Early Flood Detection and Monitoring System Based on Wireless Sensor Network

Uyioghosa B. Iyekekpolo, Francis E. Idachaba and Segun I. Popoola
Department of Electrical and Information Engineering
Covenant University
Ota, Nigeria
benedictuyioghosa@gmail.com
segun.popoola@covenantuniversity.edu.ng

Abstract

Flooding is a natural phenomenon which has attracted global attention as a result of its negative impact on the society. Developing nations such as Nigeria have been predicted to experience increased flood occurrences in the coming decade. The events of flooding are unlikely to change, however, its impact on our society can be very well reduced. This paper focuses on providing early warnings to areas likely to be ravaged by flood events using Wireless Sensor Network (WSN). The system involves the deployment of sensor nodes at specific flood vulnerable locations for real-time flood monitoring and detection. Flood events relating to flash flooding and run-off water or overflow are successfully monitored in real time which saves individuals plenty of time to prepare against predicted flood occurrence, saving them from the aftermath of flood disaster. The system was tested via simulation of different flood scenarios, and the outcome was efficient and accurate.

Keywords
Wireless Sensor Network (WSN), Internet of Things (IoT), Flooding, Cloud Computing

1. Introduction

Flooding is a natural phenomenon which attracts global interest. It results in tremendous environmental destruction and loss of lives. Flooding is a result of substantial rainfalls, structural failures and a large number of human factors. Floods rely on precipitation amounts and rates, topology, geology, land use, and antecedent moisture condition (Daramola, Eresanya, & Ishola, 2018). In Nigeria, the rainy seasons occur each year from March to September. Early rainfall is usually in March with full commencement in April, and stops in the months of October each year, with a few showers in November to herald the dry season and the typical harmattan winds (Ologunorisa & Tersoo, 2006).

Flooding occurs in Nigeria in three major forms: coastal, river and urban flooding. Coastal flooding happens in a low-lying belt of mangrove and freshwater swamps along the coast. River flooding happens in the floodplains of bigger rivers. Flash floods are also attributed to rivers in the inland areas where sudden heavy rainfall in a short period of time can turn into destructive torrents. Also, urban flooding happens in towns, on flat or low-lying surfaces mostly where surface drainage more or less does not exist, or where existing drainage has been blocked with waste (Folorunsho & Awosika, 2001). Dams are among the most important human creations in the hydrological cycle built to impound water in reservoirs amid times of high flow, with the goal that it can be utilized to meet human water prerequisites amid times that natural flows are deficient (Acreman et al., 2000). However, the value of dams to human society has been questioned as a result of failures which have been attributed to causes of devastating flood events as seen in the flood incident resulting from the destruction of Eleiyele dam situated within the upper catchment of the Ona River in Ibadan North government area during the heavy rainfall on 26 August 2011 (Agbola, Ajayi, Taiwo, & Wahab, 2012). Also, the displacement of over a thousand residents in the Ogun River catchment area which occurred in October 2010 and the Mile 12 flooding in Lagos state were attributed to the sudden discharge of water from the Oyan reservoir (Muyiwa; Olajuyigbe, Rotowa, & Durojaye, 2012).

The first recorded flood event in Nigeria occurred in Ibadan in the year 1948. Subsequently, the city has been plagued with flood events with the most notable occurring on 26 August 2011 (Agbola et al., 2012). Flood ravaged the city causing tremendous damage to lives and properties. Notable infrastructures were affected which included the Eleiyele dam and the University of Ibadan. In September 2010, Goronyo, a town located in Sokoto State was ravaged by flood. The inhabitants and their settlements were completely destroyed. The release of water from Goronyo Dam was attributed to the cause of the flooding (Nwigwe & Emberga, 2014). In 2012, Nigeria experienced its worst flood disaster with 30 states affected. About seven million people were affected, with more than 363 lives lost and 2.1 million people displaced. Damages were estimated to be worth 2.6 trillion naira. Ojigi, Abdulkadir, and Aderoju (2013) analyzed this flood event and attributed the cause to the release of water from the Ladgo dam in Cameroon into the River Benue flood plain coupled with the effects of global warming.

The events of flooding is unlikely to change, however, its impact on our society can be very well reduced. Efficient forecasting and early warning systems can help mitigate the effects of flooding. Wireless sensor network can be used to collect information from a wide range of environmental phenomenon. (Cantuña, Bastidas, Solórzano, & Clairand, 2017; Muheden, Erdem, & Vançin, 2016) developed wireless sensor networks to detect forest fire incidents in real time. Fosalau, Zet, and Petrisor (2016) developed a wireless sensor network system aimed at monitoring land slide occurrences in real-time. The sensors which are also capable of predicting the degree of glide are positioned in areas prone to landslide and communicate wirelessly, conveying data to a monitoring and processing hub. In India, frequent farm theft occurrence resulted in developing a system which employs wireless sensor network to detect movement around farm borders (Nagpal & Manojkumar, 2016). The sensors were placed at low distances in order to detect both animal and human movements. When movement is detected, a trigger is activated which raises an alarm and also sends a text message to the farm owner. Radio Frequency Identification (RFID) tags are configured in order to prevent the system from raising a false alarm when authorized persons enter the farm.

Zhuang, Junior, Cheong, and Tam (2011) designed a wireless sensor network to combat the challenges of flood in low-lying areas in China. Flood detection sensors, microcontroller and Xbee communication transceiver are embedded in a node which monitors flood events. The system detects flood occurrence and sends a notification through Public Switched Telephone Network (PSTN) to a control station. In another work, Castillo-Effer, Quintela, Moreno, Jordan, and Westhoff (2004) developed a self-adapting and self-sustaining wireless sensor network which is void of third-party interference for detecting flash flood occurrence in Mérida city. In a related work, Islam, Islam, Syrus, and Ahmed (2014) developed a wireless network system for the control of flash flooding in Bangladesh. Water level transducers, microcontroller were embedded in the sensor node and an Ethernet module for wireless communication. Real time monitoring was achieved. Chang and Guo (2006) deployed a state-of-the-art wireless sensor network technology capable of mapping out flash flood occurrences in urban areas. Three key modules were embedded in the system namely: the flood detection sensors, an embedded camera for video feed and a third module which processes the collected data from the previous modules in real time. The third module which is a server also has the capability to process Digital Elevation Model (DEM).

In this paper, a wireless sensor network with two nodes is designed that efficiently monitors and detects flood levels. The system utilizes two sensors namely: Rain sensor module and water level sensor. The sensors are embedded in each node and are controlled by a Wemos D1 microcontroller. Additional functionalities such as GPS and memory are embedded within the nodes to provide extra features. The embedded system is developed with the aim of monitoring water level at two particular flood prone areas, and when flood levels get to a set threshold either as a result of rainfall or movement of water or both, a trigger is set off, and appropriate authorities are alerted of the impending danger. The remainder of the paper is organized as follows; In section 2, we present the system design. In section 3, we present the system operation. In section 4, we provide the simulation results. The paper is concluded in section 5.

2. Materials and Methods

2.1. System Design

In this section, the design of the wireless sensor network for flood detection and monitoring is presented. As shown in Figure 1, the system consists of five stages namely:

a. Information gathering stage
b. Processing stage

c. Transmission stage
d. Collection/storage stage
e. Notification stage.

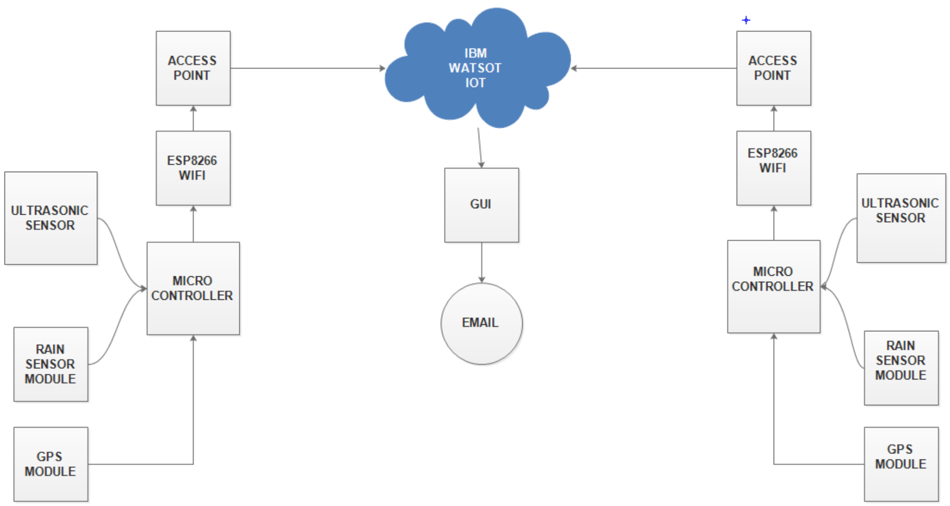

Figure 1. System design

The system has two sensors nodes monitoring two flood prone sections A and B, whereby flood water movement from section B is expected to result in flooding of section A. The information gathering stage comprises of transducers which includes a rain sensor module and an ultrasonic sensor. Also embedded in each nodes are GPS modules and SD card module for additional functionalities. Data received from the sensors and the GPS module are processed by a Wemos D1 Microcontroller and transmitted wirelessly via an embedded Wi-Fi module. A cloud service provider (IBM BLUEMIX) is responsible for collection and monitoring of the data. It also sends notification messages via email. A website is also provided to monitor the data which can be accessed from any internet enabled device.

2.1.1. Microcontroller

The Wemos D1 microcontroller utilized in the design of this system is based on the ESP8266 Wi-Fi module and the Arduino Uno. Wemos D1 is based on ESP-8266EX microcontroller having a 32-bit processor. It consists of 11 digital pins and a single analogue pin. It has a flash memory of four megabytes and 3.3V operating voltage. In size, it is 68.6mm * 53.44mm with a weight of 25gram. The Wemos D1 microcontroller is preferred to the Arduino because of its inbuilt Wi-Fi module and cost, although the Arduino Uno contains more digital and analogue pins. In terms of similarities, the Wemos microcontroller is programmable with the Arduino IDE which has similar programming structure with few notable changes. Since the Wemos D1 microcontroller is a breakout board, its digital pins do not match the digital pins of the Arduino microcontroller. It is important to note the pin configuration before other devices are connected in the microcontroller.

2.1.2. Microcontroller-Based Rain Sensor Module

The rain sensor module is based on the operation of the LM393 operational amplifier. The LM393 is a comparator which produces an output of either a 1 or a 0 after comparing two input voltages. Comparator circuits are used to determine if an input has reached a set value. The rain sensor module is used for detecting the presence of rainfall, acting as a switch when raindrop touches its board. The module measures moistness through analog output pins and provides digital results. More wetness on the board results in lower output voltage while less wetness results in greater output voltage. The operating voltage of the module is five volts and it has a potentiometer sensitivity adjustment in which clockwise increases sensitivity and anti-clockwise reduces sensitivity. The module is made up of VCC, ground, analog output and digital output pins which are connected to five volts, ground, analog and digital pins of the Wemos D1 microcontroller respectively.

2.1.3. Ultrasonic Sensor

Ultrasonic sensors work on the law of propagation of sound waves. They convert electrical energy to mechanical energy and back in the form of sound waves, similar to a RADAR. When an ultrasonic sensor detects an electric pulse, it transmits sound waves at regular intervals across a spectrum of frequencies. When the sound waves transmitted comes in contact with an obstacle, the sound waves are reflected back as echo signals to the ultrasonic sensor, and electric pulse is generated. The time-span between signal emission and receiving of echo is calculated as the distance.

$$Timespan = Signal\ transmission\ time - Signal\ reception\ time \tag{1}$$

$$Distance\ in\ cm = 0.017\ \times\ Time\ span \tag{2}$$

Materials which reflect sound waves can be detected irrespective of their shapes and sizes. Beam spread and target angle are important criteria of ultrasonic sensors. Beam spread defines the area where by a round material will be detected if it passes through the beam while target angle calculates the maximum amount by which the obstacle can be adjusted and still be detected by the sensor.

The HC-SR04 ultrasonic sensor has an operating voltage of 5 volts DC and a power consumption of 20mA. Detection range is from 0.02m to 4m, with a range accuracy of 0.002m. This sensor is employed in this design because it has an advantage of non-contact over water-level sensor. Water level sensor has to make contact with the medium before the flood level is detected. This has a draw back in the sense that there might be situations whereby the surface of the water level sensor retains water after contact giving rise to false reading which can compromise the entire system.

The HC-SR04 module comprises of a transmitter, receiver and a control unit. Its pins are VCC, GND, Trig and Echo pins which are connected to 5 Volts, GND and any two digital pins of the Wemos D1 microcontroller respectively. The Echo pin sends echo signal which detects presence of obstacle, sound wave is sent back to the ultrasonic sensor which is detected by the Trig pin. The distance is calculated from the time between sent echo signal and received trig signal.

2.1.4. Secure Digital Card Module

Secure Digital (SD) is a non-volatile memory card format developed by the SD Card Association for use in portable devices. It was introduced in the year 1999 as an advancement on multimedia card (MMC). The micro SD reader provides the solution of sending data to an SD card and also reading data from an SD card. It provides developers with the flexibility of adding a storage feature to embedded devices. With uses ranging from audio, video and graphics, it expands the limited memory capacities of most microcontrollers. The SD card acts as a backup, collecting and storing sensor data from both the ultrasonic sensor and the rain sensor module. It creates a separate file for each sensor information. Data collected is saved as a text format which provides the four gigabyte memory card enough storage space to store information over a long period of time.

Data stored over a 30 seconds period for both sensors occupied roughly 504 bytes of memory, which approximates to a kilobyte every minute. If the system operates for a 24 hour period, a total of 1.4 megabyte will be used up. At this rate, it will take about 2,875 days for the memory card to be completely used up. The micro SD reader supports a memory expansion of up to 32 gigabyte. The micro SD reader is compatible with the Wemos D1 microcontroller as it communicates using the standard SPI (Serial Peripheral Interface). This consist of the SPI buses; Chip select (CS), Serial clock (SCK), Master out Slave in (MOSI) and Master in Slave out (MISO). These pins can be programmed to enable reading from and writing to the SD card. The power pins (Vcc and GND) are connected to the power pins of the Wemos D1 microcontroller. The SPI buses MISO, MOSI and SCK must be connected to digital pins D6, D7 and D5 of the Wemos D1 respectively, while CS can be connected to any digital pin of the Wemos D1.

2.1.5. Global Positioning System (GPS) Module

The global positioning system was developed by the U.S air force in the year 1960. It currently has a total of 33 satellites that revolve round the earth at regular intervals to provide information on location and time at an accuracy of five meters. Initially, the system was developed strictly for military use, and not until the 80s before civilians were allowed access. Any location on the planet has at least four satellites at any given time.

The GPS modules NEO-6M embedded in the design works with the principle of trilateration. Initially when the module is powered on, it attempts to get a 'lock' on nearby satellites. This process can take as long as 12.5 minutes and it is best performed outdoors. Once a lock is obtained, it downloads orbital data of the satellites and stores it for future reference. In order to calculate its exact location, it calculates the distance from each satellites it is locked on to. This is done by the receiver, which multiplies the transmitted signal's velocity with the duration it took for the receiver to get the signal. The velocity, which is the speed of light is already known.

The NEO-6M has an EEPROM (Electrically Erasable Programmable Read-Only Memory) for saving its configuration parameters, a data backup battery and an operating voltage of three volts to five volts. It has an antenna with cable length of 20mm, making it in easy choice to be embedded in the design. Pinout configuration of the NEO-6M V2 GPS module is VCC, GND, RX and TX which are connected to the power, and two digital pins of the Wemos D1 microcontroller respectively.

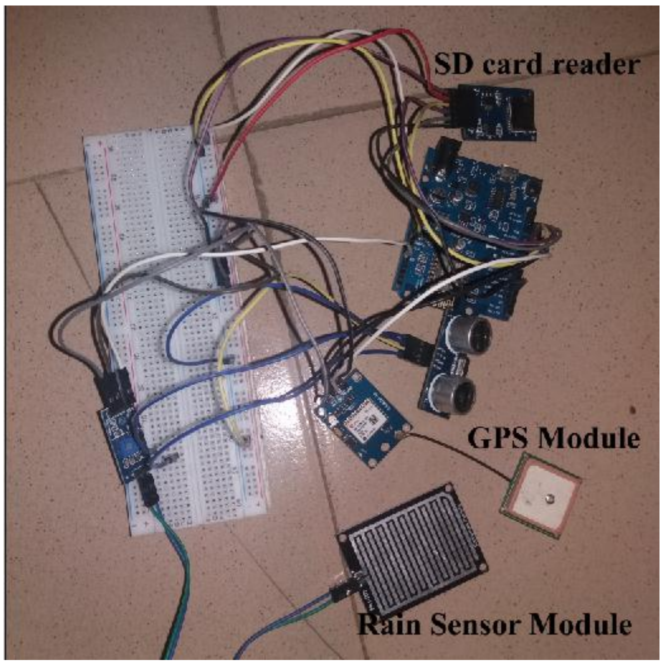

Figure 2. Microcontroller and sensors connected to a breadboard

2.1.6. Power Consumption Requirements

Since the nodes will be deployed in rough terrains, it is necessary they remain operational for some time without interference, it is important to provide them with power options. For power considerations, the voltage and current are major factors in determining the best power solution. The Wemos D1 microcontroller which is the heart of the setup, plays a major role. The microcontroller has three possibilities of providing external power to the node. Firstly, it has a micro USB port which has an operating voltage of five volts. This port which is also used for putting the microcontroller in programmable mode can also provide sufficient power to keep the system functional. Secondly, it has a power jack port which can take in input voltage ranging from 9-24 volts. The microcontroller has an inbuilt voltage regulator which regulates it down to the operating voltage of the microcontroller, although caution should be applied as too much voltage will result in generation of heat. The third, which is our source of consideration is the V input pin located among the power pins of the microcontroller. It has a voltage range of 7-12 volts and the voltage regulator brings it down to nominal voltage value.

AA rechargeable batteries of 1.26 volts with current rating of 4600mAh are employed in this design. Four AA batteries are connected in series, giving a total of 5.04 volts. An MT3608 module is used to boost the voltage from 5.04 volts to the required 7 volts of the VIN pin. In a bid to conserve energy, power saving method is employed by the microcontroller. When the microcontroller detects values that do not pose a threat to the goal of our design (such as low flood levels and no rainfall), the microcontroller goes into a sleep mode. The microcontroller only wakes up when it detects a certain level of flood for a certain amount of time. With this approach, only the ultrasonic sensor will be monitored at certain intervals, and there will be no wireless transmission to the cloud server except in cases where it is important. This will save a lot of energy and extend the duration of non-interference.

2.1.7. IBM Watson IoT Data Analytics Platform

A cloud service provider is responsible for sensor data collection and analysis. This system employs the IBM Watson IoT platform which offers sensor devices robust application access to aid in data analytics and web applications. It provides management options, stores data and connects to a wide range of devices and gateways and offers secure communication using MQTT and TLS (Transport Layer Security). Node-RED which is a virtual tool for wiring internet of things developed by IBM is used to provide a browser-based flow editor which enables users display sensor data in a graphical user interface (GUI).

2.2. System Operations

The objective is to design a system that detects and monitors flooding in real time through measurement of water level both during and after rainfall which are continually detected by sensor nodes, providing real-time alerts and determining the exact location. The information is transmitted in real time to a cloud service which monitors events. Elements contained in each node are; Rain sensor module, Ultrasonic sensor, GPS module, SD card module, Wemos D1 microcontroller and a battery bank.

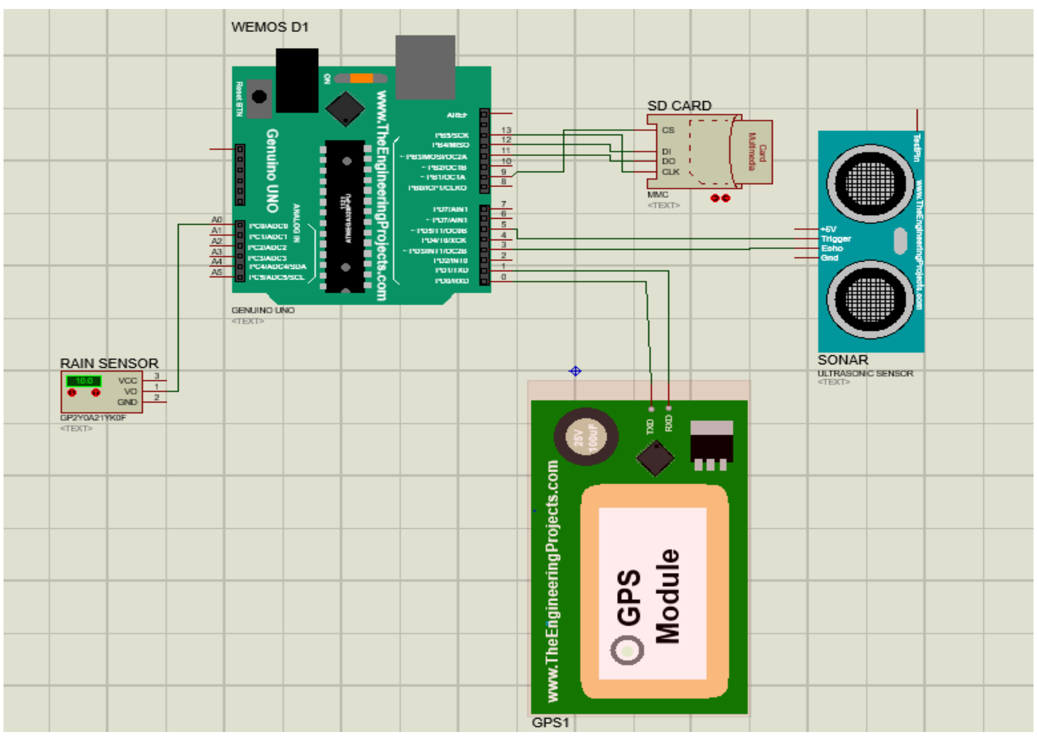

Figure 3. Circuit diagram of a sensor node

Figure 3 shows the circuit diagram of the warning system. Data from the ultrasonic and rain-drop sensors are processed by the microcontroller and stored in the SD card module and transmitted through the internet to the cloud service via the ESP8266 wireless module. The GPS module is attached to the microcontroller to get the exact location of the node in order to detect the location of the flood. A battery bank is attached to the node in order to provide flexibility of choosing location, as power supply is a necessity to function.

For flood events, since the sensor nodes are non-mobile, the scope is streamlined to wireless sensor network with immovable nodes. The projection of the system is also considered, providing it with flexibility to accommodate network growth since the system can be implemented in large scale. Once a sensor node is powered on, the ESP8266 wireless module attempts to connect to an access point. This continues until a connection is established and an IP address is obtained. After this, an MQTT connection is made to the IBM Bluemix server. If the authentication provided matches that of the server, the sensor node subscribes to a topic on the server. The SD card reader begins initialization, enabling it for read and write functions. Two text files, if not already present are created on the memory card as locations to store sensor data. It is important to close each file after creation/opening as only one file can be accessed at a particular time.

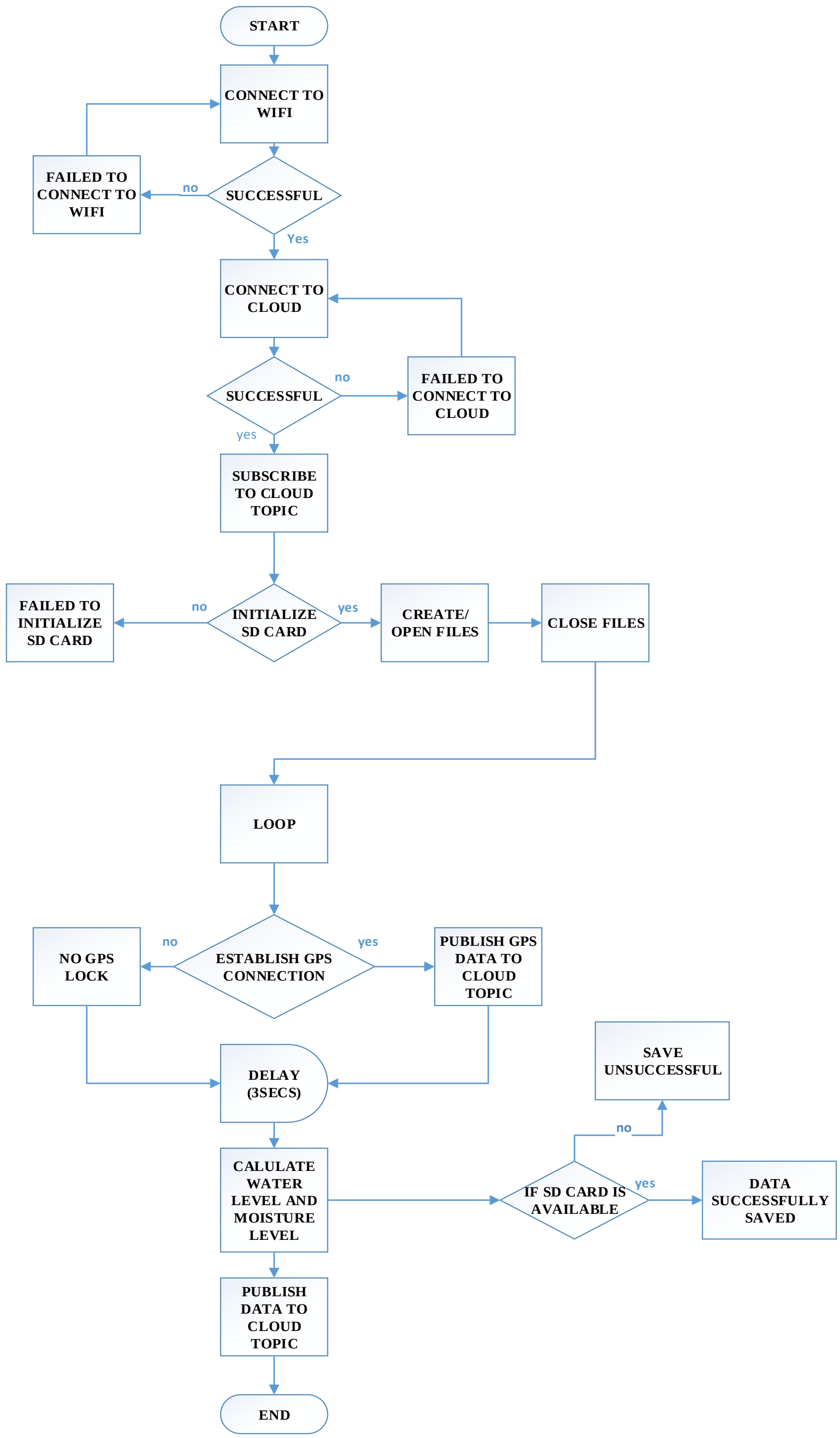

Figure 4. System flowchart

The GPS module and the sensors are initialized, and a loop kicks in. If the GPS module has a satellite lock, it publishes both latitude and longitude coordinates on the Watson IoT platform, which it has already established an MQTT subscription. Both ultrasonic and rain module sensors measure their physical phenomenon, publish their data on the Watson IoT platform and also save their data on the text files created on the memory card. The Watson IoT platform handles the responsibility of analyzing the data, creating a graphical user interface for displaying the data and creating event triggers for the analyzed data.

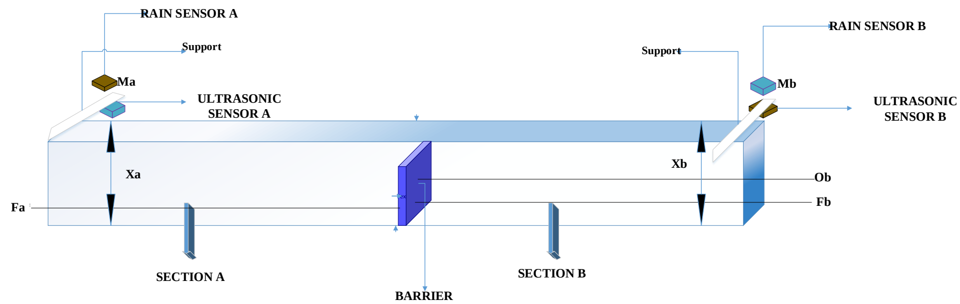

Figure 5. Diagram showing sensor placement

For practical deployment of the system design, a drum which has a height of 36 inches and a diameter of 24 inches is employed for this process. The drum is cut in vertical halves to produce a hollow surface in both halves. Any half is selected and used to design a flood scenario. The selected half is demarcated into two sections by a wooden barrier cut into shape to fit into the halved drum. The length of the barrier is just enough so that water can overflow from one section of the drum to the other section. The sections are identified as section A and section B. Two levels are marked out in both sections, with the first level indicating flood level of the section and the second indicating overflow level, which is the level of likelihood of water overflow from either sections to another section.

Figure 6. Complete system setup

Sensor nodes are positioned at both sections of the halved drum and initial readings are carried out. From figure, both ultrasonic sensors A and B are positioned at the bottom of the supports at both sections in order to effectively detect change in flood level while rain sensors A and B are placed at the top of the support to effectively detect the presence of rain.Distance of both ultrasonic sensors A and B from ground level is 61cm. The ultrasonic sensor detects increase in flood level as reduced distance i.e. flood increase is detected in descending order. To appropriately portray flood events graphically in ascending order, map function is used to reverse the readings of the ultrasonic sensors. In other words, low flood levels are mapped to low values and increased flood levels are mapped to higher values. The ultrasonic sensor takes default readings for the two levels marked out in both sections which are used for setting threshold values in the system.

3. Results and Discussions

3.1. Setting Threshold Values

Initial setup for the system is carried out with the distances between the ultrasonic sensor and the base of the drum recorded for both sections. Also, initial flood threshold values are set for both sections and an overflow threshold is set at section B. Rain sensor values are set to a minimum value of 10, indicating lack of rainfall and is expected to increase when rain is detected.

Table 1. Initial setup parameters

	Parameters	**Readings**
Section A	X_a : distance measured by ultrasonic sensor A when drum is empty	X_a = 82cm
	M_a : Rain sensor A reading (no rainfall)	M_a = 10
	F_a : Flood threshold at section A	F_a = 85cm
Section B	X_b : distance measured by ultrasonic sensor B when drum is empty	X_b = 80cm
	M_b : Rain sensor B reading in the absence of rainfall	M_b = 10
	F_b : Flood threshold at section B	F_b = 82cm
	O_b : Overflow at section B	O_b = 84cm

Table 2. Multiple flash flood events parameters

		Parameters	**Readings**
Section A	**Event 1**	XR_{a1} : range measured by ultrasonic sensor A MD_{a1} : Rain detected by rain sensor A (Yes/No) F_{a1} : Flood threshold at section A Ta_1 : Time taken to reach flood threshold	XR_{a1} = 82 – 94 (cm) MD_{a1} = Yes F_{a1} = 88cm Ta_1 = 18t
	Event 2	XR_{a2} : range measured by ultrasonic sensor A MD_{a2} : Rain detected by rain sensor A (Yes/No) F_{a2} : Flood threshold at section A Ta_2 : Time taken to reach flood threshold	XR_{a2} = 85 – 98 (cm) MD_{a2} = Yes F_{a2} = 92cm Ta_2 = 18t
	Event 3	XR_{a3} : range measured by ultrasonic sensor A MD_{a3} : Rain detected by rain sensor A (Yes/No) F_{a3} : Flood threshold at section A Ta_3 : Time taken to reach flood threshold	XR_{a3} = 80 – 99 (cm) MD_{a3} = Yes F_{a3} = 96cm Ta_3 = 35t
Section B	**Event 1**	XR_{b1} : range measured by ultrasonic sensor B MD_{b1} : Rain detected by rain sensor B (Yes/No)	XR_{b1} = 80 – 93 (cm) MD_{b1} = Yes F_{b1} = 86cm

	F_{b1} : Flood threshold at section B Tb_1 : Time taken to reach flood threshold	Tb_1 = 30t
Event 2	XR_{b2} : range measured by ultrasonic sensor B MD_{b2} : Rain detected by rain sensor B (Yes/No) F_{b2} : Flood threshold at section B Tb_2 : Time taken to reach flood threshold	XR_{b2} = 82 – 93 (cm) MD_{b2} = Yes F_{b2} = 90cm Tb_2 = 35t
Event 3	XR_{b3} : range measured by ultrasonic sensor B MD_{b3} : Rain detected by rain sensor B (Yes/No) F_{b3} : Flood threshold at section B Tb_3 : Time taken to reach flood threshold	XR_{b2} = 86 – 96 (cm) MD_{b2} = Yes F_{b2} = 94cm Tb_2 = 40t

3.2. Flash Flooding at Multiple Locations

Flash flooding at independent locations were experimented using both sections A and B. initial distances measured by both ultrasonic sensors when the drum was empty. Both rain sensors detect the presence of rainfall over time which results in water level reaching its flood threshold at time Ta and Tb for sections A and B respectively. This experiment was carried out three times each for both sections.

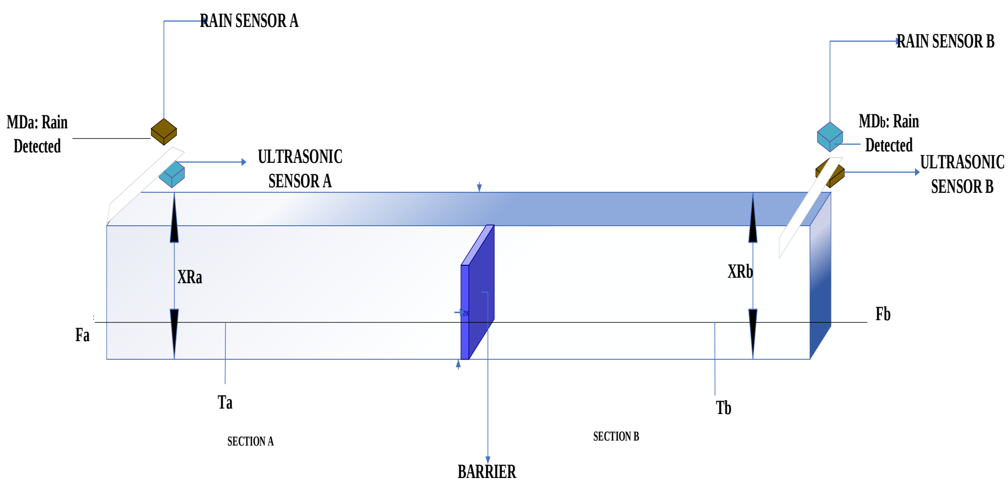

Figure 7. Diagram showing parameters for flash flood

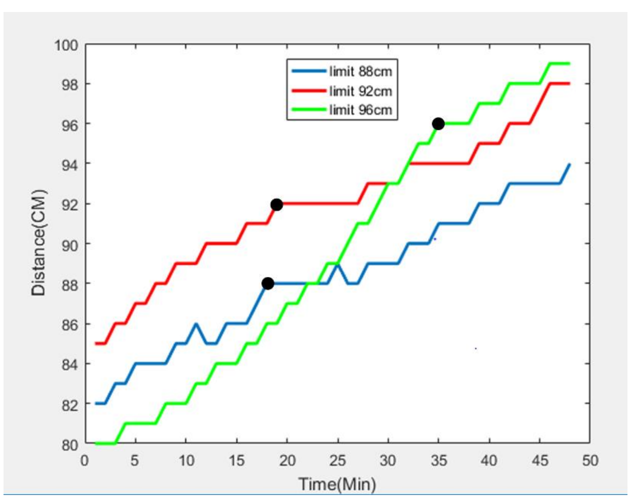

Figure 7: Three flash flood events at section A

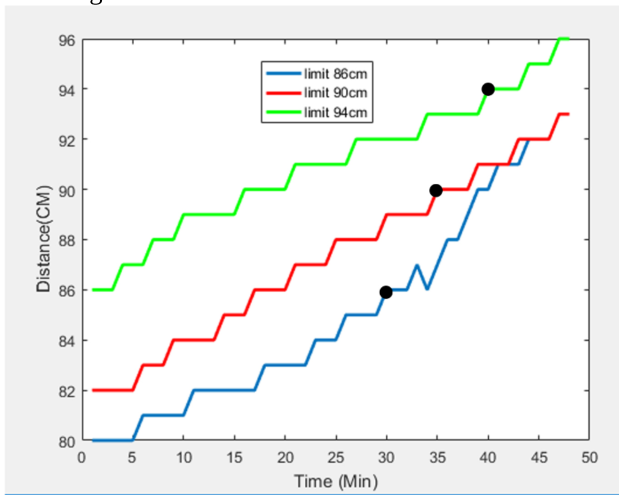

Figure 8: Three flash flood events at section B

Figures 8 and 9 are graphical representations of the three flood events at both sections A and B. Each event employs the different parameters shown in Table 2. The ascending nature of the lines on the graph indicate water rise as a result of different intensity of rainfall over a period of time. Marked points on each event on both figures 8 and 9 represent the flood threshold reached for each event. As a result of continuous rainfall, water level rises above the flood threshold for each event in both sections. Also, the time taken for water level to rise to the point of flooding (Ta and Tb) can be deduced from both figures.

3.2. Single Location Overflow

Flood event resulting from water overflow was experimented. Rainfall in section B resulted in increase in water level of the section which led to overflow of water into section A, causing it to each reach flood limit.

Table 3. Parameters for overflow event leading to flow

Parameters	**Readings**
XRa_1 : range measured by ultrasonic sensor A	XRa_1 = 85 – 96 (cm)
XRb_1 : range measured by ultrasonic sensor B	XRb_1 = 80 – 88 (cm)
MD_{a1} : Rain detected by rain sensor A (Yes/No)	MD_{a1} = No
MD_{b1} : Rain detected by rain sensor B (Yes/No)	MD_{a1} = Yes
F_{a1} : Flood threshold at section A	F_{a1} = 88cm
O_{b1} : Overflow threshold at section B	O_{b1} = 88cm
Ta_1 : Time taken to reach flood threshold	Ta_1 = 32t
TO_{b1} : Time taken to reach overflow threshold	TO_{b1} = 28t

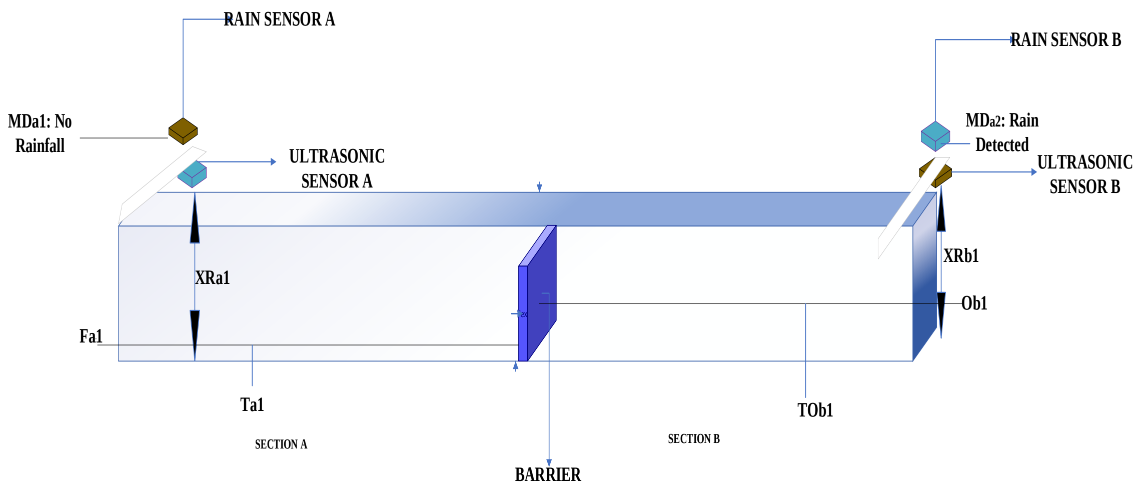

Figure 10. Diagram showing parameters for flood overflow

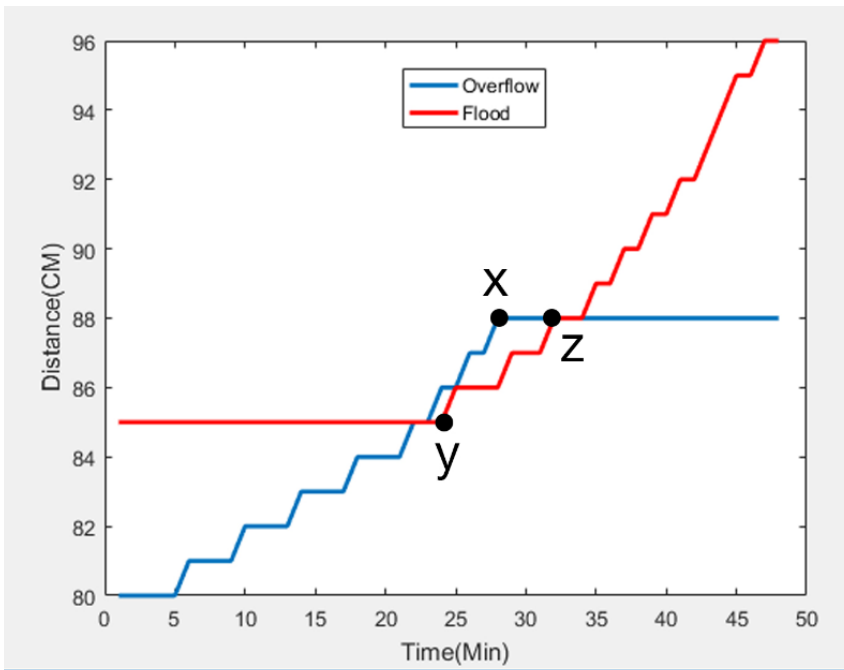

Figure 11. Flood event resulting from overflow

In the experiment, parameters indicated in Table 3 was set up. Rain sensor at section B detects rain and as a result, water level rises gradually reaching the overflow threshold at time TOb1. Section A whis is not experiencing rainfall begins to detect increase in water level as a result of water overflow from section B. At time Ta1, water level reaches flood threshold at section A and continues to rise.

From figure 11, point x indicates water overflow level at section B. It remains constant upon reaching its overflow level because the section has reached its saturation point and cannot contain more water. With continuous rainfall, water is forced to flow into section A. point y indicates water level increase detected at section A as a result of water overflow from section B. point Z indicates flood threshold reached at section A as a result of overflow from section B.

The total time of flood occurrence at section A can be calculated from the time taken by section B to reach its overflow threshold (TOb1) and the time taken by section A to reach its flood limit (Ta1)

4. Conclusion

Development of a wireless sensor network has been successfully carried out, with considerations on area of deployment and efficiency. The system utilizes state-of-the-art technologies in providing solutions to real-life challenges, thereby bringing relief to people in communities ravaged by persistent flood occurrences. The system designed in this paper shows a concise improvement of existing sensor networks and also goes a step further in trying to provide early warnings by actively monitoring water flow as well as rainfall. The sensors utilized were fundamental in obtaining the required data necessary for monitoring and predicting flood events, and a live feed was also actualized for end users. Several test scenarios were designed, and the system was utilized in providing early warning signs. The results were efficient and accurate.

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Biographies

Uyioghosa B. Iyekekpolo obtained his Bachelor of Engineering (B.Eng) degree in Electrical and Electronics Engineering from Ambrose Alli University in 2014. He completed his Master of Engineering (M.Eng) degree in Information and Communication Engineering at the Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria. His research interests are in Internet of Things (IoT), Wireless Sensor Networks (WSN), embedded systems, and biomedical engineering.

Francis E. Idachaba is a Professor of Communication Engineering in the Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria. He obtained his PhD in Electronics and Telecommunication Engineering from the University of Benin in Edo State Nigeria. With over 18 years in the academia, he has within the last five years served as a research fellow in 2013 at the Massachusetts Institute of Technology in the US and as a Research Advisor with Shell Petroleum Development Company in Nigeria between 2010 to 2012. He has over 100 publications in both journals and conferences. He is actively involved in Oil and Gas research with special interest in the development of oil and gas spill containment systems, digital oilfields, enhanced oil recovery among other interests. He is also actively involved in Communication Engineering research working on 5G communication, e-Health and Internet of Things.

Segun I. Popoola completed his Master of Engineering (MEng) degree in Information and Communication Engineering at the Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria with a *Distinction* in June, 2018. He was the Overall Best Graduating Masters Student in Covenant University (2017/2018). Segun graduated from Ladoke Akintola University of Technology, Ogbomoso, Nigeria in 2014 with a BTech (*First Class*) degree in Electronic and Electrical Engineering. He was awarded the Best Graduating Student in the Department of Electronic and Electrical Engineering by the Faculty of Engineering and Technology in conjunction with the Nigerian Society of Engineers (NSE). He has authored and co-authored more than fifty (50) academic papers published in international peer-reviewed journals and conference proceedings. His research interests are, but not limited to: wireless communications, radio propagation modelling, Internet of Things (IoT), machine learning, and data analytics.