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Original Article

Design and Implementation of a Road Flood Detection and Alert System for Urban Areas in Uganda

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ABSTRACT

In Uganda today, the land use has tremendously changed, especially in the urban areas, which has in turn led to significant changes in the climatic conditions. This has led to an increased frequency of storms and rainfall, leading to an increase in water runoff. As most of the surfaces are mostly impermeable and given the increased occupation of the swamps, most of this water finds its way onto the roads, leading to flooding, which puts the lives of the different road users, especially the motorists, at risk as well as increasing traffic congestion. A flood detection and alert system on roads is a system designed to monitor the state of the roads, especially at well-known flood points and then send out alerts to the different road users based on the data read. The system then notifies the motorists of which alternative route to use in case the particular route is flooded. The system will therefore reduce the fatalities on roads as a result of floods as well as save motorists time as they will be able to know beforehand what lies ahead of them and then act accordingly.

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INTRODUCTION

Generally, floods are caused by local factors such as the growing occupation of floodplains as a result of rapid population increase, increased runoff from hard surfaces, inadequate waste management and silted drainage, and increased uncontrolled and usually unplanned urbanisation. This restricts where floodwaters flow as large parts of the ground are covered with roofs, roads and pavements, thus obstructing natural channels, especially within the urban areas and cities (Douglas, 2008), whenever it rains**.** Therefore, intense rainfall coupled with inadequate or poorly maintained local drainage systems can lead to the rapid onset of surface water flooding. This reduces their capacity, either directly as a result of damage rendering the road unusable or as a result of deep floodwater rendering the road impassable (Pregnolato, 2017a).

Uganda, as a country, has not survived the wrath of flooding, as many areas are usually affected. The most affected areas are urban centres, low-lying areas and areas along river banks and close to swamps (Pregnolato, 2017b). The areas prone to them are Kampala, Northern and Eastern parts of Uganda (OPMDRDR, 2010).

Over the last 10 years, there has been an increase in the frequency, magnitude and duration of urban flash flooding incidents in Kampala City during or after the occurrence of extreme convective rainfall events. This flooding is as a result of a mix of factors that include; periods of intensive rainfall during the wet seasons, the landscape of the city which features many hills that drain into numerous relatively flat valleys and wetland areas, the densely developed hills and valleys, the high rates of rainwater run-off, inadequate drainage networks and water management, the spread of unplanned development, inadequate solid waste management, silting of drainage channels, the increased impermeable surfaces especially roads and pavements among others. This is mainly because they reduce infiltration of the rainfall, thereby leading to runoff, which usually flows over roads (KCCA, 2012). In 2018 alone, the city experienced various fatalities, widespread property damages and major traffic disruptions[8]. The urban poor settlements such as Bwaise, Kinawataka, Natete, Ndeeba and Katwe are prone to increased flash floods that destroy the infrastructure of roads, culverts, drainage systems, houses and water supply (KCCA, 2017).

Taking a case of the Nakawa-Banda area, the major flooding points are at Ntinda Industrial area (Nakawa), at Kyambogo, at Banda Moil Petrol station and at Banda Petrol Station (Kawooya Channel). These floods here are mainly due to increased industrialisation in the area that has led to the occupation of the Kinawataka swamp, the construction of permanent structures within the channel, which was previously a floodplain, as well as the small culvert crossings along the road (KCCA, 2019). All these factors, combined with the intense rainfall, reduce infiltration of water, thereby encouraging flooding along Jinja Road, hence disrupting traffic flow.

Different road users are threatened by different flood levels, and below is a table showing the risk faced by pedestrians and the average family car. The average speed of flood water is usually between 6 and 12 miles per hour.

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Flooding on roads disrupts the flow of traffic as road users have to wait for the flood waters to recede before continuing with their journeys, or some take risks to cross flooded roads, which may result in loss of lives (Maria, 2014). This therefore calls for a system that will be able to monitor the state of a road network during a flood and then continuously provide real-time updates to the road users, together with safer alternative routes that can be used.

Therefore, the main objective of this study was to design and implement a system that will monitor the status of floods on roads, notify and redirect motorists. In all this, we needed to design a module that will be able to monitor the state of floods on roads, to design a module that will be able to inform road users of the state of floods on roads and then offer information on the available safer alternative routes, and finally integrate, test and validate the system.

FINDINGS

Related Works

Flash Flood Detection Using Video Cameras

This system uses multiple video cameras placed in open areas over a region, each monitoring a visible marker affixed on a ground-level surface such as a street or road. Surface water over a marker alters the visible characteristic captured by the camera monitoring the marker. Results derived from multiple cameras over the region are correlated to detect patterns indicative of flash flooding, and appropriate reports, alerts, and warnings are issued (Pachipala *et al*, 2019). The weaknesses with this system include the high initial camera installation costs and the possibility of marks fading away easily.

Using the Smartphone Applications

This involves using mobile phone applications which, when installed and opened, offer a simple and intuitive interface that would offer the user a simple form to complete. After the form is filled out and validated, the content is delivered to a decision centre, which in turn could broadcast the alert within 5 kilometers from the point transmitter. People entering the perimeter of 5 km (tourists, for example) would also be informed of the measures and actions to take (Sekedoua & Joohnny, 2015).

The weaknesses with this system include the optional installation of the application is shows that there is no guarantee that all people within the affected area will get the information. It also involves a lot of bureaucratic tendencies.

Motes-based Sensor Network

This was proposed in Florida, US, and it consists of **an** Ultrasonic Water Level Monitoring Module to measure water level, the Network Video Recording Module to provide traffic monitoring information in video and images and the Data Processing Module this combines all the information from all modules. Information from this system is accessed online (Acosta-coll *et al*., 2015). However, this one was geographically limited to Florida. More so, the information was being accessed online, thus requiring internet access at all times.

Visual Sensing

This system proposes using cameras and visual sensing applications to automatically monitor and analyse water levels and then determine the occurrence of floods in the area. According to the analysis results of high-risk areas, the system automatically alerts the ultimate decision-makers, who will then choose suitable disaster reduction actions based on the geographic images and runoff data (Lo *et al*., 2015). However, the system is weakened by the bureaucratic tendencies and requires ambient lighting, which may not be clear.

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Early Flood Detection and Warning System on River Manafwa in Uganda

The system used to monitor the water level in the river Manafwa basin and alert people via siren within a radius of 5km on the onset of floods (Atyang, 2014). This system, however, is no longer operational.

The Designed System

The system mainly consists of two nodes, one at the flood point while the other is placed a distance away from the flood point to notify the road users, especially the motorists.

At the flood point, the node consists of a water level sensor and a water flow sensor for measuring the level of water and the speed of water flowing on the road surface. The recorded values are processed by the Arduino Nano and then transmitted to the notification node through the RF transmitter and RF receiver at the notification node.

At the notification node, the sensor readings are then sent to a database via a GSM module, and they can be accessed by users intending to travel along that particular route via a web application. Through the LCD screen, motorists can also view the sensor readings and the risks they face at the different readings should they proceed through that particular point. The buzzer goes off in case the readings are extreme, where the road is no longer safe for any user, and the servo motor controls a barrier, which then closes off that particular section of the road when this occurs.

METHODS AND MATERIALS

Requirements Elicitation

A number of research mechanisms were used in order to gather the information required to develop the flood monitoring and alert system. These include: the *Literature review***:** This involved reading documents whose major sources included policy briefs, textbooks, journals, magazines and scholarly books. The *Consultations:* This method involved seeking advice from experienced people and experts, as well as people with knowledge about the field from which the project was picked. Those consulted included: lecturers, engineers in the field of Computer technology and IT and some of the students who knew some aspects of the project.

Functional Requirements

The system is able to detect the flooded parameters under consideration, including the flood level and speed. It is able to give constant updates to road users depending on the variations.

The system is also able to store and retrieve from the database the information and display it in the web application in real-time. This information can be analysed in graphical form.

Non-Functional Requirements

These requirements include those that are not directly seen while the system is in execution and are therefore considered as the properties of the system.

System Availability: The system results can be accessed either online or physically while travelling along the road.

Efficiency: The system is able to provide real-time information without any intervention, thus maintaining the correct outputs ever.

Response Time: The system is able to detect the changing parameters of the flood and send the data to the database full time.

Usability: The system is easy to use

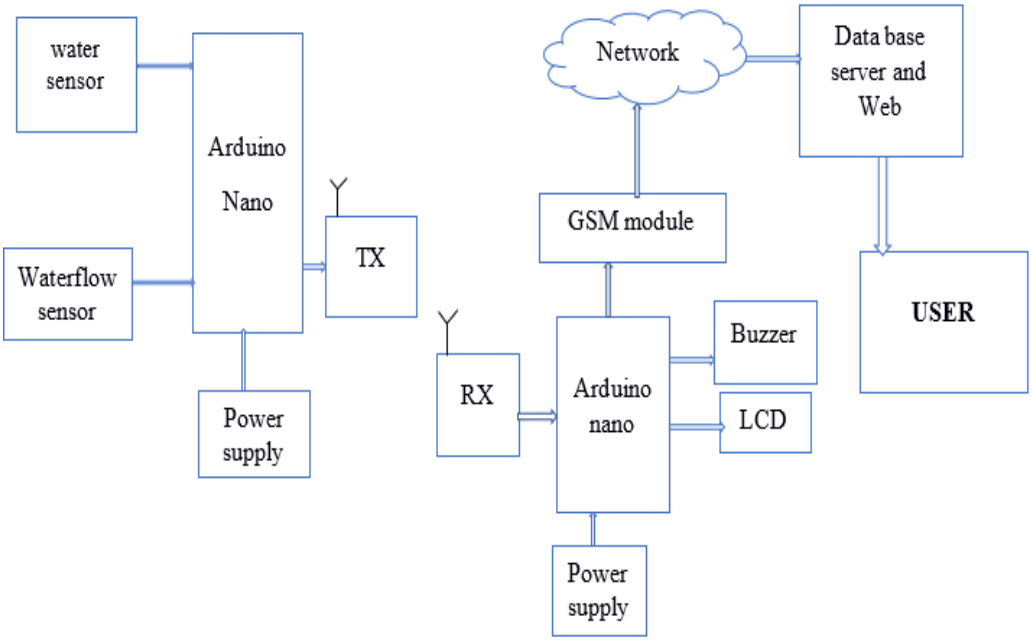
Maintainability: The system is easy to maintain.

The Block diagram in Figure1 summarises the basic components of the system.

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Figure 1: System Block Diagram



This system consists of the following basic components:

Arduino Nano

The Arduino Nano is a small, complete and breadboard-friendly board based on the ATmega 328p (Arduino Nano 3.x). It has more or less the same functionality as the Arduino Duemilanove, but in a different package. It has 14 digital input/output pins, 8 analogue inputs, though it lacks only a DC power jack, and works with a mini-B USB cable instead of the standard one.

RF Transmitter

A radio frequency (RF) transmitter is a circuit which consists of a transducer, modulator, wave guide and an antenna used to transmit radio waves to the RF receiver.

RF Receiver

An RF receiver is an electronic device that takes the modulated RF signal and demodulates it. It enables a particular radio signal to be separated from all others being received and converted into a format for video, voice or data.

Liquid Crystal Display

This is an output device, in particular used for the presentation of information in visual form. An LCD is a flat panel display, electronic visual display, or video display that uses the modulating properties of liquid crystals. It is energy efficient and can be disposed of more safely. Its low electrical power consumption enables it to be used in battery-powered electronic equipment. It is an electronically modulated optical device made up of any number of segments filled with liquid crystals and arrayed in front of a light source or reflector to produce images in colour or monochrome.

GSM Module

SIM800L is a miniature cellular module which allows for GPRS transmission, sending and receiving SMS and making and receiving voice calls. Low cost, small footprint and quad-band frequency support make this module a perfect solution for any project that requires long-range

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connectivity. After connecting, the power module boots up, searches for a cellular network and logs in automatically. On board LED displays connection state (no network coverage - fast blinking, logged in - slow blinking)

Water Flow Sensor

YF-S201 1/2-inch Water Flow Sensor sits in line with the water line and contains a pinwheel sensor to measure how much water has moved through it. There is an integrated magnetic Hall-Effect sensor that outputs an electrical pulse with every revolution. YF-S201 1/2-inch water flow sensor has only three wires and it can be easily interfaced between any microcontroller and Arduino board. It requires only +5V Vcc and gives pulse output, the sensor needs to be tightly fitted between water pipelines.

Water Sensor

This works on the principle of resistivity, whereby the more water the sensor is immersed in, results in better conductivity and will result in a lower resistance. The less water the sensor is immersed in, results in poor conductivity and will result in a higher resistance.

Servo Motor

Micro Servo Motor SG90 is a tiny and lightweight servo motor with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds, but smaller.

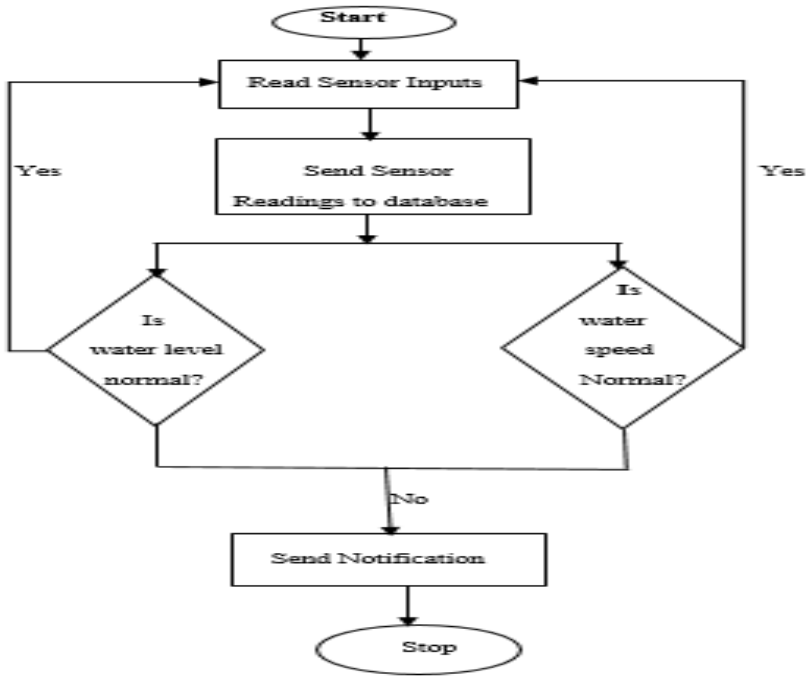
Buzzer

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 sound.

Logical Design

Here is the real representation of an algorithm, workflow or process.

Figure 2: Flow Chart



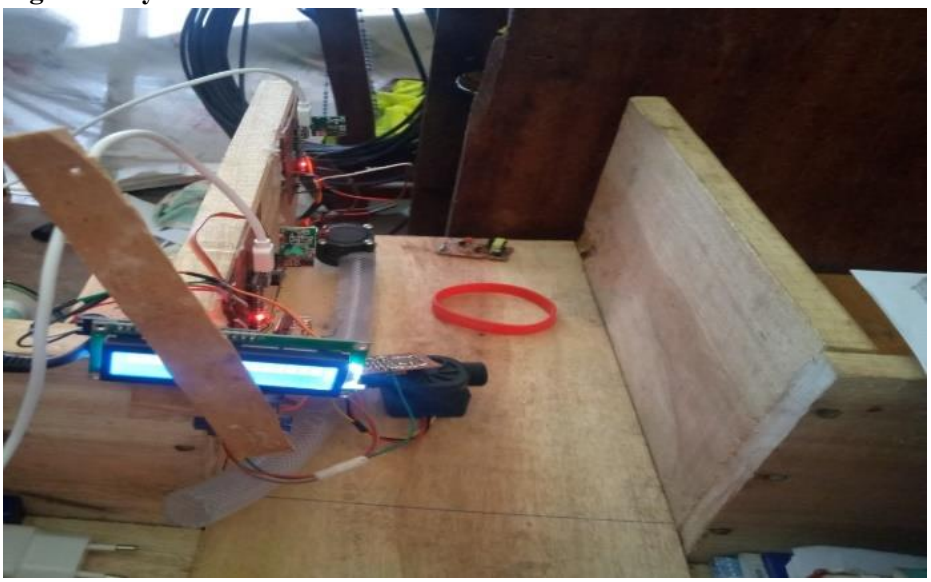
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Implementation of Physical Design

The physical design started with laying the components on the breadboard and soldering them to create connections among them, as observed in Figure 2.

Figure 1: System under Safe Conditions



Results of the Integrated Test.

Different vehicle classes have different Kerb weights and ground clearances and therefore are affected differently by flood waters.

Table 1: Vehicle Classes and their Kerb Weights and Clearance off the Ground

Class of vehicle	Kerb weight(kg)	Ground Clearance(m)
Small passenger	< 1250	< 0.12
Large 4WD	>2000	> 0.22

Table 2: Vehicle Classes and the Limiting Depths and Velocities.

Class of vehicle	*Limiting still water depth (velocity =0m/s)*	*Limiting high velocity depth (velocity =3m/s)*	*Velocity at low depth*
Small passenger	0.3	0.15	3.0
Large 4WD	0.5	0.3	3.0

The system database consists of different vehicle classes and their kerb weight and ground clearance.

Initially, the flood point is free of floods, and therefore the LCD displays safe for all road users, the buzzer is off and the barrier is raised so that all vehicles can proceed.

In case of a flood, the sensor readings are taken and this information is relayed to the different road users and the risk they face if they drive through the flood point. The risks faced include: stalling of the engine when water enters the engine, and the vehicle could float and therefore could be carried by the flood waters.

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Based on the kerb weight and the vehicle clearance off the ground, different vehicle classes are affected by different speeds and levels of water. When the sensor readings are taken, they are compared with the levels that affect the different vehicle classes, and if a vehicle falls in a particular class that is affected, the LCD displays that the road is no longer safe for that particular vehicle and the safer alternative road that should be used.

The buzzer goes off, and the barrier is lowered when the water level and speed are extreme that all vehicle classes are affected, and the LCD displays the alternative route that should be used by all the road users until the flood water clears.

DISCUSSION

The main objective of this project is to read the different parameters of a flood and then offer information on the safer alternative routes available to motorists in case of high flood levels.

The system can easily be positioned at any point along a flooding section of the road.

It is easy to use as it doesn't require much human interference to operate. It is very necessary given the changing weather conditions as well as land use in the country.

Challenges

The study posed some challenges that included, among others, the implementation of this project was at the expense of the components. Most of the components were very expensive and very delicate; The price fluctuations of components, having realised it was a season of projects, affected the budget drawn at the start.

Recommendations

The study recommended the following:

-For more accuracy and precision, the system could be improved so that it is able to verify how safe the alternative route is.

-The system could be improved to be able to predict the onset of a flood given the changes in the weather conditions.

-A mobile application could also be developed such that the motorists do not have to keep looking up at the billboards, which could be hard when driving.

CONCLUSION

The project can go a long way in reducing fatalities on roads as a result of flooding, as well as enable road users, especially motorists, to save valuable time while on the road.

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