Inventing a Robust Road-Vehicle Flood Level monitoring Device for User-defined Safe Threshold Alert on Road-Flood Disaster

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Research Article

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Abstract

Flooding impedes road utility and the frequency has increased across countries of the world owning to global climate change phenomena. Global road flood casualties have risen from 371,800 in 2015 to 842,000 in 2017 resulting to economic losses valued at approximately US$71 billion. Existing devices that offer warning signals on safe threshold during flooding are predictive in nature and based on complex technologies that are cumbersome and rather expensive thereby affecting the attractiveness to low-economy societies of developing countries. There is therefore a dare need for better inventions towards greater mitigation. This paper presents an adaptive, affordable, robust, efficient and effective road vehicle flood level monitoring device for detecting rising flood on roads above a user defined safe threshold to tackle road flood disasters. The device consists of a water sensing column, microcontroller unit, GSM module, transistors coupled to arrays of Light Emitting Diodes (LED) that connects to a buzzer through a Stable-Multivibrator circuit. The device operates on the principle of level conductivity sensor. The flood level notification device senses the rising flood level using water sensor probes that activates arrays of LEDs and warning alarm through a microcontroller on exceeding a permissible limit of about 60cm; sending short message service (SMS) to enrolled mobile phone number of meteorological agencies on road flood level reports. By this, road users are alerted of the dangerous flood level. The study therefore recommends for adoption of mandatory inclusion of this invention on roads towards averting the usual road flood hazard in countries.

1.0. Introduction

The rapid spike of the number of casualties of road flood and the associated huge economic losses demands urgent solutions given the tremendous rise of global road flood casualties in recent times from 371,800 in 2015 to 842,000 in 2017; resulting to economic losses valued at approximately US$71 billion**.** Incidentally, the risks associated with global climate change have manifested in various forms in various regions. In recent times, unprecedented rise in temperature, melting of ice in the Polar Regions as well as heavy rain falls and flooding in the Great Plains, Midwest, and Northeast among others are associated with global climate change. Such rise in floods is attributed to a warming planet and rise in sea level. Hirabayashi*et al.*, (2008).The findings of the various climate studies presented in literature predicts that rainfall intensity will grow by 40% if the toxic emissions that cause global warming continue unabated. Milly*et al.*, (2002); Peduzzi*et al.*, (2009). The various multiple global climate models for estimating the exposure to flooding in a warmer future climate warned about global flood risk rising exponentially at the end of this century. Jongman*et al.*, (2012). However, the inter-annual fluctuations and variability will depend majorly on the planned adaptation before any significant warming and the global implemented prevention strategies. Chang*et al.*, (2010). These adaptations include the developed global river routing model and the toxic radiation control mechanism to reduce planet warming. The toxic radiation control is focused on reducing greenhouse effect, an issue of major concern causing global warming. According to World Health Organization, Low-income countries have the highest annual road traffic fatality rates linked with road flooding at 31 per 100,000 inhabitants in 2015 and 67 per 100,000 inhabitants in 2017. Highincome countries are lowest at 5 per 100,000 inhabitants in 2015 and 9 per 1000,000 inhabitants in 2017. Road traffic injuries associated with road flooding claim over 1 million lives each year and have had heavy impact on health and economy worldwide. The Sustainable Development Goals (SDG) target of a 50% reduction in road traffic deaths and injuries by 2020 cannot be achieved with the present uncontrolled and unmonitored vehicle traffic on flooded roads in most low-income countries. There is therefore a compelling need for road users to be aware of the level of flood on the road before attempting to drive through hence, this work.

2.0 Literature Review

The impact of the increase in flood has led to undesirable flooding of roads to levels that are dangerous to motorists. Jaroszweski*et al.*, (2010), Pyatkova*et al.*, (2015). For instance, motorists risk drowning with their vehicles submerged in water arising from incessant high level of flood on roads. Furthermore, it is also important that the speed limit close to potential flood spots on the road should be low enough for motorists to drive cautiously. Oduah*et al.*, (2017). Thus, the present work was motivated by the desire to provide a safeguard in the form of a simple flood level monitor to act as early warning system for road users in time of road flooding.

There exist many road flood monitoring devices that have been commercially deployed for tracking road flood levels. But most of these devices are presently not widely deployed in several flood prone roads because their functionality is based on complex technologies that are cumbersome and expensive. Natividad and Mendez, (2018). Also, their operations are not suitable for muddy roads encountered in most developing and underdeveloped countries because of the limitations owing to their sensor architecture. At such, this invention was motivated by the need to address the challenges with the current range of road flood monitoring devices.

One of the ranges of flood level monitoring device is the flashing beacons. The flashing beacons are used mainly to detect wet, slippery and flooded roads. The sensors are not suitable for dirty muddy water which occurs mainly in poorly constructed roads experienced in developing countries. Its operation relies on Flashing Beacon Controller Remote Series 3580 performance. Same applies to the use of ultrasonic sensors because they sometimes deliver wrong results with slurry muddy dirty water. It is so because ultrasonic sensor technology operates by emitting high frequency acoustic waves between 20kHz and 200kHz that are reflected and detected by emitting transducer. Consequently, turbulence and foam prevents the sound waves from being properly reflected to the sensor. Also, chemical mists absorb or distort the sound wave. The sensing accuracy of ultrasonic waves is altered by changes in temperature of 5 to 10 degrees Celsius or more. So the accuracy of ultrasonic sensor for the purpose of road flood detection is low and the response speed is also slow. The technologies are more expensive, cumbersome to install, and have very short lifespan compared to the developed technology. The other existing flood warning systems are not designed specifically for flooding of roads rather they are hinged on flood forecasts based on information collected from specialized meteorological stations. Parker, (2017). Also they function with predictions by monitoring of the current hydro meteorological situation. They are based on distributed hydrological simulation of numerical ensemble weather predictions with global coverage. The float actuated flood warning system with remote telephone reporting is a US patented device that is stationed at only one strategic location. It warns communities at riverine areas of rising water levels and is usually positioned underground in wells to detect rising water above sea level. Other flood warning devices deploy rising water in sump pits for their operation. Yuliandoko and Rohman, (2019). Some flood level detectors operate with pressure sensors which are susceptible to various variations in environmental factors such as high temperatures. The existing flood warning devices with all their limitations are used in different countries; but predominantly used in Philippines, Honduras among others.

Therefore, this research work identifies high cost, inappropriate sensor technology and inefficient implementation as the challenges that limits the existing road flood level caution devices. Hence, the invention of a simple, robust, adaptive and affordable device to address these limitations.

3.0 Theory/methods

3.1. Conceptual Framework and Design of the invented Road Vehicle Flood Level Monitoring Device.

The principle of detecting water level using electrode sensors is applied in this work. The water acts as a conducting channel which completes the electric circuit between the electrode probes. Initially, the electrode probes are open circuit positioned at calibrated levels. As the water level rises from the reference probe to each target level thereby making contact with the electrode probe, it completes the circuit and becomes a closed switch. The corresponding arrays of LED are activated.

The block diagram of the development process for the invented Road Vehicle Flood Level Monitoring Device is shown in Figure 1.

In the present work, a novel, reliable, adaptive and cost effective road flood level monitoring device was designed, constructed and implemented by mounting it on street lights or poles with power supply. The invented Road Vehicle Flood Level Notification Device is designed to trigger alarm and flash a red light whenever the flood level on roads exceeds a permissible threshold for motorists. The device is calibrated into four different levels and mounted on the street light/ poles with the water sensors positioned in such a manner that they detect water levels at the user determined safe and unsafe depths. The introduction of the device will reduce road hazards caused by floods on roads. A global mandatory inclusion of the developed device on all roads with advanced warning traffic symbol for flood is proposed.

The power source for this prototype consists of a 12-Volts battery. However the device is to be installed on street lights enabling it to share power from the street lights for the recharging of the 12-Volts battery when the streetlights are ‘On’ at night. The voltage source is fed into the water detection circuit comprising of four bipolar-junction transistors, arrays of green, yellow, light orange, and red light emitting diodes (LED) and four metallic water probes. The circuitry for the connection is illustrated in Figure 2. The circuit board is packaged inside a water tight plastic container to ensure protection from water moist and corrosion. The arrays of LED's are for detecting the various target depths. Cataldoet al., (2014). The green, yellow, and light orange LED's indicates the various rising water levels which vehicles can pass. But the red LEDs were used for the highest depth indicating danger "no entrance". The NPN bipolar junction transistors were used because they possess fast switching time since electrons are their majority carriers Jin*et al.*, (2015). The connection of the transistors is in the common emitter mode with the emitter connected to the ground as shown in the circuit diagram in figure 2. The base is the input to the BJT while the collector is the output. An input resistor of 100Ω is connected to the base of each of the BJT and an output load of 220Ω connected to the collector.

The NPN transistor that is linked to the highest depth water probe is connected to an astable-multivibrator circuit. The astable-multivibrator circuit consists of two NPN bipolar junction transistors connected back to back with the output of one fed into the input base of the other. Milosavljevic*et al.*, (2012). The switching time of the two transistors is determined by the resistors-capacitors time constant. The circuit generates oscillations which are transmitted to the speaker to produce a loud buzz. This danger warning alarm is an indication that vehicles are not allowed to pass. The diagram of the multi-vibrator circuit is presented in Figure 3.

3.2. *Component Sourcing Integration and Prototyping.*

The packaging of this invented device was designed to suit and adapt to the prevailing conditions of the operating environment even as experienced in developing countries with most poorly constructed roads. A hard plastic material is used for the construction of the water column. This prevents the device from rusting and protects it from moisture. The inlet opening is shielded with three different gauze casing with varying pore spaces to sieve water inside to prevent dirt from covering the water sensor probes. The three layer casings contain pore spaces to allow easy flow of water inside and outside the water column as the flood level rises or falls. The aperture of the gauze materials are graded with the outermost cover with size 8 x 8 cm^2, followed by the middle gauze aperture 5 x 5 cm^2, and the innermost gauze aperture 2 x 2 cm^2. So the water column does not trap water inside but instead its water content level maintains the same level with the flood. The arrays of red LEDs are positioned at a height, 3 meters above the ground in such a manner that the light is visible at a distance about 20 meters away from the mounted pole. The developed Road Vehicle Flood Level Monitoring Device is described in Figure 4. The installation of the device on a street light is demonstrated with Figure 5. Alternatively, the invented device can be mounted on a pole with solar or power supply to recharge the battery. The costing of the developed device is presented in Table 1. The price range of other variants of flood detection systems available in the market are between $160 (One hundred and sixty Dollars) to $1000 (One thousand Dollars) which places the developed device much cheaper when commercialized. At such, the invented device is far more affordable than the existing ones.

3.3. *The Applied Sensor Technology*

Conductivity level sensors are effective, efficient and very suitable for detecting the depth of water in a tank compared to ultrasonic sensors and other sensor technologies. The technology requires metallic electrode rods as sensing probes. Each electrode needs at least two contact points to function; one electrode point is a reference point positioned at the base of the container, while the other is connected to a specific defined level. Multiple water level detection will need electrode probes for each target level.

The applied methodology relied on a simple, efficient water sensor technology using common electronic components, and wide coverage implementation mechanism that is adapted for poorly constructed roads.

Table 1. Costing of the invented Road Vehicle Flood Level Monitoring Device

Item	**Quantity**	**Unit cost ($) USD**	**Cost ($) USD**
Light emitting Diodes (LED indicator lights)	36	0.45	16.20
Bipolar Junction Transistors (C945)	6	$4.70	28.20
Resistors (100 Ω)	4	$5.99 for a pack of 100 pieces	0.24
Resistors (220 Ω)	6	$6.43 for a pack of 100 pieces	0.39
Resistors (2.2 kΩ)	2	$2.63 for a pack of 2	2.63
Capacitors (100 μF)	2	$5.57 for a pack of 5 pieces	2.23
Speaker (Electric Buzzer)	1	$4.49	$4.49
PCB board	1	$12.99 for a pack of 40 pieces	0.33
Water filter gauze	3	$5.00	$15.00
Plastic Casing for water column and Packaging the device	1	$50.00	$50.00
Water sensor copper wire probes		$10.00	$10.00
Total			**$129.80**

Source: Authors, 2017.

4.0 Results And Discussions

4.1. *Testing and Validation*

The operation of the invented device was tested to ensure prompt detection of flood level on roads. The developed electronic flood level notification device was powered with a 12-Volts rechargeable battery and placed vertically upright in an empty 500 liters open ended plastic tank. Few bowls of sand mixed with mud were poured onto the floor of the tank to make it appear dirty like flood water. Water was now passed gradually into the tank with a hose and the solution stirred to form very slurry dirty water. It was observed that the first arrays of green LEDs switched on immediately the water level got to 0.2 meters touching the first sensor. As the water level rose to the second water sensor, the second arrays of yellow LEDs light on. Also the third arrays of light orange LEDs light on immediately the water level got to the third water sensor. When the water level got to the fourth water sensor, the arrays of red LEDs immediately started blinking followed by a very laud audible buzz from the speaker. The caution alarm sounded continuously and simultaneously with the blinking red light from the arrays of red LEDs. The device also sent SMS alert and placed a phone call to the enrolled GSM numbers. Furthermore, the water level was now reduced gradually by opening a water outlet at the bottom of the tank. It was observed that the red LEDs switched off together with the alarm immediately the water level receded. Also, the other arrays of LEDs switched off as the water level dropped below the sensor which respectively controls them. The Road Flood Level Monitoring Device performed well with each arrays of LEDs switching on promptly as the water level touched the controlling sensor. Rather than being predictive, the invented device simply monitored Road Flood Level according to the prevailing situations by adapting to existing conditions.

4.2. *Effectiveness and Efficiency of the invented device.*

The invented Road Vehicle Flood Level Monitoring Device is designed to be mounted on existing streetlights. This is designed to reduce cost of erecting poles. The close spacing of the device enables it to have a far wider road network coverage compared to other existing technologies that are positioned at a spot. The staggered positioning of the device along the road allows it to monitor levels of flood even on poorly constructed roads with undulating topography which are very prevalent in underdeveloped and developing countries. The flood sensing technology, the water probes architecture, the numerous number of the device staggered and mounted on streetlights and the very wide road network coverage all makes the developed device highly effective and efficient in monitoring road flood.

4.3. *Progress towards Commercialization*

The invented device is a prototype which can still be modified to enhance its capabilities before commercialization. The device water column uses three water filters with different aperture to sieve water inside the column. The gauze prevents dirt from entering the water column and so protects the water sensor probes from contamination. There is an inherent risk of the water column gauze for water inlet to be blocked because of accumulation of dirt. It is therefore important that the water column is inspected and washed periodically to remove blockages that can hinder the inflow of water inside the column. Also, the four metallic probes need to be inspected and cleaned to keep them in good working conditions. The materials used for the invention of this device are resistant to corrosion. The water sensor metallic probes used are easily pluggable and replaceable during routine inspections. On the average, the metallic probes should be changed every two years. Emergency electric power supply is made available for the functioning of this device during power outage using a12-Volts battery or power generators that runs on fuel or any economically viable electric power source within the locations. This is to recharge the battery of the invented device. Further validation of the performance of the invented device via real-time field-test on flood prone roads to actually track its capability for advance warning before commercial deployment is imperative.

4.4. *Practical Implications*

The rise in sea level leading to flooding of the vehicular roads is a major concern in developing countries with poorly constructed roads causing huge economic losses. The existing technology of road flood caution alarm devices malfunction on muddy, slurry, dirty water which damages the ultrasonic sensors. The developed cost effective and highly efficient road vehicle flood level monitoring device warns road users of flood level above a predetermined permissible threshold. The implication of the developed device is that road accidents associated with excessive road flood is averted. A mandatory inclusion of the developed device on all roads with advanced warning traffic symbol for flood hazard is proposed. The mechanism of installing the device on street lights creates wider coverage and also reduces operational cost of this device. However, poles connected to solar panel or source of power supply is an alternative for areas where there are no street lights.

Resistivity of water is a measure of the ability of water to resist an electrical current. It is directly related to the amount of dissolved salts and other impurities in the water.

Flooding could be as a result of several factors, the most prominent ones being

- Ocean Surge
- River overflowing its banks
- Run-off during Heavy Rain-fall.

The response of the device therefore may be affected indirectly by the cause of the road flooding. Table 2 shows a comparison of different water source resistivity/conductivity.

Table 2. Comparison of Water Resistivity/Conductivity (Values are at an average temperature of about 25ºC).

WATER	RESISTIVITY (Ωcm)	CONDUCTIVITY(Siemens)
Pure Water	20,000,000	5 x 10^{-8}
Distilled Water	500,000	0.000002
Rain Water	20,000	0.00005
Tap Water	1000 – 5000	0.001 – 0.0002
River Water	200	0.005
Sea Water	30	0.033

Source: Authors, 2017.

This implies that the invented device has a very high response rate. Accordingly, it is fastest with ocean surge and least with rainfalls. Moreover, the response time in all cases is still less than one second which is highly insignificant with reference to the purpose for which the device is required.

The sensitivity of the metal probes depends on the resistivity of the material used which in this case is copper. The resistivity of copper is 1.72 x 10^{-8} Ωm. This translates to a conductivity of 5.8 x 10^{7} Siemens. This is very high compared to that of water and therefore makes that of water insignificant. It is also important to note that the spacing of the probes would be just a few centimeters say between 10cm to 40 cm depending on the determined user safety flood water level imputed to be detected.

5.0 Conclusion And Recommendation

An easily deployable simple and robust road flood level monitoring device has been invented and implemented so as to address the challenges confronting the existing models of the device. The effectiveness and efficiency of the invented device has been demonstrated on some very wide road network coverage and its ability to function effectively, even on poorly constructed roads with undulating surface has been ascertained. The invented device provides a solution to the menace which flooding poses on roads to the risk of motorists and other road users particularly in low economy societies. A cost comparison of the device prototype with an existing variant provides a cost advantage of about 50%. This establishes the fact that the invented device is also affordable and will compete favorably with other variants currently in the market.

This paper therefore recommends for a mandatory inclusion of the invented device on all roads that are prone to flood hazards so as to provide users with the required advanced warning. In situations whereby there are no streetlights on the roads prone to flooding, metal pole supports can be used for the installation of the invented device. The electric power supply could be from solar panel power supply, fossil fuel power generator, or any economically viable electric power source within the location of target areas. **The invented device has been patented in Nigeria with registration number NG/P/2018/14.**

Declarations

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Figures

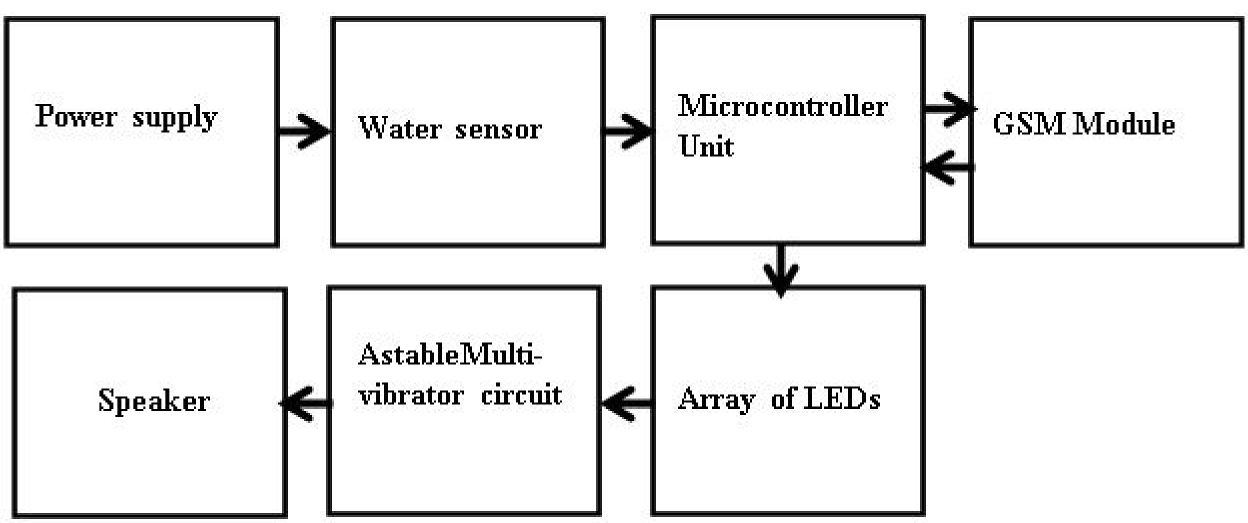

Figure 1

Block diagram of the Road Vehicle Flood Level Monitoring Device. Source: Authors, 2017.

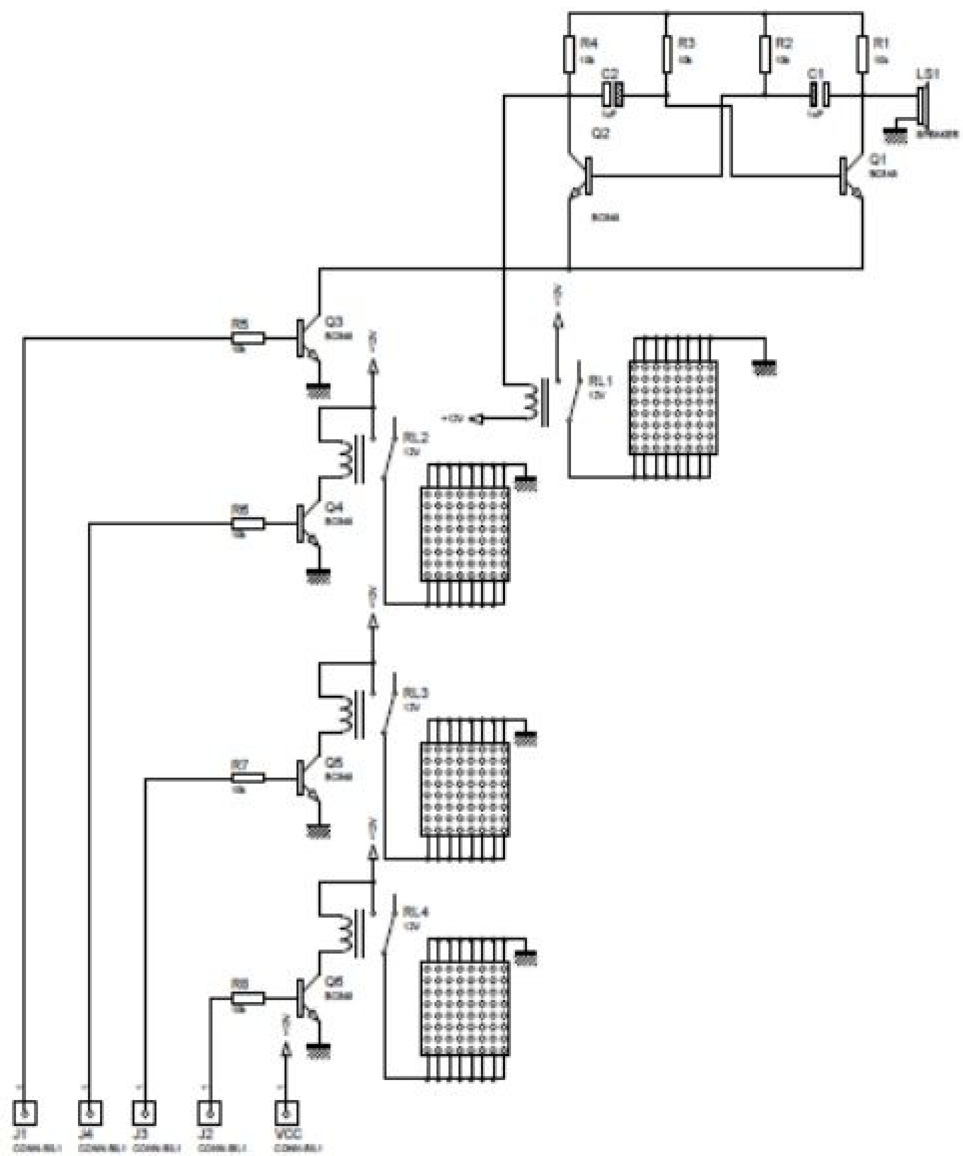

Figure 2

Water detecting probes circuit. source: Authors, 2017.

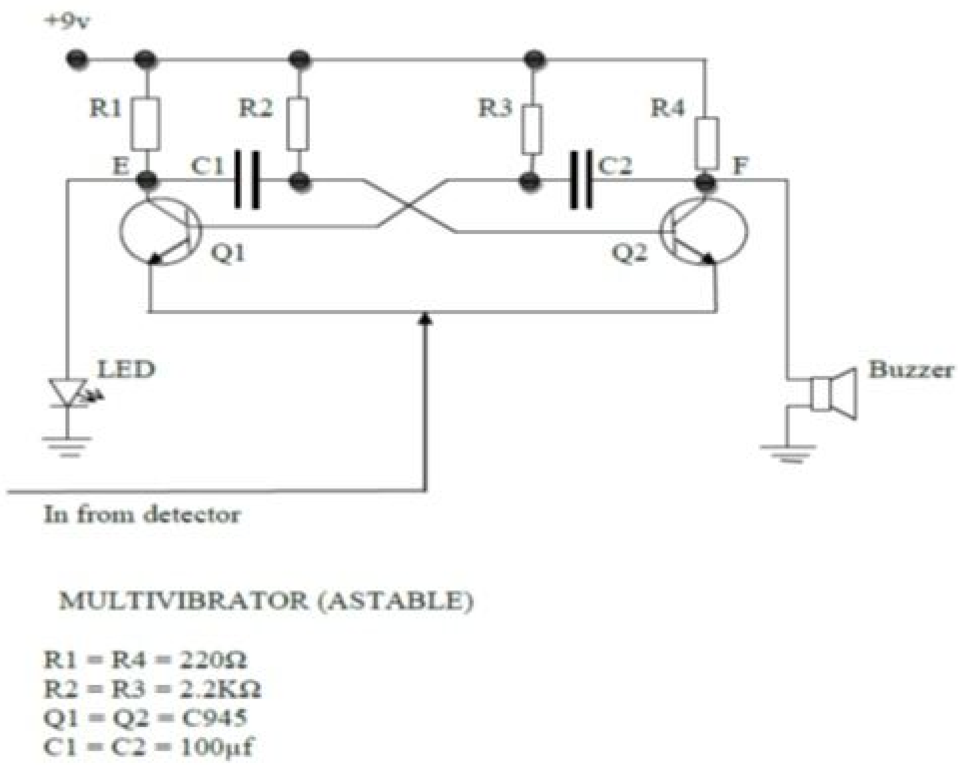

Figure 3

Astable-multivibrator circuit. Source: Authors, 2017.

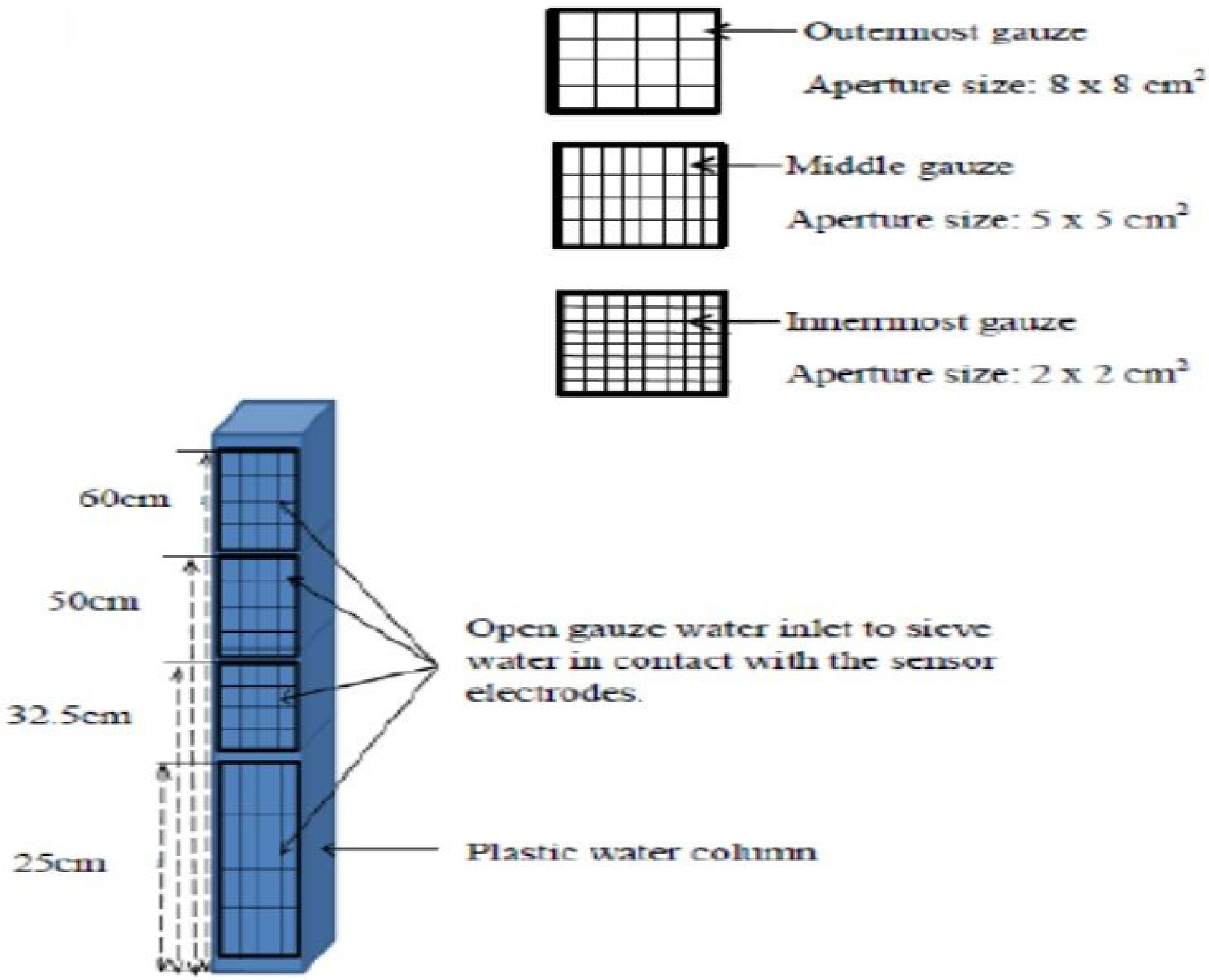

Figure 4

The Road Vehicle Flood Level Monitoring Device describing the water column, the gauze with different aperture size, and the position of the LEDs. Source: Authors

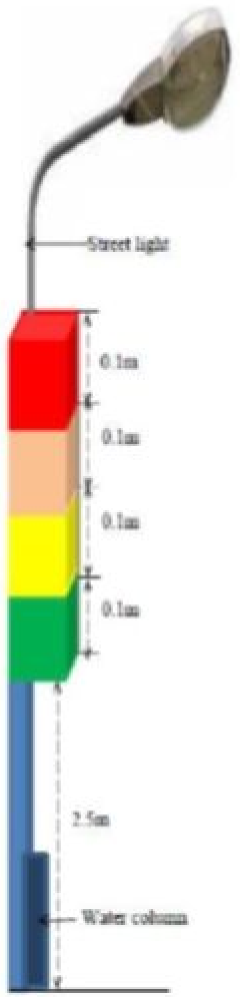

Figure 5

Illustration of a Road Vehicle Flood Level Monitoring Device mounted on street light. Source: Authors, 2017.