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Iot Based Flood Detection, Alarm and Monitoring System Using Multilayer Perceptron and Regression

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ABSTRACT: Flooding is a common natural event caused by heavy rainfall and high tides in the Philippines. While this disaster cannot be prevented, people can prepare themselves to face it. The City of Ilagan in the province of Isabela is one of the highly prone areas to flooding caused by the welling of the Cagayan River. Many communities are living in low-lying areas which most likely experiencing floods. An analysis of the location is conducted including the people living in the area. The analysis resulted in the development of an IoT-based technology for detection and early warning signals to people using sms notifications that can help lessen the difficulty of evacuation. The system uses Arduino UNO as a microcontroller where sensors are attached. These sensors are Light Detection and Ranging (LiDAR) for flood level measurement in feet (ft), Rain Gauge to measure the precipitation rate (mm/hr), and Flow Rate Meter to measure the fluctuation flow of the river in (L/hr). Data gathered from these sensors are processed and sent immediately to people living nearby to monitor the flood level in real-time. The predictive models are developed using the Pinacanauan River dataset taken from the river stations. The multilayer perceptron is used to develop the predictive model with 99% accuracy. The data from sensors are used also and processed using linear regression and calculated as 88% accurate and significant for prediction.

KEYWORDS: Flood Detection and Monitoring, Multilayer perceptron, multi-linear regression, predictive model, SMS notification, IoTTechnology

I. INTRODUCTION

Flooding is one of the most observed natural disasters in the Philippines. The area of Luzon has the longest river and the largest river by discharge volume of water called the Rio Grande de Cagayan. The swelling of the river is due to a heavy amount of rainfall (Abalos, 2022) which causes property damage and a wide loss of agricultural income-generating products.

Technology created a direction for humans in reconsidering modern tools as a solution to seasonal problems. The Internet of Things (IoT) defines a new way of building connections to humans and acquiring real-time information on water level depth and changing conditions. IoT for flood monitoring is a crucial demand to modernize solutions for early flood warning systems as highlighted in the study of (Tang,et.al.,2018). A flood warning is the provision of prior notice of scenarios that are probable to occur in flooding of the primary residence and a potential risk to life. Hudson, (2022) emphasized flood monitoring systems have total integration and adaption with emergency plans that help prevent excessive damage and loss.

Machine Learning algorithm is now essential in manipulating data, offering predictive algorithms and protocols. A huge amount of data is collected using devices such as rain gauge to determine the amount of water and gauge height tools for leveling water in bridges. These data are used and processed to develop model for prediction and extract knowledge. Predictive model can be used and implement for IoT programs and mobile applications integration. This innovative technology helps the community to be prepared and ready as early warning information is delivered from the main gauge water level meter to mobile phones of people nearby river. Hence, Flood Monitoring Systems with implemented predictive model provides significant importance for hazard assessment and extreme event management. Robust and accurate predictions contribute highly to flood management strategies, safety, and evacuation protocols. Flood predictions modeling and monitoring are powerful tools for mitigating flood damage.

The City of Ilagan in Isabela is experiencing floods especially in rainy seasons for it lies near the Rio Grande de Cagayan River. Some parts or Barangays of the city are under low lying areas prone to calamities and disasters such as flashfloods, typhoons and landslide which also stated in the website of Aqua Barrier (2021). Figure 1 shows the City's Hazard Map where the blue shaded part has a high susceptibility to floodings where the faded blue color is medium susceptible in flooding. Regardless of the level of risk, flood is still a threat to the people in areas. The land area is still wide and many people are still possibly in danger zone. Since the city is still relying on broadcast, social media updates, local news updates for open gates on dam or continuous heavy rains, the problems found here are the delays of information dissemination before the potential disasters or dangers come. National Disaster Risk Reduction Council (NDRRMC) uses broadcast service protocol on mobile phones with network providers to warn nearby areas of precautionary measures. However, the delay of the broadcast is intolerable-the user only receives the alert warning message right after the damage has occurred. Another potential factor for information dissemination is social media, before a disaster such as an incoming typhoon, subscribers could get updates on when and where the typhoon may landfall and different possible catastrophes may arise based on their updated information regarding the incoming threat and precautionary measures are bound to be executed. Nonetheless, that is causing too much reliance on an internet connection which may only have good experience before the typhoon. In this case, during the disaster, an electricity outage may experience, and loss of internet connection may come unexpected which then causes possible loss of information from the media.

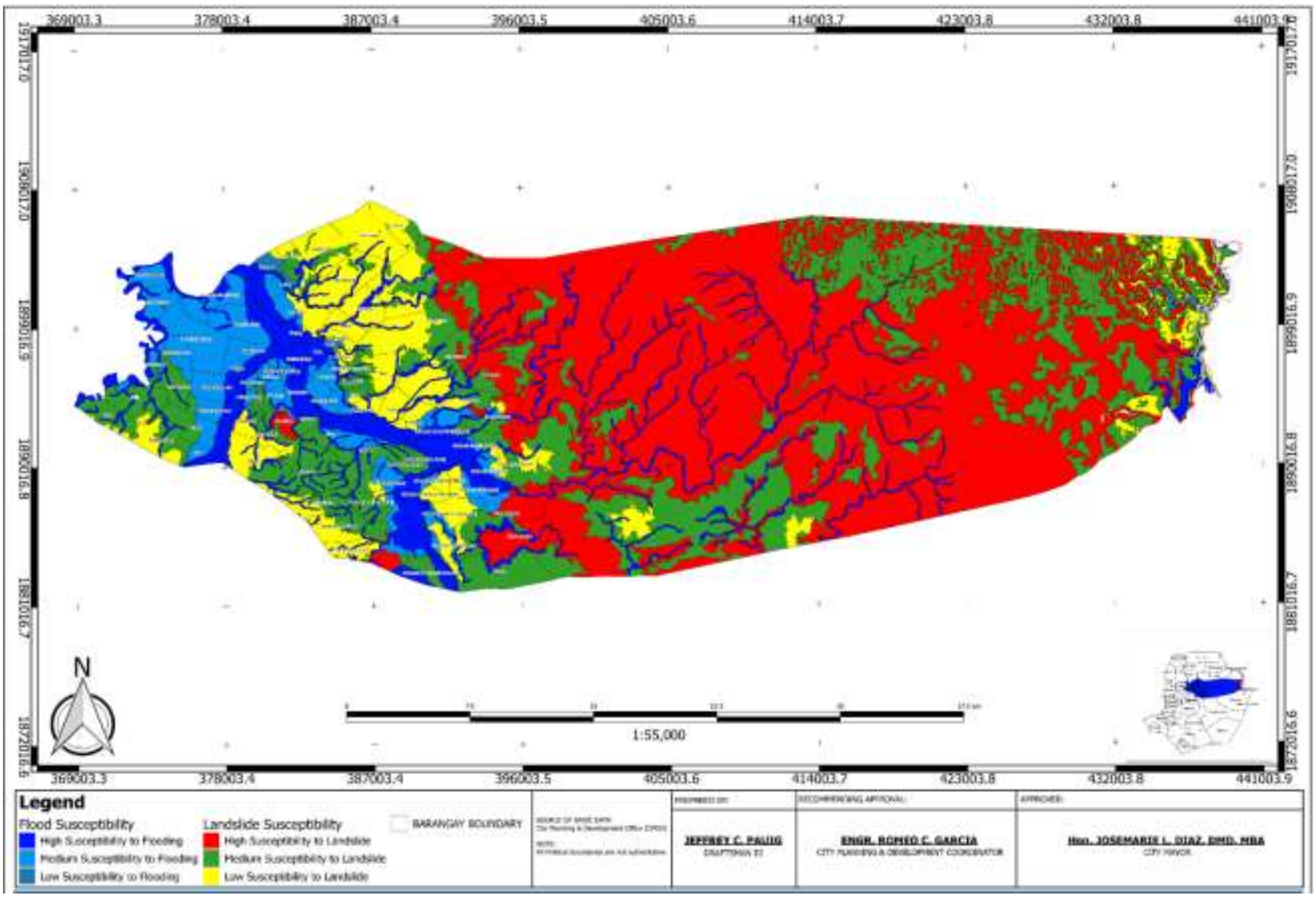

Figure 1: City of Ilagan Hazard Map (source: www.cityofilagan.gov.ph)

The advent of mobile phones changes the way people communicate. In case of emergency the only reliable communication is the Short Messaging Service (SMS) and Direct Call form Network Providers services and IoT programmed devices. SMS notification is an alternative way to disseminate information to all the nearby communities lying the river side (Tang, et.al., 2018). With this, early forecasted or predicted information on the situation of the disasters is important for communities' readiness. As per City Disaster Risk Reduction and Management Office, City of Ilagan barely implement flood monitoring devices installed in some bridges. By implementing the flood monitoring system, it may enhance the understanding of how to interact with all those who lives in the area. Systems can assist minimize excessive damage and loss caused by floods, as well as potentially save lives. In the study of (Wahidah Md. Shah et. al., 2018), they found that it is crucial to develop a flood control system with prediction mechanism to reduce the flood risk. Also, Joey Natividad, et.al. (2018), in their study of flood monitoring, the community around the river has already been using several technologies for flood risk reduction on the threats of flooding especially in populated areas. The Department of Science and Technology-Project NOAH, set up Water Level Monitoring Stations and Automated Rain Gauge along the principal river basins of the place. And through actual visiting the river for inspection of the water level.

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This study addressed concerns on natural disasters especially typhoons, heavy rainfalls, and flashfloods. The damage brought by these calamities is significantly affects the lives of the people, economic stability, community health concern, agricultural and wildlife concern and loss of properties and income generating agricultural products. Through innovative technological solutions, these concerns may minimize and lead to more safe, ready and prepared community. Hence, this focuses on the development of flood early warning signs with predictive model using IoT and linear regression predictive classification algorithm and multiple linear regression.

II. METHODOLOGY

A. System Architecture

This project designed an iOT based technology for flood detection, monitoring and prediction. The main microcontroller used is the Arduino UNO which has connected sensor devices. Three parameters are considered in the architecture. To measure the precipitation rate which is in (mm/hr) unit, rain gauge is used. The flood level in (m) is measured using LiDAR (Light Detection & Ranging) and the flow rate is recorded using Flow Rate meter sensor in (L/hr) unit. These devices are connected forming single operated system performing flood monitoring and prediction. Arduino UNO as its central signal processing microcontroller, reads signal data from different sensors connected. These signal data is then converted to digital value that can be read by the microprocessor. The sensors are used to supply data to the parameters needed for more processing. As shown in figure 1, there are four general elements in the system for Flood Monitoring and Detection i.e. Sensors, Power Supply, Microcontroller, and Notification Function. The Power Supply provides electric charge to power up the system and it uses solar panel to store energy. The rain gauge sensor is responsible in measuring the precipitation rate of rainfall. LiDAR is used for the Water Level and is measured using bridge column water measurement unit. The last sensor considered is the Flow Rate Meter measuring volumetric flow rate of water Liter per hour unit. The data received from these sensors are then process for early warning and predictive model and send through SMS (Short Messaging Service) as notification.

B. Detection System

Flood detection is one of the functions intended to develop in this study. Shown in figure 2 is the intent pseudo algorithm for flood detection where these protocols are occurring simultaneously to execute the system intended function. The entire system will check first sensors and device parameters. When there is an occurrence of Rain, the system will throw a Boolean True value checking threshold level. The rainfall measurement is used to calculate precipitation rate under continuous raining scenario. The increase rate of precipitation triggers the water level and flow rate module to check for change in the water level and calculate rate of rise over a certain period. Both continuous rain and no occurrences of rain will loop the preliminary function until a certain threshold for flood detection is met Data from these system processes is used for the predictive model parameters. The system will send nearby community a warning notification for possible evacuation due to increase water level and chance of flood.

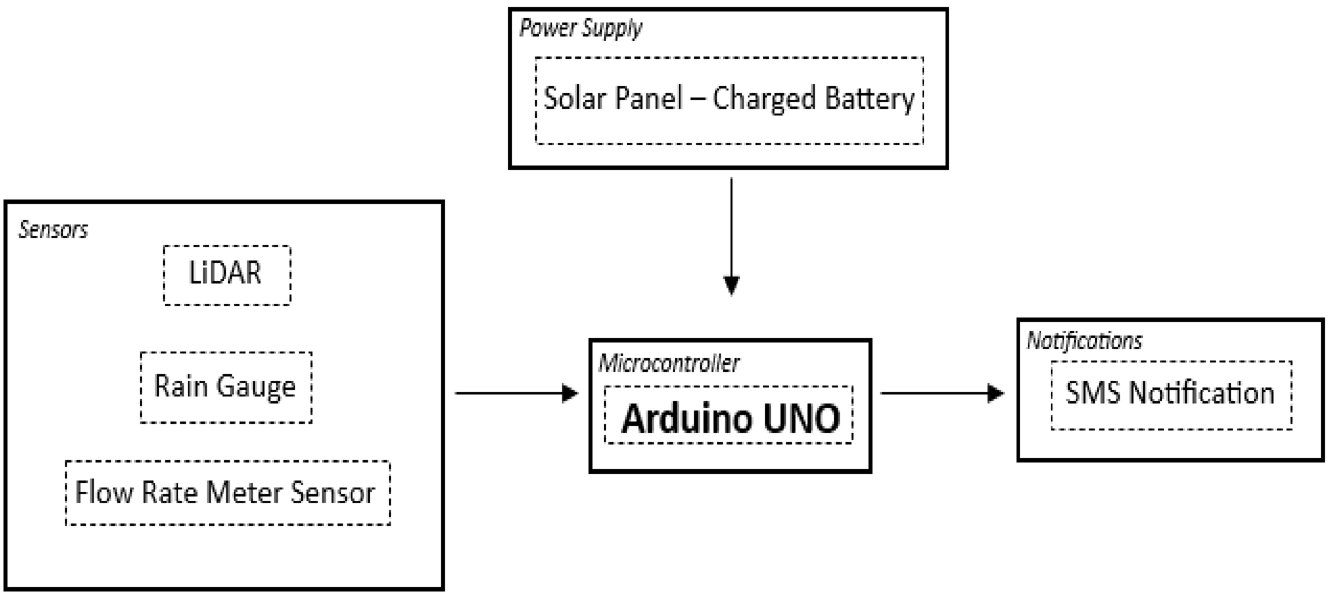

Figure 1: System Architecture Diagram of the Proposed Flood Monitoring & Detection System

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procedure: Flood Detection & Monitoring <-(Rain(R), RainFall PrecipitationRate (Pr),
WaterLevel(Wl),FlowRate(Fr), FloodLevelThreshold(Flt)
R<-boolean(TRUE, FALSE)
Pr<-m2-m1
Wl<-l2-l1 && Fr <-r2-r1
Flt<-boolean(TRUE,FALSE)
        repeat-execute
        for Flt(param2) check
                if R(param1) then
                        Calculate continuous -> (Pr)
                        Calculate continuous increase rate -> (Wl+Fr)
                        Return (Pr,Wl,Fr) -> determine threshold
                else if R(param2) then
                        Calculate current -> (Pr)
                        Calculate current increase rate -> (Wl+Fr)
                        Return (Pr,Wl,Fr) -> determine threshold
                end if
        end for
        until Flt(param1)
        return notif
end procedure
```

Figure 2: Intent Pseudo Algorithm for Flood Detection

For the system, the threshold is set as shown in table 1. This is used during calculation processing based on the gathered data from the different sensors.

Table 1. Threshold Value Set for the System

Water Level (m)	Alert Level	SMS Notification Time of Delivery
26-29m	BLUE	None
30m	YELLOW	10 minute interval
31-33m	ORANGE	2 minute interval
33 and above	RED	1 minute interval

C. Predictive Model

This study developed two predictive models. The first model is generated using collected dataset from different stations from Pinacanauan River Rain Gauge measurement from 2016 to 2022. The dataset is subjected for data preprocessing using Python and Waikato Environment for Knowledge Analysis (Weka) for further processing on predictive model. The dataset contains time, rain gauge reading and average rainfall computation on a nine-hour reading daily throughout the year. The actual attribute to predict is the average rainfall based on the entity parameters. On this dataset, the predictive model used classifier function multilayer perceptron algorithm where it consists of input layer, hidden layer and output layer as shown in figure 3. The process is executed as Training Set test option linear and sigmoid nodes are considered which consisted of Inputs, Weights, and Threshold. These are used to calculate Correctly Classified Instances, Kappa statistic (ks), Mean Absolute Error(mae), Root Mean Squared Error(rmse), Relative absolute error(rae), and Root relative squared error(rrse). The developed predictive model in the given dataset is used as enforcement on possible flood detection and early warning in given period of the year.

The second model used multiple linear regression algorithm represented by the mathematical equation in (1). The predicted flood level is the only variable dependent to precipitation rate, flow rate, and current flood level. In this case, precipitation rate is calculated using rain gauge during rainfall in millimetres per hour (mm/hr). The river flow rate is the volume of water flows in a given location of the river over period measured in Liter per hour while the current flood level pertains to the current height of flood measured in feet. Given all the data gathered from the sensors, the system will evaluate the data to predict the flood

$$y = B_0 + B_1x_1 + B_2x_2 + e \quad (1)$$

Where:
y = predicted flood level
B_0 = precipitation rate
B_1 = flow rate
B_2 = current flood level
e = error term

status for the next hour. The system checks the processed data if it meets the threshold for an imminent flood. When the threshold is met, the system will send early notification to the community using their registered number to the system. Otherwise, the system considered the data value insignificant, and the preliminary function of the system will be re-executed. Once the three independent variables are obtained, the predictive model implemented to the system is executed and automatically computed.

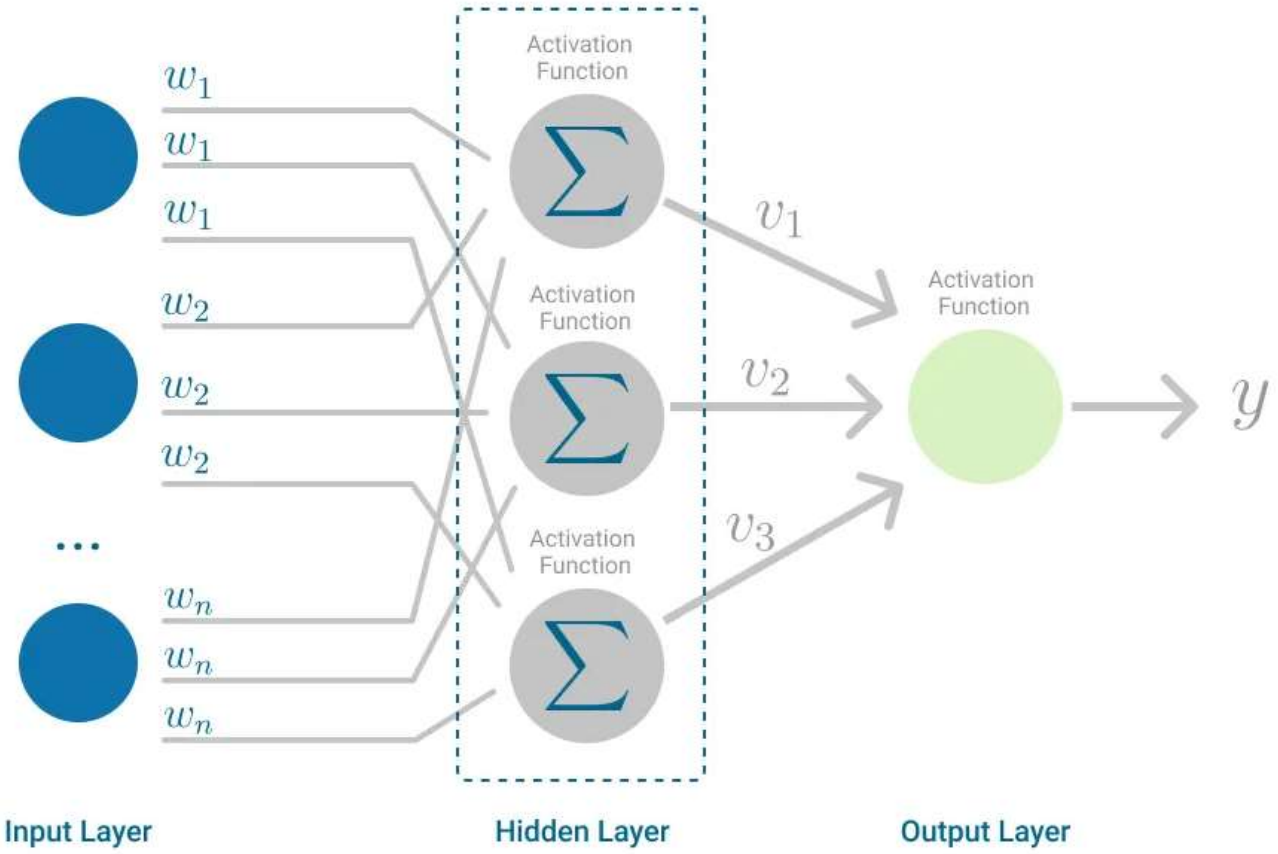

Figure 3: Multi-Layer Perceptron (MLP) (Bento, 2021)

D. SMS Notification

The SMS Notification function of the system can send early warning messages to the nearby community. It sends an information to people on the predictive scenario that might happen on the current month of the year based on the calculated dataset. The system sends Water Level or the flood level, flows rate, precipitation, and the warning. This feature of the system allows nearby community to evacuate before the danger comes. However, before the notification arrives to the community, a five-hour interval of function loop of the system is executing, and the authority only receives the information. When a possible flood is coming, the system is automatically sending the information to the nearby settlers. The automatic sending of information to the community is continuous especially when there is incoming typhoon and heavy rainfall. There will be intervals of sending information if there are weather disturbances near to the location based on Philippine Atmospheric Geophysical & Astronomical Services Administration (PAGASA). If the warning signal turns to yellow, there will be an earlier delivery of information. Table 1 shows the codes for an early warning signal.

Table 2. SMS Notification Flood Warning Status

Status Level (Codes)	Flood Warning Status	Notification Time Delivery
BLUE	No occurrence of flood.	None unless there's a Weather Disturbances
YELLOW	Approximately ½ foot (Ground to Ankle). Prepare for Evacuation.	10-minute interval
ORANGE	Approximately 2ft. (Ground to Knee). Evacuate.	2-minute interval
RED	Approximately 3ft. and beyond (Ground to above waist). Evacuate.	1-minute interval

III. EXPERIMENT & RESULT

This study is conducted at Malalam, City of Ilagan, Isabela, and one of the high-risk flood zones located alongside the Cagayan River. The Malalam bridge served as water level measurements as shown in figure 4.

Figure 4. Malalam Bridge Water Level Measurement

Historical Data is used for the first predictive model of this study. Dataset is gathered from the Rain Gauge meter of different bridge stations built along the Cagayan River. This dataset is used to develop a predictive model in determining possible flood or river situation in a specific period of the year. The dataset is preprocessed using Python and mined through Weka tool. Multi-layer perceptron classification algorithm is used to further examine the data and create a predictive model. All attributes are visualized and seen the distribution of data from different attributes as shown in figure 5. The FloodPrediction status indicated values of BLUE as much as other color codes which implied that the area is more likely to experience less floods over six year.

However, there were times where the city experienced massive floodings throughout the area and usually occurs duing "ber" months. Figure 6 shows the neural network of the processed dataset where the colors indicate the Flood Prediction. The developed model consisted of eight Sigmoid Nodes and four Classes. These classes are the classification of flood prediction status. Figure 6 and 7 on the other hand, described the evaluation of the model. As per summary, the model is 99% correctly classified and only has 0.0029 mae which indicates that the model is accepted for prediction purposes.

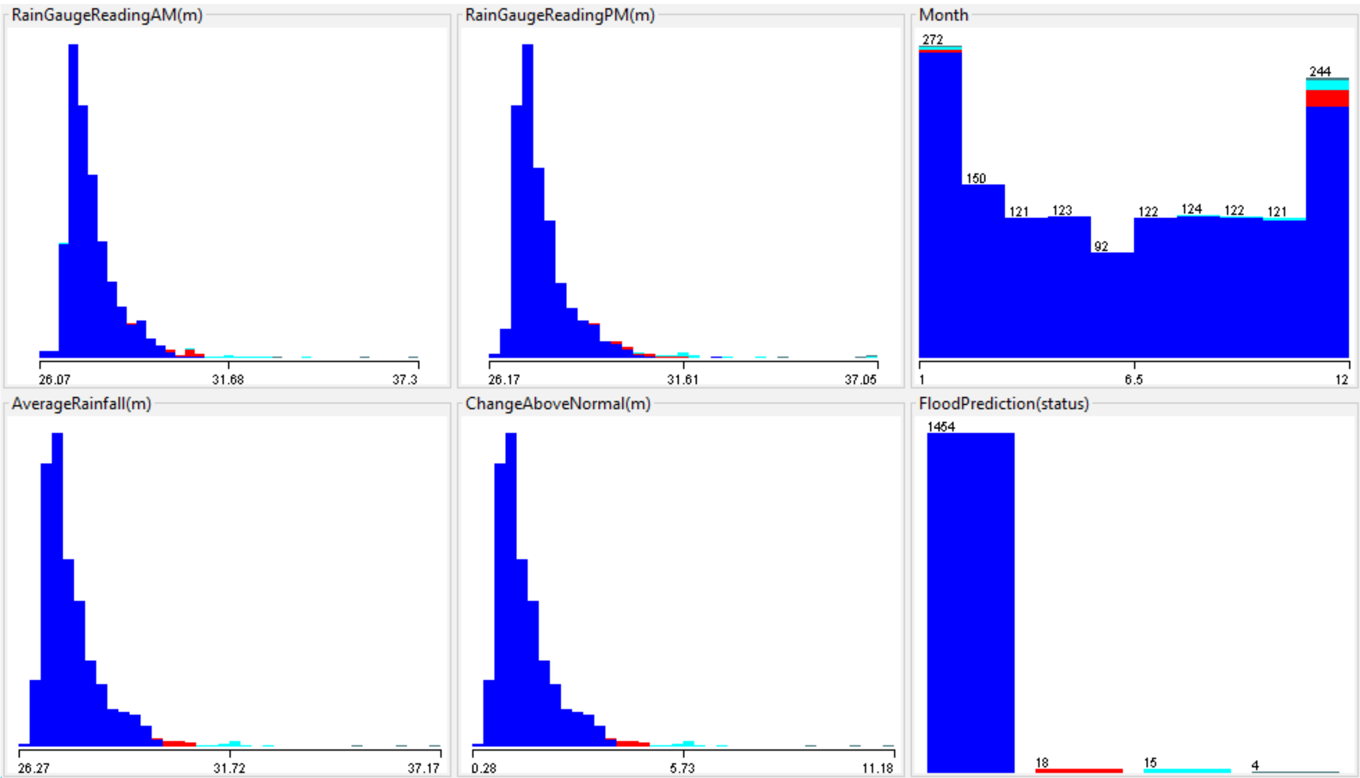

Figure 5. Attributes Visualization of the Dataset

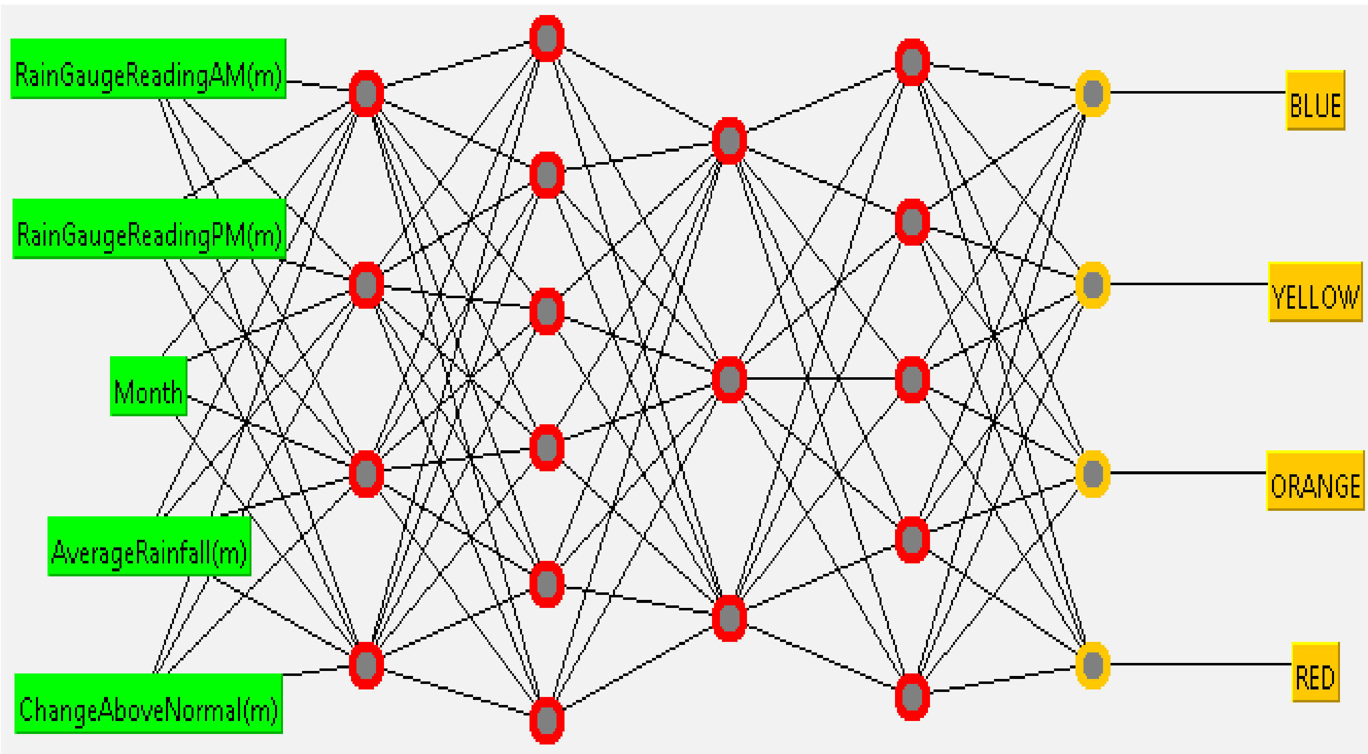

Figure 6. Multi-Layer Perceptron Neural Network (Pinacanauan Dataset)

Correctly Classified Instances	1487	99.7317 %
Incorrectly Classified Instances	4	0.2683 %
Kappa statistic	0.945	
Mean absolute error	0.0029	
Root mean squared error	0.0332	
Relative absolute error	11.365 %	
Root relative squared error	30.0786 %	

Figure 7. Summary of Mulit Layer Perceptron Dataset Evaluation

a	b	c	d	<-- classified as
1454	0	0	0	a = BLUE
0	18	0	0	b = YELLOW
0	0	15	0	c = ORANGE
0	0	4	0	d = RED

Figure 8. Confusion Matrix on Multi Layer Perceptron Dataset Evaluation

The second model developed for this study is a real-time prediction from the developed iot based technology. Figure 9 displays the collected data from rain gauge cumulative rainfall for two-day records. Figure 10 shows the river flow rate or the flow fluctuation and figure 10 depicts the water level reading. Statistically based on calculations, the regression plot of the flood level and precipitation rate as shown in Figure 11 depicted a coefficient of determination equal to 0.8932 or 89%. This further suggests that there is a variation of flood caused by rainfall. Figure 12 shows the regression plot of cumulative rainfall and flow rate. As per calculations, the figure implies that when there is a long and heavy rainfall, a flow rate of the river also increases. This supports mathematically by coefficient of determination or equal to 0.926 or 92%. Flood level and flow rate as shown in figure 13, calculted 87.89% that implies flow rate does have correlation with the rise of water level. The result of Figure 11 and 13, it can be determined that water or flood level can be predicted based on the changes in the precipitation rate since its coefficient of determination is higher.

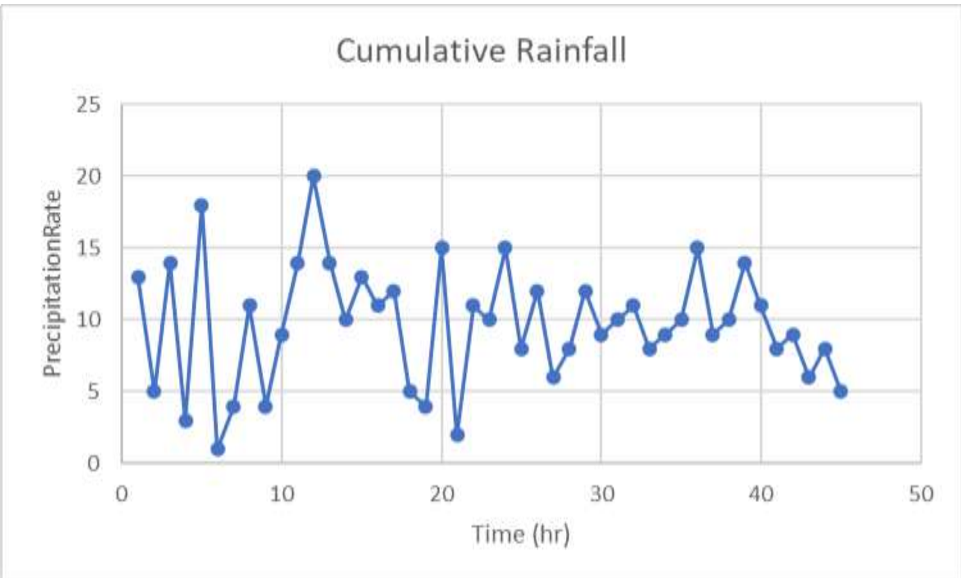

Figure 9. Precipitation Rate Reading

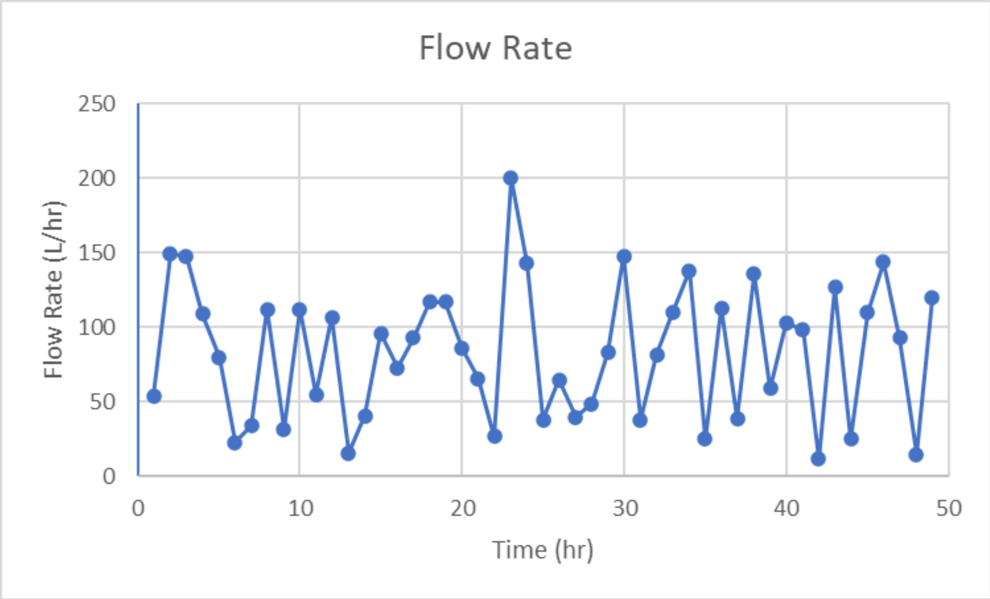

Figure 10. Flow Rate Reading

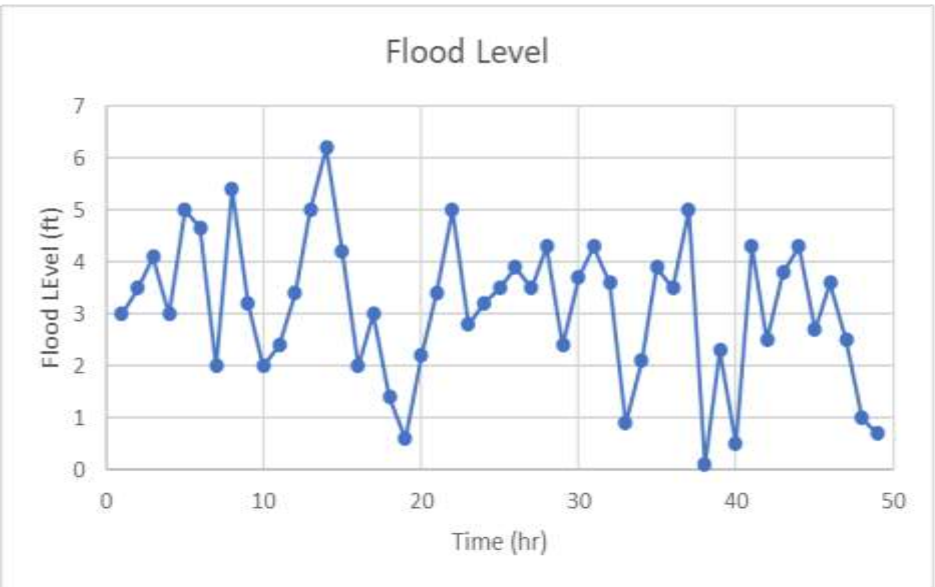

Figure 10. Water Level Reading

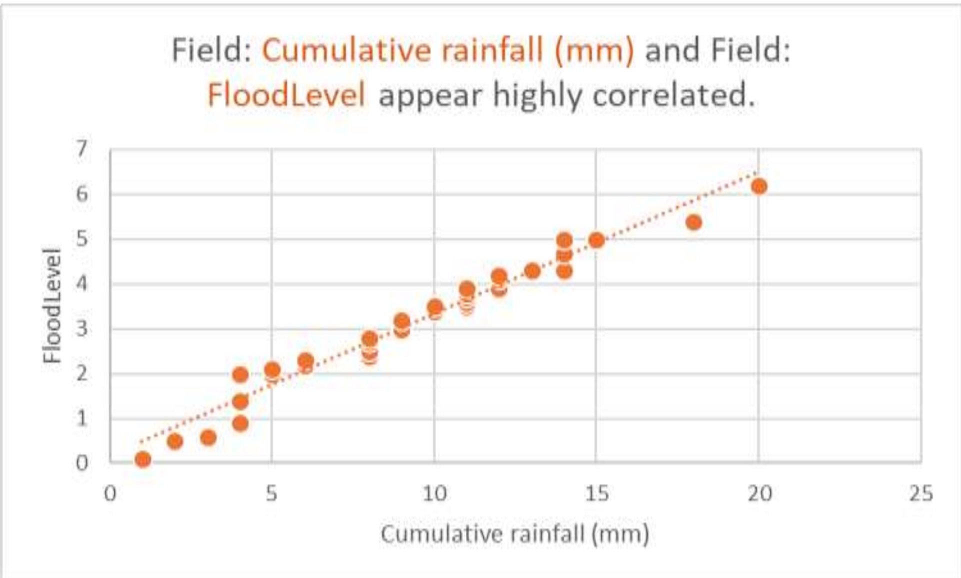

Figure 11. Regression plot of Precipitation Rate and Water Level

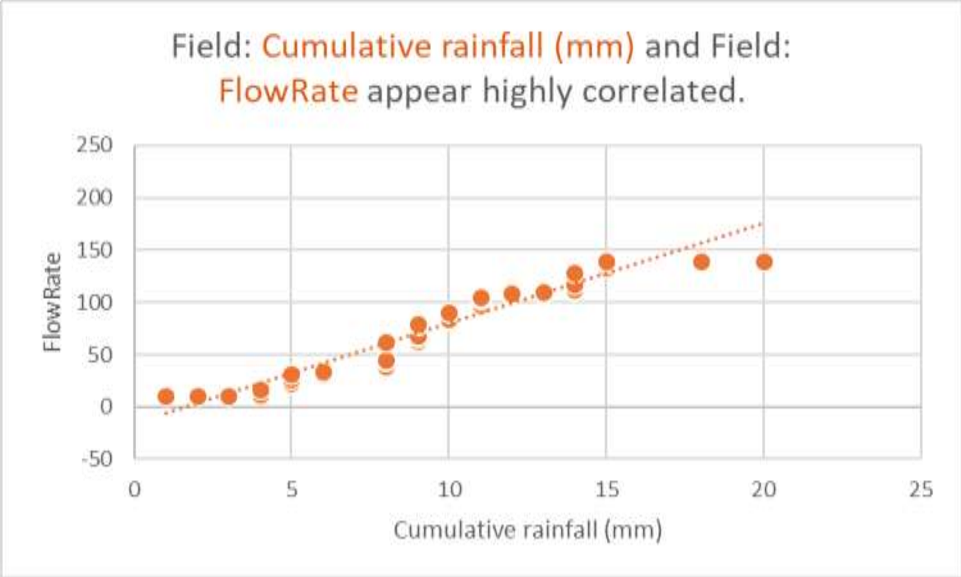

Figure 12. Regression plot of Precipitation Rate and Flow Rate

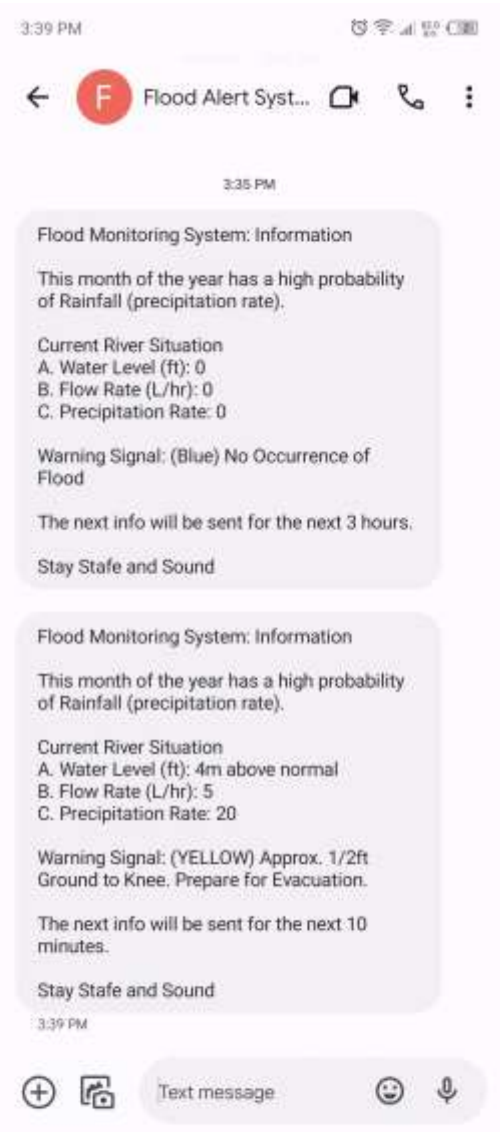

Figure 14. Sample SMS Notification of the System

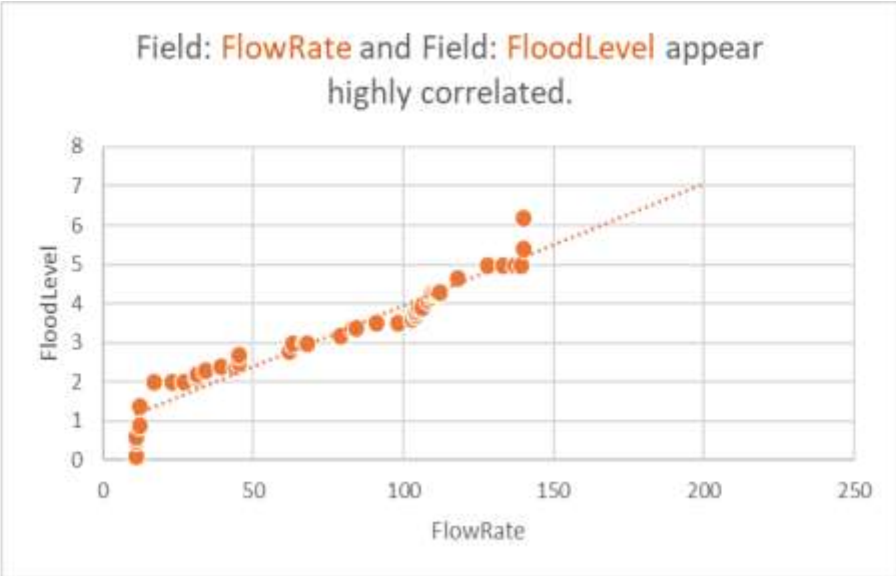

Figure 13. Regression plot of Flow Rate and Flood Level

The Flood Alert system is used as a receiving contact of the SMS Notification Function of the project. The message contains the Name of the system and its general prediction for the current month which indicates a probability of rainfall or floods during the time period. Also, the message significantly highlights the current river situation using the following parameters: A. Water Level (ft), Flow Rate (L/hr), and Precipitation Rate (mm/hr). These parameters are used to indicate the warning signal of the current readings. Color Codes are used with designated warning status as indicated in table 1. The system also let the receiver wait for further readings and indication on the next alert messag**e.**

IV. CONCLUSION

After extensive testing and data collection, it has been determined that the devices used in the system are effective and produce dependable outcomes. The Pinacanauan Dataset provides historical data which underwent data mining techniques under multi layer perceptron classification algorithm and it provides significant value as a predictive model implemented into the system. The ioT-based technology plays a useful and important role in detecting and monitoring floods in the City of Ilagan. With the different sensor devices attached to the microcontroller, data are sent and subjected for further processing for appropriate community notification. Other than the historical data taken from different stations of the river, data are also collected to the developed system and further subjects for processing. Functions of the project are satisfied such as the detection of a flood using sensor devices (liDAR for detecting flood level, rain gauge for measuring precipitation rate and flow rate in measuring the volume of river flow). The system is powered by Solar Panel which provides adequate amount of electrical energy. Lastly, the predictive calculation of the system is the most significant feature for it provides early warning dissemination to nearby community avoiding danger and possible loss of properties or lives..

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