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Flash flood warning system as a mitigation for flash flood on Nkpolu Road, Rumuigbo in Port Harcourt

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Abstract
The most hazardous type of floods are flash floods, which combine the devastating force of a flood with extremely high speeds. This project entails creating a flash flood warning system that can identify floods and instantly notify drivers plying Nkpolu Road in Rumuigbo, Port Harcourt, using a mobile device. Soil samples collected from Nkpolu Road were transferred to the laboratory and examined, along with rainfall data collected from the Nigeria Meteorological Agency (NIMET). On the basis of the examination of the soil samples and rainfall data, the measurement apparatus was constructed. The HC-SR04 ultrasonic sensor, the SIM900L data transmission module, the DFRobot gravity pH sensor, the SHT20 soil temperature/humidity sensor, and the Arduino microcontroller are all integrated into the system. According to the analysis, the soil types on Nkpolu Road are sandy loam and loamy sand, and the intensity of the rainfall is often highest between July and September. The analysis's conclusion indicated that the road experienced flash floods because of the heavy rainfall and the soil's limited capacity to hold water. As a result, water runoff was heavy, particularly in July and September. When the system was installed on Nkpolu Road, it could detect flash floods when it rained and could send out warning alerts via a mobile device every six minutes. The alerts would first say "no flooding," but as the rain got heavier, they would change to "minor flooding," "moderate flooding," and finally "severe flooding," sending out warnings in real time as soon as each level of flooding was identified. "No flooding" was the warning issued on the day it drizzled. There was no warning signal issued when it did not rain at all. This system developed help road users on Nkpolu road to avert the road when flooded and use other available routes in real time.

Keywords: Flood, flooding, flash flooding, River state Nigeria, flash flooding warning system, mobile device, rainfall

Introduction

In general, flooding is one of the most dangerous natural calamities that the entire planet has to deal with. Numerous variables affect how vulnerable an area is to flooding and how much damage they do. Due to the severe effects of flash flooding on a community's environment, it is essential to assess the flooding status and devise a method of informing the stakeholders in advance so that they can take timely preparations and avoid being caught off guard.

According to the National Weather Service (2017), flash floods happen when low-lying terrain quickly becomes inundated, including washes, rivers, dry lakes, and depressions. Rainfall during a hurricane, tropical storm, or violent thunderstorm may be heavy, and water from melted snow or ice may pour over ice sheets or snowfields. Flash floods can be caused by the collapse of both a natural ice or debris dam and a man-made structure like a dam. The difference between flash floods and regular floods is that there is less than a six-hour window between the start of the rain and the start of the flooding. West African regions of Africa have more extreme or heavy rainfalls than snow. Changes in hydrological systems, which are one of the reasons for the risk of flooding, can result from a range of changes in how land is used. Less water accumulates in the basin and more runoff occurs as a result of wetlands being eliminated, urbanization brought on by development, and logging industry-related deforestation. The risk of flash floods increases as a result of urbanization, which also increases the quantity of impervious surfaces (such as roads, walkways, parking lots, etc.). Both the natural ecosystem and the developed environment are negatively impacted by flash floods. Flash floods can cause catastrophic damage to infrastructure and buildings as well as a wide range of unfavorable side effects on plants, human and animal lives, and livestock. Consequences in urban environments are particularly difficult (Diakakis *et al*., 2020).

Many people and animals have been killed by flash floods. People are harmed more frequently, and some people lose their houses. People are put under stress and suffer as a result of the interruptions to the water and energy sources. Flu, the pneumonic plague, dermatographia, and dysentery are only a few of the diseases and infections that are transmitted by flooding. Occasionally, creatures like snakes and insects make their way to the area and cause havoc.

Many academics have recently created a variety of techniques to lessen flash floods' detrimental effects in various areas. The majority of the remedies proposed are centered on warning the residents ahead of time about the potential for flash flooding at a given time so that appropriate preparations can be taken. To deal with the non-linear situation of flash flood detection and monitoring, only a non-linear technique may be applied. Current techniques like proportional integral (PI), proportional integral derivative (PID), and others are based on linear control systems. Evidently, as the entity being detected and monitored is non-linear in nature, real-time detection and monitoring requires the deployment of a non-linear controller, such as a system built with predictive modelling.

According to Frankenfield (2022), artificial intelligence (AI) refers to the simulation of human intelligence in machines that have been created to think and act like humans. Artificial intelligence is the ability of a machine to mimic the functions of the human brain, including learning and problem-solving.

The ideal attribute of artificial intelligence is the capability to reason and carry out activities that have the highest probability of achieving a specific goal. Machine learning (ML), which is a subset of artificial intelligence, is the concept that computer programs can automatically learn from and adapt to new data without the help of humans (Frankenfield, 2022).

Predictive modelling is a statistical technique that employs data mining and machine learning to anticipate and forecast potential future outcomes. It does this with the aid of historical and present data. It works by comparing data from the past and the present and extending what it learns to a model designed to forecast future events (Rami, 2020).

In this study, a predictive modeling approach is proposed to be used to develop a flash flood warning system.

Materials and Methods

The flash flood warning system proposed in this chapter consists of an Arduino MEGA 2560 microcontroller, a SIM900L module for data transmission to a mobile device for receiving alerts, and an HC-SR04 ultrasonic sensor, DFRobot Gravity pH sensor, and SHT20 soil temperature/humidity sensor. The system is designed to measure water levels in real time and provide early warning alerts to people using flash flood-prone roads.

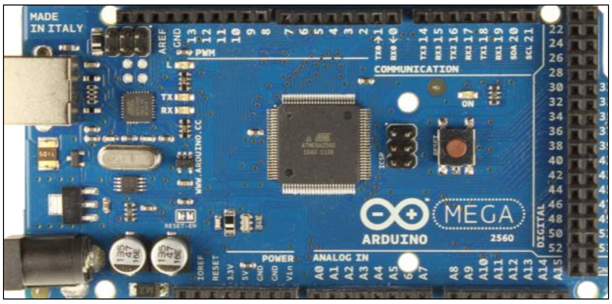

Fig 1: Arduino Mega 2560 (Arduino.cc)

The Arduino MEGA 2560 microcontroller is used to read the distance measured by the sensor, convert it to water-level measurements, and check if the water level exceeds a predefined threshold, which indicates a potential flash flood risk. If the water level exceeds the threshold, an alert is triggered, and the SMI900L module transmits the alert to a mobile device.

Fig 2: HC-SR04 ultrasonic sensor (Sheldon, 2022)

The HC-SR04 ultrasonic sensor is mounted on a pole above the water surface, and its position is calibrated so that the sensor faces the water at a perpendicular angle. The sensor sends out an ultrasonic wave, which travels toward the water's surface and reflects back to the sensor. The time taken for the wave to travel to the water surface and back to the sensor is measured and used to calculate the distance between the sensor and the water surface.

SIM900A GSM Module

The SIM900A GSM module was integrated into our system to enable real-time communication and SMS notifications. This module is responsible for sending alerts to relevant parties in case of flooding.

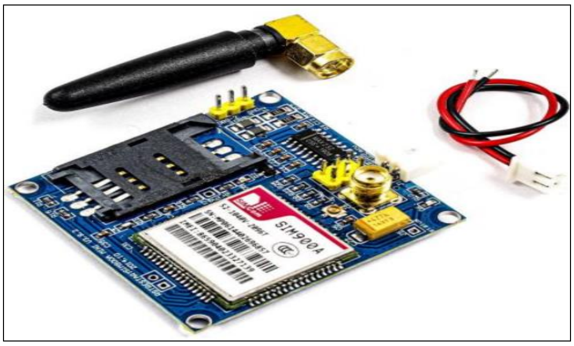

Fig 3: SIM900A GSM Module (Sheldon, 2022)

The following components are used in the flash flood warning system

1. **Arduino Mega 2560 Board:** The Arduino Mega 2560 is a microcontroller board with an ATmega2560 microcontroller at its core. It offers a large number of digital and analogue input/output pins, making it suitable for complex projects. It also offers the required computing power and interfaces to connect and control various sensors. The Arduino Mega will act as the system's brain.

2. **HC-SR04 Ultrasonic Sensor:** The HC-SR04 is an affordable and widely used ultrasonic sensor that measures distances by emitting ultrasonic waves and calculating the time it takes for the waves to bounce back. In our system, the HC-SR04 will be used to measure the water level in a particular area susceptible to flash floods.

3. **SIM900L GSM Module:** The SIM900L GSM module will be in charge of communicating the water level data obtained by the HC-SR04 sensor to a mobile device over the Global System for Mobile communication (GSM) network.

4. **DFRobot Gravity pH Sensor:** The DFRobot Gravity pH sensor, which measures a solution's acidity or alkalinity, can be used to analyze the pH levels of soil, revealing important details about the soil type.

5. **SHT20 Soil Temperature/Humidity Sensor:** The SHT20 sensor provides precise readings of soil temperature and humidity, which are essential for comprehending soil moisture content and the likelihood of flash floods.

Design Concept

The first step in implementing the flash flood warning system is to assemble the hardware components:

1. The HC-SR04 sensor's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. Its Echo pin is connected to a digital input pin on the Arduino, and the Trig pin is connected to a digital output pin on the Arduino. The sensor requires two digital pins (trigger and echo) to communicate with the Arduino. The trigger pin sends the ultrasonic pulse, and the echo pin receives the reflected pulse. By measuring the time it takes for the pulse to return, the water level can be calculated.
2. The SIM900L module's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. A serial communication connection between the Arduino and the SIM900L module is established using the appropriate serial communication pins. The module requires power connections and communication via AT commands to transmit data to the cloud. The Arduino will send commands to the SIM900L module to establish a GPRS connection and upload the sensor data.
3. The DFRobot Gravity pH sensor's VCC pin is connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. The SIG pin is connected to an analog input pin on the Arduino.
4. The SHT20 Soil Temperature/Humidity sensor's VCC pinis connected to the 5V pin on the Arduino board. Its GND pin is connected to the ground (GND) pin on the Arduino. The SDA pin is connected to the Arduino's SDA pin (for I2C communication), and the SCL pin to the Arduino's SCL pin.

The second step is programming the Arduino

Write a code in the Arduino programming language (based on C/C++) to read the sensor data from the HC-SR04, format it appropriately, and send it to the cloud via the SIM900L module. The code should include logic to handle communication with the SIM900L module, establish a GPRS connection, and upload the data to a mobile device. After the HC-SR04 sensor is connected to the Arduino MEGA 2560 microcontroller, and the SIM900L module is connected to the microcontroller's serial port. The software program for the microcontroller is then uploaded using the Arduino Integrated Development Environment (IDE).

The software program for the microcontroller consists of two main parts: the code for reading the distance measured by the sensor and the code for triggering alerts based on predefined thresholds. The code for reading the distance is implemented using the *pulseIn() function*, which measures the time taken for the ultrasonic wave to travel to the water surface and back to the sensor. The distance is then calculated using the speed of sound in the air and the time measured by the sensor.

The code for triggering alerts is implemented using an ‘if statement’ that checks if the water level exceeds the predefined threshold. If the water level is above the threshold, an alert message is sent through the SIM900L module to a mobile device.

Once the software program is uploaded to the microcontroller, the system is ready for testing. The HC-SR04 sensor is mounted at a suitable location above the water surface, and the system is powered on. The water level measurements are then monitored using a mobile device connected to the SIM900L module.

The third step is System Operation:

Once the system is set up and running, it will operate as follows:

1. The HC-SR04 sensor continuously measures the water level and sends the data to the Arduino Mega 2560.
2. The Arduino Mega 2560 receives the sensor data, processes it, and sends it to the SIM900L GSM module.
3. The SIM900L module establishes a GPRS connection with the mobile device using the GSM network.
4. The Arduino sends the formatted data to the SIM900L module, which in turn transmits it to the mobile device.

Finally, the integration of Arduino Mega 2560, HC-SR04 ultrasonic sensor, and SIM900L GSM module provides a robust solution for flash flood warning system. This system allows real-time monitoring of water levels in vulnerable areas and enables timely response to potential flash floods. By uploading the sensor data to the mobile device, stakeholders can have a comprehensive view of the flood situation, aiding in disaster preparedness and response efforts.

Implementation Considerations

During the implementation of the flash flood warning system, several factors need to be considered:

1. **Calibration:** Calibrate the sensors before deployment to ensure accurate readings. Follow the calibration procedures provided by the sensor manufacturers to achieve reliable and precise measurements.

2. **Power Supply:** Ensure a reliable and continuous power supply for the system. This can be achieved through a combination of battery power depending on the deployment location and requirements.

3. **Sensor Placement:** Place the sensors strategically to ensure representative measurements. Consider the soil depth at which the sensors are inserted, as it can affect the accuracy of the collected data. Install the sensors in locations that reflect the characteristics of the area under study.

Applications and Benefits

The flash flood warning system offer several applications and benefits:

1. **Early Warning System:** By monitoring soil moisture levels and analyzing temperature and humidity data, the system can provide early warnings for flash floods. This allows authorities and communities to take timely actions and implement preventive measures, potentially saving lives and reducing property damage.

2. **Water Management and Agriculture:** Understanding soil types and their characteristics is vital for effective water management and agricultural practices. The system can assist in optimizing irrigation strategies, identifying suitable crops for specific soil types, and managing soil erosion.

3. **Environmental Planning and Land Use:** The data collected by the system can contribute to environmental planning and land use management. It provides valuable insights into soil properties and their spatial distribution, assisting in making informed decisions about infrastructure development, urban planning, and ecological preservation.

In a nutshell, flash flood warning system plays a crucial role in mitigating the impacts of extreme weather events. The implementation of this system using the DFRobot Gravity pH sensor, SHT20 soil temperature/humidity sensor, HC-SR04 ultrasonic sensor and Arduino Mega 2560 board provides a powerful tool for assessing water level, soil conditions, understanding flood risks, and optimizing water management strategies. By continuously monitoring soil parameters, early warnings can be issued, and informed decisions can be made to prevent and mitigate the devastating effects of flash floods.
This flowchart shows the architectural view of the system and helps to visualize the workflow of the project,

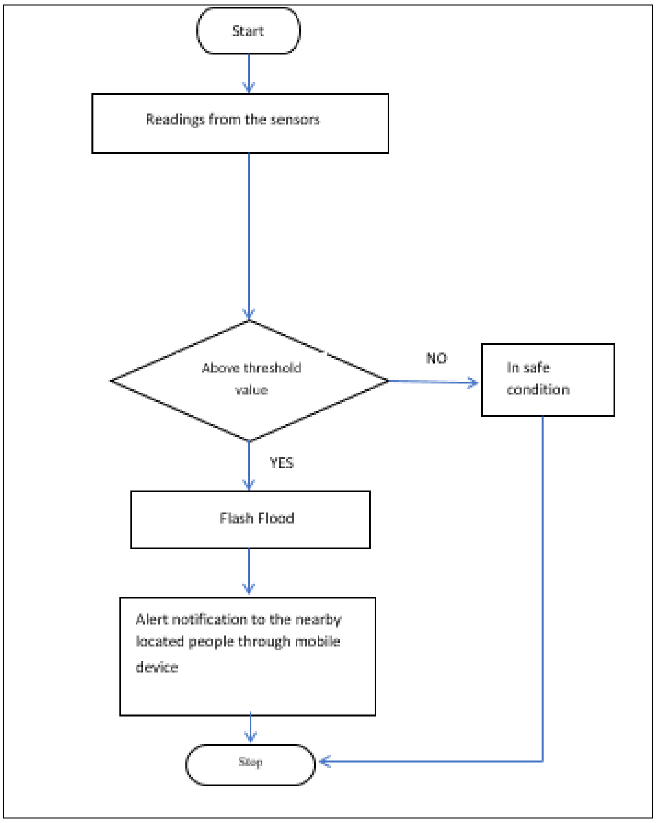

Fig 4: System Flow chat

Results

The study conducted in 2011 by Chiadikobi *et al*. states that rainfall in Port Harcourt peaks in July, August, and September, with August serving as a brief interlude. According to the study, Port Harcourt floods in reaction to rainfall, with the biggest floods occurring during periods of peak rainfall. The City always faces flooding between July and September of each year, mostly due to rains.
General information on the type, composition, moisture content, and permeability of the soil was revealed by two soil samples that were taken for analysis at Nkpolu Road in Port Harcourt. After both samples were analyzed, it was determined that one was sandy loam (SL) and the other was loamy sand (LS). The high percentage of sand (average over 80%), silt component (average 6%), and clay component (average over 13%), characterize loamy sand (LS). The majority of the time, loamy sand has a moderate moisture content of over 15% and an average permeability of 2.0 cm/sec x 10-3. Loamy soil permits water to pass through sometimes until the moisture content reaches its maximum and is no longer able to do so, resulting in flash floods. During the sampling phase, a single location for sandy loam (SL) soil samples was taken. The average percentage of sand in the soil is between 74% and 79%, the average percentage of silt is 4%, and the average percentage of clay is more than 19%. The sandy loam soil typically has an average moisture content of more than 12% and a permeability of roughly 1.7 cm/sec x 10-3. Floods are possible because the sandy loam soil fills in quickly and lets little water through. The findings of the soil analysis revealed that all of the sand fractions were medium and fine in size. The percentage of soil that was retained on a sieve with a 2.00 mm mesh size ranged from 87.73 to 97.89%, and the particle size diameter was between 0.84 and 1.92 mm. The samples' average moisture content was medium, and their permeability values were typically very low in one and too low in the other. These characteristics contributed to the flash flood that was seen during the rainy season. This was in line with a 2011 study by Chiadikobi *et al*. that found that the aforementioned characteristics of soils make them more prone to floods. The primary causes of flash floods are heavy rains that come primarily between May and September each year. Because of the city's highly moist soil, which is less porous and readily filled to capacity, runoff from heavy rainfall occurs frequently, leading to flash floods. Because of the city of Port Harcourt's rugged terrain, the drainage system is extremely intricate. Because most of the city is constructed on average low to somewhat sloppy terrain, flash floods can be quite destructive in certain places while remaining mild and low in others. Residents of the city are at risk of flash floods during the rainy months due to the city's high precipitation rates, sloppy terrain in some areas, less permeable soil with a moderate to high moisture content, poor land use and land cover, and high drainage density.

Summary

Due to the high impact of flash flooding in a locality's ecosystem, it is important to analyze the flooding situation and develop a way of warning the stakeholders so that they will not be caught off guard and as well as precautions to be taken on time.
Flash flood warning systems are essential for reducing the effects of such catastrophes because they provide timely and accurate information about water levels on roads that are vulnerable to flash floods. They also monitor soil moisture levels and provide temperature and humidity data of the soil and transmit the information to mobile phones via the SIM900L module.
Finally, a flash flood warning system was created that could inform drivers in real time about the flooding circumstances or states on Nkpolu Road in the Port Harcourt metropolis.

Conclusion

According to Pratatomo (2016), flash floods can be triggered either alone or in combination by intense rainfall, abrupt lake breaches, check dam collapses, and extremely steep terrain. Due to a number of issues with forecasting and the speed at which they inflict havoc, flash floods are particularly destructive and devastating floods that slow down and minimize emergency responses (Smith and Petley, 2009). Due to climate change variability, which produces rainstorms, snowmelt, glacial lake outbursts, and high intensity rainfall, flash floods are affecting people, wildlife, homes, and populations all over the world. These events lower living standards and result in significant economic loss as well as infrastructure damage (Ali *et al*., 2016). Floods are the most frequent and well-known natural disaster, with virtually no chance of prevention or mitigation. Therefore, efforts to lessen their influence or impact on the human population are crucial (Ali *et al*., 2016).

Protection, readiness, and prevention are the main objectives of flash flood warning systems in order to drastically reduce future flood-related expenses.

A warning system for flash floods is primarily designed to advise cars to stay off flooded roads in an effort to prevent or reduce casualties, property damage, and social disturbance. Their objective is also to promote deliberate planning for effective use of water and land.

Due to the speed and suddenness of flash floods, their brief duration, and the interaction of several natural variables, it is nearly impossible to prevent them; however, we must take action to lessen their negative effects on people and property. By gathering dependable data with enhanced technology and developing forecasting techniques based on modeling and risk assessment expertise, significant efforts are currently being undertaken to raise public knowledge and awareness of flash floods. Every time there is a flash flood, an assessment is required to determine what went wrong and what can be done better. Similar to how a thorough understanding of the causes that contribute to flash floods as they relate to Port Harcourt would help to mitigate the damage, accurate data on regions of risk will help to tame the danger. The study yielded the following results:

1. The average monthly rainfall in Port Harcourt varied from 136.0 mm to 232.58 mm.
2. The largest monthly rainfall totals were typically seen in July or September; these two months together account for 16% of the annual rainfall totals in each of those years.
3. Rainfall in Port Harcourt is responsible for almost half of the city's flooding.
4. 88% of the time that a study on rainfall was carried out, the total amount of rainfall exceeded 2000 mm.
5. Low permeability causes excessive surface runoff in most of the loamy sand and sandy loam soil samples collected along Nkpolu Road in the Port Harcourt metropolitan area.
6. Ultimately, the Port Harcourt metropolis's Nkpolu Road flood conditions could be instantly communicated to road users via the development of a flash flood warning system.

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