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Development of a Low Cost Community Based Real Time Flood Monitoring and Early Warning System

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ABSTRACT

In most developing countries, flood monitoring and early warning systems are critical due to the devastating effects of flooding on lives and properties. Unfortunately, in developing countries a vast majority of citizens living in high risk flood zones do not have any flood monitoring/early warning system and in the eventuality of a flood, lives, properties and means of livelihood are greatly affected. This paper therefore proposes the development of a low cost, community based, real time flood monitoring and early warning system. A prototype was implemented to validate the proposed flood monitoring and early warning system using low cost of the shelf components. The proposed system employs the use of low cost Arduino Uno microcontrollers and other low cost devices to detect potential flood and alert the community in real time. Results obtained shows that the proposed system is robust and effective for flood monitoring and early warning.

Keywords: Flood Monitoring, Early Warning System, Real Time, Low Cost

I. INTRODUCTION

Floods are some of the most common causes of weather-related global disasters, causing billions of dollars' worth of damages and the loss of hundreds of thousands of lives [6, 16]. In Nigeria, solutions to flooding and its impact are critical issues of importance for exploring more realistic flood risk mitigation and disaster management measures [7, 8]. Development of smart, accurate, real time flood monitoring and early warning system are key elements in flood risk and disaster management and should be made a priority for action [1, 2, 3 and 4]. In many developing countries including Nigeria, majority of the citizens living in high risk flood zones do not have any flood monitoring/early flood warning systems. Cost is a major precursor to this, therefore the availability of cheap and capable technologies, will further encourage the development of real time flood monitoring/early warning systems for developing countries. Community based real time flood monitoring/early warning systems go a long way in mitigating against the devastating impact of flood on lives and livelihood of the poor and most vulnerable in the society, especially in developing countries [4, 8, 9 and 16]. In this regard, this work proposes the development of a community based, low cost, real time flood monitoring and early warning system.

This paper is organized as follows. The related work done in this area of research is reviewed in Section 2. Section 3 explains our proposed method in detail. Section 4 presents and discusses the experimental results obtained and finally, summary and conclusion are found in Section 5.

II. RELATED WORK

In 2006, the United Nations (UN) released its Global Survey of Early Warning Systems which highlighted four major elements in natural hazard early warning systems. These are: Risk Knowledge**,** Monitoring and Warning Service**,** Dissemination and Communication**,** and Response Capability [17]. To achieve the required elements, traditionally human intervention was highly required to collect data from the locations of interest. This is fast fading away as automatic sensors and data logger systems are now being deployed to reduce operational human resource requirements [18]. These automatic sensors and data logger systems provide high temporal data resolution and permit local automatic and unsupervised data gathering which reduces environmental perturbation.

In [4] a system was proposed in their paper titled "Community based early warning systems for flood risk mitigation in Nepal" identified the short lead times available for early warning as a major problem to be tackled and proposed the development of a robust operational flood forecasting methodology to compliment the community based systems.

An intelligent flood monitoring system for Bangladesh using wireless sensor network was developed by [10]. Their paper presented a neuro-fuzzy controller based flood monitoring system using wireless sensor network.
A prototype system for flood monitoring based on flood forecast combined with COSMO-SkyMed and Sentinel-1 Data was implemented by [12]. They developed a system that was able to trigger SAR image acquisitions based on flood forecasts and thereafter produce a near real time flood mapping system for the affected areas.

A visual sensing technique for urban flood monitoring was developed in [13]. The technique is an image-based automated technique that monitors flood formation and analyses the water level fluctuations.

A framework that attempts to reduce the effect of flooding by providing a real time monitoring method of floods near a river was proposed by [14]. The design framework is made up of components which include; Arduino microcontrollers, water level sensors and wireless sensor networks. The framework was designed for rural communities in Rwanda.

Most of the developed systems highlighted above are not suitable for developing countries due to high cost, complexity, limited internet and mobile network coverage. For example, the works of [12, 14] respectively, relied mainly on the use of remotely sensed satellite data which is not well suited for flood monitoring in terms of cost and real time capabilities especially for small water bodies [5, 14, 15]. The use of neuro fuzzy controllers as described in the work of [10] introduces greater computational complexities and cost. Furthermore, most neuro fuzzy systems make use of gradient descent algorithms for the learning process [19] and these algorithms are typically plagued with convergence issues [20]. In the work of [11, 13], no physical implementation of the framework was reported.

The proposed system is a low cost, real-time fast flood monitoring and early warning system. It is easy to operate with low computational complexity which makes it ideal for communities with fluctuating or limited access to mobile network coverage and internet accesses.

III. METHODS AND MATERIAL

A prototype of the proposed system was implemented using low cost, commercial off the shelf hardware components and the selected study area was a semi urban community. The methods used are discussed in this section.

A. STUDY AREA

The study area is located at Mokola in Ife Central Local Government Area of Osun State, South-Western Nigeria. It lies between latitudes 7° 29' 55.55''N and 7°29' 55.44''N and spans between longitude 4° 33' 0.11''E and 4°33' 0.0''E as shown in Fig. 1. Fig. 2 shows the Satellite image of the study area.

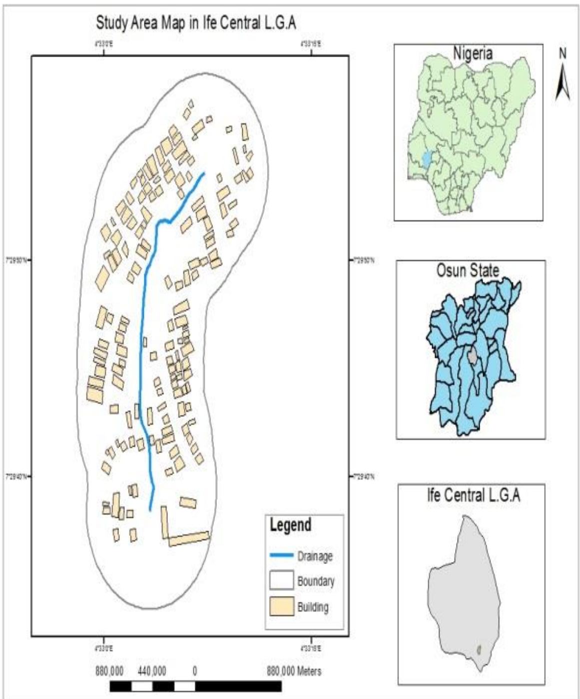

Figure 1: Study area map

Figure 2: Satellite image of the study area **(Source: Geo-eye (0.6m resolution)).**

B. SYSTEM DESIGN

The proposed system is shown in Fig. 3.

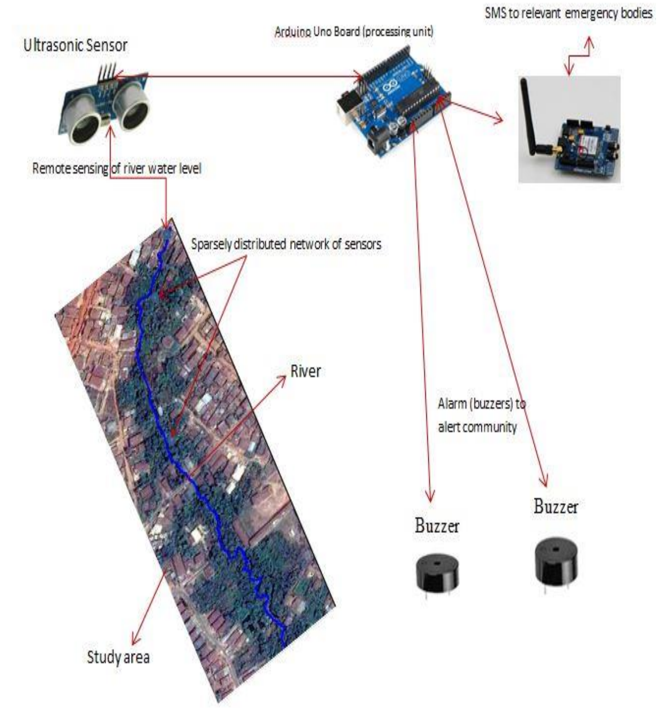

Figure 3: Diagram of the proposed system

1. Operational Flowchart of the Proposed System:

The operational flow chart is illustrated in Fig. 4 and can be explained as follows

Step 1: {Monitoring and detection} Monitor and detect water level from the river using ultrasonic sensors.

Step 2: Send the readings from the ultrasonic sensor to the Arduino microcontroller for data analysis and interpretation.

Step 3: If {readings exceeds the critical point (maximum or minimum)} {Arduino microcontroller triggers an alarm corresponding to the critical point exceeded and sends an SMS alert to relevant emergency agencies}

Else

{continue data analysing and monitoring}

End.

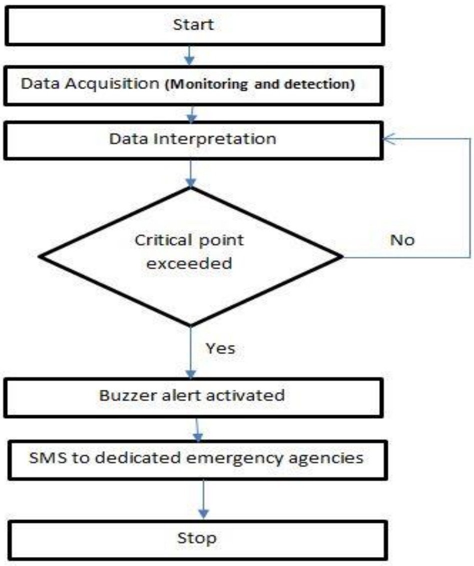

Figure 4: Operational flowchart of the proposed system

2. Design Components:

The components used for the prototype design are descripted in this section.

Arduino Uno Microcontrollers

An Arduino Uno is a microcontroller board based on the ATmega328. This microcontroller provides sets of digital and analogue input and output pins that can be interfaced with various expansion boards, sensors and circuits. It has 14 digital input/output pins (of which 6 can be used as pulse width modulation outputs), 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, and a power jack. It is a flexible programmable hardware platform designed for various strata of users and applications. Fig. 5 illustrates an Arduino Uno Board.

Figure. 5: An Arduino Uno Board (https://www.arduino.cc/en/Main/ArduinoBoardUno)

HC-SR04 Ultrasonic Sensor

The HC-SR04 ultrasonic sensor uses sonar to determine distance to an object. It offers excellent range accuracy, stable readings and is an easy-to-use device.). The HC-SRO4 has a resolution of 0.3 cm and makes use of 5V for its power supply. Fig. 6 shows an HC-SRO4 Ultrasonic sensor.

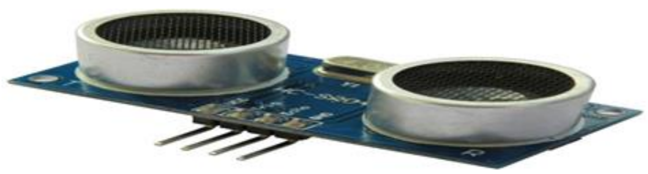

Figure 6: An Ultrasonic Sensor (http://www.robotshop.com/letsmakerobots/hc-sr04-ultrasonic-sensor)

Piezo Speakers (Buzzers)

A "piezo buzzer" is basically a tiny speaker that you can connect directly to an Arduino. "Piezoelectricity" is an effect where certain crystals will change shape when you apply electricity to them. By applying an electric signal at the right frequency, the crystal can make sounds. Fig. 7 illustrates a piezo buzzer.

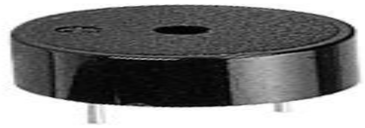

Figure 7: A buzzer (http://shallowsky.com/arduino/class/buzzer.html)

C. BUFFERING ANALYSIS OF FLOOD VULNERABILITY

Fig. 8 shows multiple buffer of the drainage at 100 and 50 meters. This was performed to determine flood risk extent and areas liable to flooding along the river channel in the study area. Buildings within 50 meters' buffer distance from the river banks are classified as highly vulnerable, while those within the 100 meters' buffer are classified as moderately vulnerable. The buffer analysis will be useful in determining the number of houses that are vulnerable to flooding. Also, it will be useful in deciding the choice of alarm system that will be audible across the study area in the event of flooding.

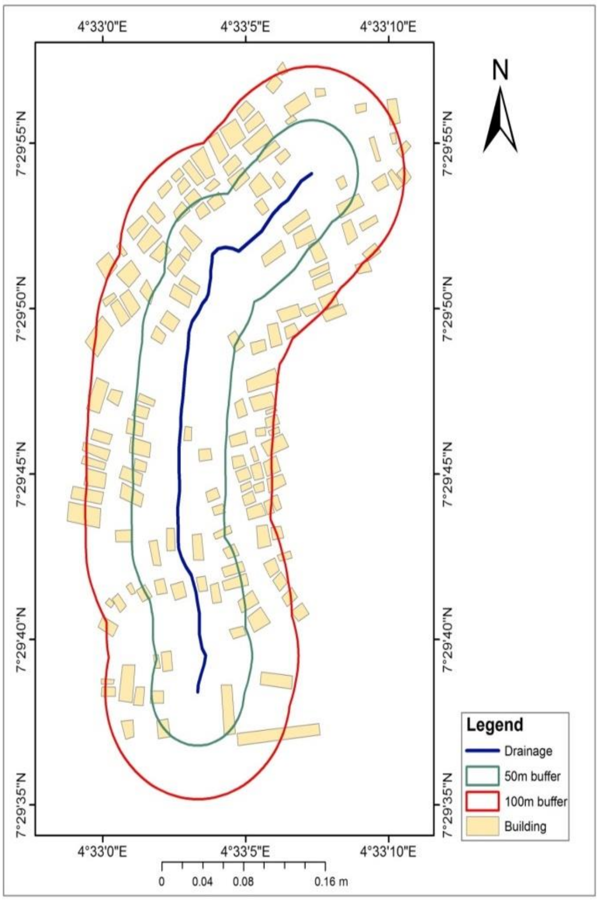

Figure 8: 100m and 50m buffer distance along drainage lines.

IV. RESULTS AND DISCUSSION

Buffering Analysis

Buffering analysis was carried out and the results obtained are highlighted in Table 1.

TABLE 1: NUMBER OF HOUSES IN THE 50M AND 100M BUFFER ZONES.

Number of houses within the 50m buffer zone	Number of houses within the 100m buffer zone (>50≤100)	Total number of houses within the study area
59	94	153

Table 1 shows that 59 houses fall within the 50m buffer zones while 94 houses are solely within the 100 m buffer zone (>50≤100). The buffering operation shows that a total of 59 houses are highly vulnerable (those that fall within the 50 m buffer zone) while 94 are less vulnerable (those that fall within the 100m buffer zone). The economic and social impact of flood in the study area is substantial. The development of an early warning system for this community will go a long way in mitigating the devastating impacts of flooding.

Prototype Testing

An Arduino based prototype was created to test and fine tune the Arduino sketch and to establish the system performance of the developed flood monitoring and early warning system. The Arduino microcontroller board will read the value received from the ultrasonic sensor and trigger an alarm depending on the value of the water level. Fig. 9 illustrates the prototype designed.

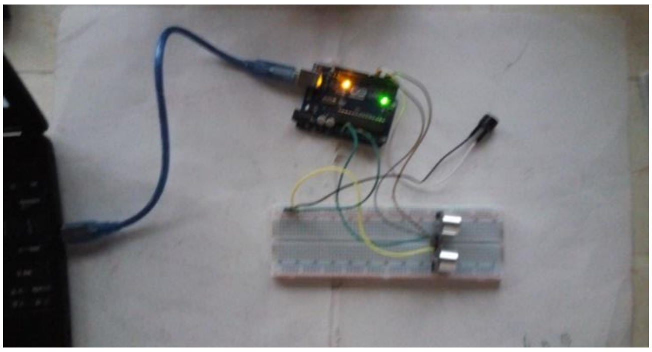

Figure 9: Diagram of the Arduino based prototype

Water Level at Minimum Critical Point

The minimum critical point was set to all levels between ≤ 4 feet > 2 feet. If the water level is between these levels (≤ 4 feet > 2 feet) the Arduino microcontroller triggers a subtle alarm that buzzes periodically. If the water level is > 4 feet's, the buzz stops. The system buzzed periodically when the height of the ultrasonic sensor was adjusted to fall within the minimum critical point level (≤ 4 feet but > 2 feet) with respect to a bucket filled with water placed on the floor.

Water Level at Maximum Critical Point

The maximum critical point was set to all levels ≤ 2 feet. If the water level rises to this level the Arduino microcontroller triggers an alarm that buzzes continuously at high pitch. A high pitch buzz indicates a potential flooding scenario. It is a signal to inhabitants in the community that there is a high probability of flood occurring. This provides early warning for inhabitants to evacuate their buildings and alert relevant emergency agencies. The system buzzed continuously at high pitch when the height of the ultrasonic sensor was adjusted to fall within the maximum critical point level (≤ 2 feet) with respect to a bucket filled with water placed on the floor.

Field Testing

Field testing was conducted at a central location along the river bank in the study area. The same procedures used in the prototype testing were carried out.

Water Level at Minimum Critical Point

The minimum critical point was set to water levels between ≤ 4 feet > 2 feet. If the water level is between these levels (≤ 4 feet > 2 feet) the Arduino microcontroller triggers a subtle alarm that buzzes periodically. If the water level is > 4 feet, the buzz stops. The water level at the time of field testing was not high. The measured water level (distance of water level to height of river bank where the ultrasonic sensor was placed) at the time of testing was approximately 6 feet. The minimum critical point was therefore adjusted to ≤ 7 feet but > 2 feet, in order to test how the system will react in the event that the water level rises beyond the assigned minimum critical level. After the adjustment the Arduino microcontroller triggered an alarm that buzzed periodically. This signifies that the water level has risen beyond the assigned minimum critical point.

Water Level at Maximum Critical Point

The maximum critical point was set to all levels ≤ 2 feet. If the water level rises to this level the Arduino microcontroller triggers an alarm that buzzes continuously at high pitch. The water level at the time of field testing was not high. The measured water level at the time of testing was approximately 6 feet. The maximum critical point was therefore adjusted to ≤ 7 feet but > 2 feet, in order to test how the system will react in the event that the water level rises beyond the assigned maximum critical level. After the adjustment the Arduino microcontroller triggered an alarm that buzzed continuously at high pitch. This signifies that the water level has risen beyond the assigned maximum critical point.

V. CONCLUSION

In this paper we have proposed a low cost community based real time flood monitoring and early warning system. The proposed system employs the use of low cost Arduino Uno microcontrollers and other low cost devices to detect potential flood and alert the community in real time. Results obtained from the system prototype/field test demonstrated its capability in mitigating the devastating impacts of floods especially for the poorest and most vulnerable communities in developing countries.

VI. FUTURE WORK

This work will be scaled up to accommodate a web based Flood Information System (FIS). The FIS will provide easy access to real time flood information and early warning. Also it will serve as an archive for flood related data which will be useful for researchers and the general public.

VII. ACKNOWLEDGMENT

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