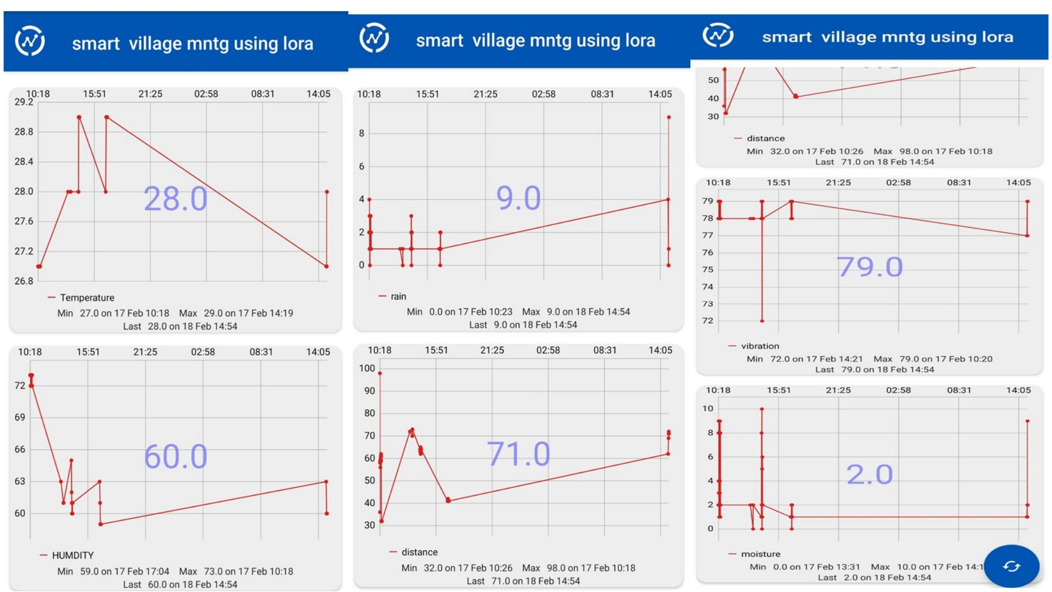

Fig 6. Testcase 3 results

The algorithm performance was further evaluated using additional performance metrics (e.g., precision and recall). As a result, the Random Forest algorithm had very low precision (e.g., a low number of false flood alerts) and high recall (i.e., the majority of the actual flood conditions were identified). Having both a low rate of false alarms and high rate of detecting flood conditions is critical in flood prediction systems; because either false alarms or missed detections can cause severe loss of life or property.

In addition, each metric was represented in graphical form so as to show visually the relationship between performance metrics. A bar chart comparing the accuracy, precision and recall values all showed considerably high values for each of the three metrics, therefore confirming the reliability of the proposed model. Therefore, this is an additional way of demonstrating how the proposed model performed well against a variety of evaluation metrics.

The proposed model was evaluated in a real-time setting with actual live data collected from sensors connected through Arduino boards. The proposed system continuously monitored and processed all incoming data for generation of predictions in real time. Based on a prediction, the system classified the predicted flood condition into one of three categories: normal, moderate or warning.

One key feature of this system was its ability to send real-time alerts. When the predicted flood condition reached either the moderate or warning stages, the system successfully generated and sent an alert via the Telegram messaging platform; alerts were sent in real time with very short response times, allowing for timely communication. Additionally, the proposed system also included a method for preventing repeated alerts on the same flooding condition to enhance efficiency of operation and user experience.

VI. CONCLUSION

This study describes an effective and intelligent flood warning system that utilizes IoT technology with machine learning methods for monitoring and forecasting weather in real time. This new system uses sensor data like wind speed; ambient temperature; relative humidity; rainfall; water elevation; vibration and soil wetness to assess the potential for flooding; then generates warnings when needed. The Random Forest classifier employed in this new system produces both high accuracy and high reliability for all levels of flooding based on a large amount of highly complex, nonlinear data.

The ability of the system to continuously monitor real-time changes in our environment increases the amount of time available to identify a potential flooding situation. Additionally, through an automated alert system using the Telegram messaging service, people can be notified immediately if a flood warning occurs allowing for prompt action to take place before the flood occurs. This drastically reduces the length of time from when the flood occurs to when it can be detected from historic methods of monitoring floods.

The tests performed by other researchers have provided consistent high results regarding accuracy, precision, and recall. The new model provides both the ability to reduce false alarms while still accurately detecting critical instances of flooding. Therefore, it is believed that the new flood warning system will be a viable solution when utilized in "real-world" applications. As a bonus, the alert system allows people to receive notice of an impending disaster without relying solely on internet access for information.

VII. FUTURE SCOPE

The flood warning system that is being suggested has proved successful at both predicting floods accurately and at monitoring floods in real time; there are numerous avenues available now for the application and improvement of the technology that will allow it to develop further. For example, the system can be improved by integrating machine learning and deep learning algorithms such as LSTM (Long Short-Term Memory) and ANN (Artificial Neural Network) to achieve an increasing level of accuracy in long-term forecasting of floods.

Environmental data (e.g., amount of direct river flow, degree of wind velocity, atmospheric pressure, and satellite-based rainfall data) would need to be included in order for the system to have a more complete view of conditions leading to floods. Inclusion of these data parameters would also increase the accuracy of predictions.

The integration of big data technologies using cloud applications for storage and processing of sensor data, along with the growth of cloud-based monitoring via web dashboards and mobile apps, provides an opportunity for historical analysis for training models and scaling model deployments such as with large areas experiencing flooding. Cloud-based incursion can facilitate real-time access to information from around the world, allowing for timely responses.

GIS mapping can improve the proposed system by showing where flood zones and at-risk areas for flooding are in real-time. This will help government agencies and emergency responders plan for evacuations, allocate resources, and make decisions based on current conditions.

The alert system could be expanded beyond Telegram to other ways of receiving alerts such as SMS text messages, mobile apps, and sirens. The goal is to reach as many people as possible. Therefore, utilizing multiple methods to alert the population would allow more people to receive warnings effectively than if they were only using one form of communication.

By developing a WSN rather than a wired or serial communications system, more reliable hardware connections can be created, and therefore, the reliability of the overall system can be increased.

The amount of coverage will also increase when using wireless technology because of its ability to operate over much larger geographic areas. Solar-powered sensors would improve the sustainability of the system and allow for local deployment at remote sites.

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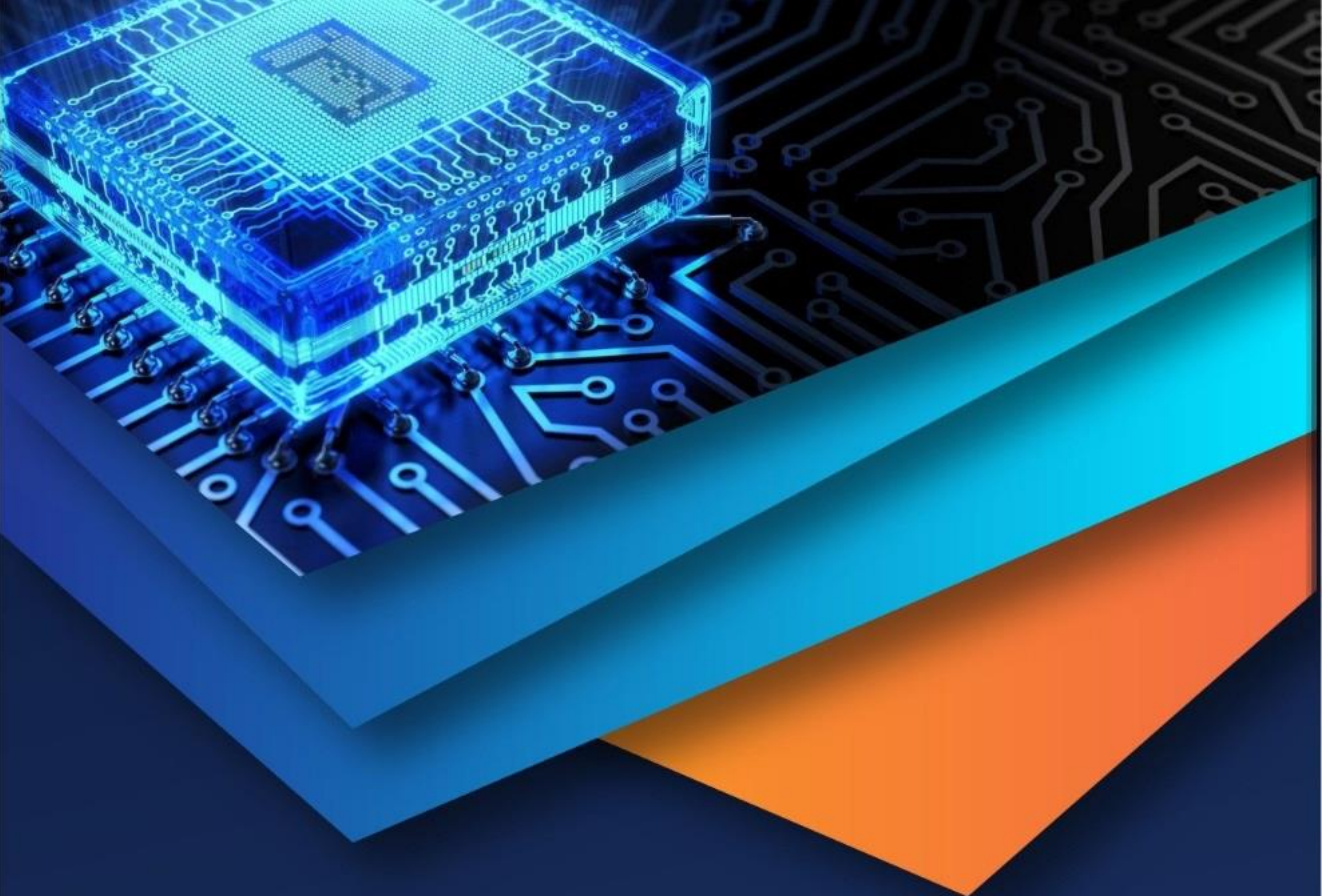

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