Development of a Laboratory Model for Automated Road Defect Detection

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Abstract—**Potholes and bumps are responsible for a large number of accidents on roads, leading to the loss of lives and properties. Developing proactive and early detection measures will be an effective approach for reducing accidents, and a source of information for timely road maintenance. Consequently, a laboratory model of a road defect detection system is proposed using a combination of an Ultrasonic sensor, a Global Positioning System (GPS) and an alert system. The methodology used involved computing the best placement for the ultrasonic sensor, and developing an algorithm for detecting the presence/absence of bumps or potholes using the time taken to receive reflected pulse signals. This laboratory model is also capable of logging road profile information to a database where vehicle users and road maintenance agencies can access for planning route movement and prioritising road repairs.**

Index Terms—**Accident; GPS, Potholes Detection; Road Bumps; Ultrasonic Sensor.**

I. Introduction

Defective asphalt roads (see Figure 1) are characterised by defects, such as cracks, potholes, road bumps and rutting. These defects have led to the increase in road traffic accidents [1]. The causes of road defects include poor drainage systems, asphalt roads exceeding their design lifetime, the use of poor quality materials for road construction as well as poor road maintenance culture [1, 2].

Reducing the occurrence of road accidents could involve ensuring that drivers comply with safety rules and regulations, as well as training and retraining of drivers [3, 4]. Other solutions include the enforcement of road laws by road safety agencies [5] and adherence to vehicle road worthiness by Inspection Officers [2]. However, these methods depend largely on the availability of funds for the repair and construction of roads, ensuring that roads are constructed in accordance with acceptable standards and regulations. Thus, in the interim, it is necessary to develop technology-driven solutions for minimising accidents caused by road defects.

One solution is to use Vehicular Adhoc Network Technology (VANET) [6]. This technology [2, 6, 7] involves using automated systems for prior sensing and detection of road defects. In this regard, researchers have developed methods for realising VANET related solutions. For example, in [8], a Neighbouring Difference Histogram Method (NDHM) for segmenting road defects from road surface images was proposed. The developed algorithm was able to segment and classify road defects from the background image using neighbouring differential statistical values as the classification criteria. However, the efficacy of the proposed system depends on the type of lens and resolution of the camera used, as well as environmental conditions, such as sunlight, time of the day, visibility, and many others. In [9], an Entropy theory and GA based approach was presented for detecting and classifying pavement distress on asphalt roads. The choice of the optimal threshold segmentation was based on information theory from the objective function defined from the acquired pavement images. The proposed technique was able to enhance and extract distress from the background image. However, environmental factors were not considered during the segmentation process, thus affecting its performance.
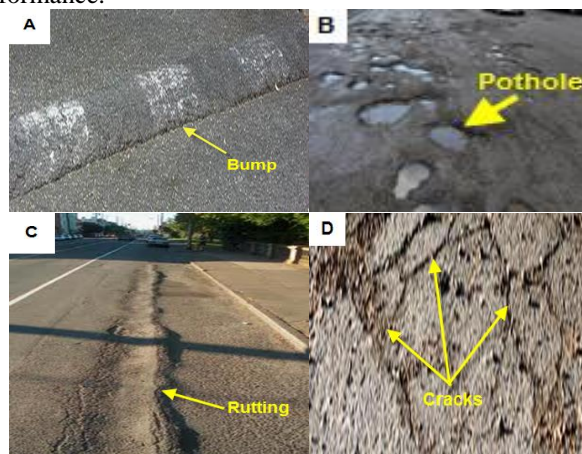

Figure 1: (A) Typical Bumps (B) Potholes (C) Rutting (D) Cracks

An automated pothole detection method based on asphalt pavement images was proposed in [10]. Pavement images were segmented into defects and non-defects using a histogram shape-based thresholding method. The proposed approach was able to reasonably detect potholes from asphalt

pavement images. However, the performance of the proposed technique was limited by the process of manual training. An extensive discussion on image based road defect detection can be found in [2]. Similarly, an accelerometer based approach for road defect detection, specifically potholes and road bumps using android phones and a participatory sensing approach was proposed in [11]. A multi-layer perceptron machine learning technique was used for detection, and the technique was able to detect defects from the acquired road surface data. However, the effectiveness of the technique was limited by the high level of noise presented in the acquired data and the use of the manually set threshold value.

In [12], an accelerometer embedded smartphone was used for monitoring and classifying road surface based on good, fair, bad and poor metrics. Results obtained showed a linear relationship between an accelerometer pattern and unevenness of road surfaces. However, the accuracy of the proposed solution depends greatly on the speed of the vehicle. Road surface anomalies detection using a mobile phone accelerometer, gyroscope and inertial sensor was presented in [13]. But its performance depended greatly on the type of mobile phone with the accelerometer device embedded and used for data acquisition. Similarly, the works in [14], [15], [16], and [17] all used different approaches to detect the presence of road defects. However, they focused on the use of vibration sensors and image processing. With respect to the use of Ultrasonic sensors, authors in [18] used Ultrasonic sensors for detecting and identifying road defects. The proposed system was able to log coordinates of defect area detected and stored in the cloud. This approach was identified to be cost effective, and hence adopted in our work.

In a summary, most approaches involve the use of image processing for road defect detection [2], [19], [20], [10], vibration techniques [21], [7] and accelerometer sensors [21], [17]. However, this paper presents the use of an Ultrasonic sensor, Global Positioning System (GPS) and an alert system for road defect detection, particularly potholes and bumps as an improvement to [18]. Furthermore, a detailed analysis was carried out to examine the proposed approach, as well as how road defects were classified into potholes or bumps.

The remainder of the paper is structured as follows: Section II presents a survey of automated road defects detection, the architecture and implementation of the proposed system is presented in section III. Section IV presents the experimental results and analysis, while section V concludes the paper.

II. METHODOLOGY

The methodology adopted comprises of three main blocks namely, the road model development, road defect sensing and road defect notification modules as shown in Figure 2. An explanation of the design and development in each block is presented as follows:
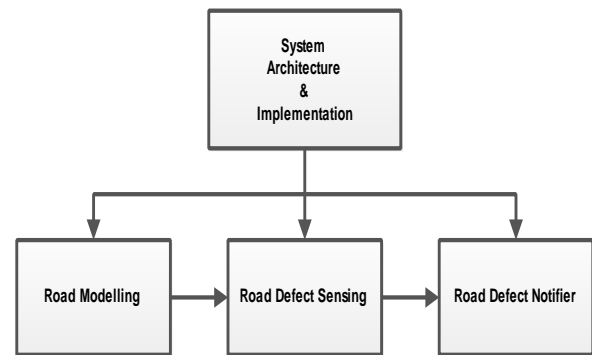
Figure 2: Proposed System Architecture and Implementation

A. Road Model Development

This involved the design and development of model of a poorly conditioned road characterised by defects, such as potholes and bumps. The road model was developed based on the assumption that asphalt roads are hard and dark surfaced. A particle board was used for the construction because it is easy to drill to model potholes, and it easily adheres to glued objects to model bumps. This board was shaped to meet a design specification of 97x50x3inches length, breadth and height respectively (see Figure 3a), to ensure a long enough runway for the model car. This defective road model was then used to simulate the laboratory model for defect detection. The developed system was embedded inside the model car as shown in Figure 3b.

Figure 3a: Developed Road Surface Model and Prototype Model Car

Figure 3b: Developed Road Surface System Embeded in the Model Car

B. Road Defect Sensing

In this module, a low cost distance measuring transceiver based on an Ultrasonic sensor was used with a separation distance of 2cm between transmitter and receiver. This was used to approximate the distance between the transmitted ultrasound signals at a frequency of 40Hz and the time taken to receive the reflected echo pulse by the receiver. The deployed HCSR04 ultrasonic sensor is capable of measuring distances between the ranges of 2cm to 400cm.

The mathematical model in (1) was used to determine the optimal tilt position of the ultrasonic sensor mounted on the model car. This was based on the assumption that the height 'h' of the model ca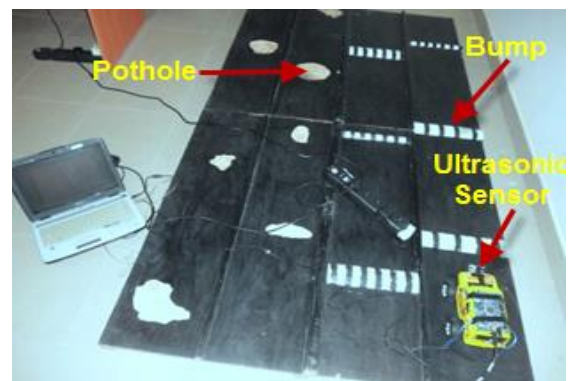r with reference to the road surface formed a right angle, while the ultrasonic sensor was tilted at angle 'ϑ' in front of the model car to the approximate detected distance 'c' of road surface. This was based on the time taken by the echo pulse to be transmitted and received by the sensor as illustrated in Figure 4. In the actual scenario, the Sensing module comprising of the Ultrasonic sensor and the microcontroller unit can be placed around the front panel of the vehicle. This was placed at an angle, whose value will be described next. Then, the module sends out pulses that will be received and interpreted by the controller to make decisions.

A threshold value of 40cm was set based on the measured constant distance, when the ultrasonic sensor was placed at 11cm on the model car and tilted at an angle ϑ with reference to the smooth road surface. The developed algorithm measured the deviation from the sensed distance and the set threshold value to make decision and characterise the defects into pothole or bump. If the distance measured by the sensor is smaller than the defined threshold, a bump is identified. However, if it is greater than, or equal to the defined threshold value, then a pothole or smooth road is declared, respectively.

Figure 4: Proposed System Tilt Position

$$\vartheta = cos^{-1}\frac{h}{c} \qquad (1)$$

An Arduino UNO R3 microcontroller based on ATmega328 was used for programming the detector system. It comprises 14 digital input and output pins, 6 analogue inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains the necessary requirements to support the microcontroller, as shown in Figure 5. An Arduino integrated development environment was used to programme and upload the code. The algorithm for the overall flow of the proposed system is presented in Algorithm 1.

ALGORITHM 1
1. *Initialise the GPS*
2. *The Microcontroller triggers the sensor using a pulse.*
3. *Sensor sends 8 cycle bursts of sound waves.*
4. *Sensor echo pin is set high, and if echo heard is detected by sensor, if YES, do*
   a. *Sensor echo pin is low*
   b. *Measure echo pulse with time (round trip)*
   c. *Check for discontinuity in distance, if yes, do:*
      i. *Display the depth*
      ii. *Display obstacle/pothole*
      iii. *Send GPS coordinates*
      iv. *Store acquired information*
      v. *Return to step 1*
   If no, do:
      i. *Return to step 1*
   If No, do:
   a. *Echo pin remains high*
   b. *Wait for 30ms*
   c. *Echo pin goes to low after time out*
   d. *Return to step 1.*
5. *Return to step 1*

A Global Positioning System (GPS) module was integrated in the design to track the coordinates and location of the detected road defects as seen in Figure 3b. The GPS has a detachable onboard memory card, which can be used to store the location of these defects. It stores the defects with the following categories latitude, longitude, distance, and type of defect. This information was stored in CSV format

The proposed system was designed and simulated using the circuitry in Figure 5. An alternating voltage source was fed as input into the ultrasonic sensor with a voltmeter placed across to measure the source voltage value. The trigger and the echo pin were connected to pin 7 and 6, while LED1 and LED2, which trigger an alarm to notify drivers of detected defects were connected to port 13 and 8 respectively. The GPS receiver was connected to port 4 and 5 on the Arduino microcontroller and the overall circuit diagram for this system can be seen in Figure 5.

Figure 5: Developed Circuit Diagram of the Proposed System

The ultrasonic sensor was triggered by the microcontroller trigger pin 7, which starts one cycle of range conversion and sends eight bursts of sound waves of 40 kHz from the transmitter. The echo pin on the ultrasonic sensor becomes high as soon as the signals were transmitted and remains high until the same sound waves were received by the receiver. If the received sound waves are the same as the transmitted, then the echo pin goes to a low level. The time taken by the echo pin to go high was used to compute the distance between the sensor and road surface (either smooth-road or defect). The distance was computed as:

$$D = he \cdot v / 2 \qquad (2)$$

where D is the computed distance (cm), he is the Echo pulse width high time, and v is Sound velocity (m/s). The velocity of sound is 340m/s or 29microsecond per cm, and this was used to find the distance to the detected defect based on the transmitted and received signal from ultrasonic sensor. If no obstacle is detected after 30ms, the echo pin will automatically go to a low level. The received time is converted into distance by the micro controller, and this distance is displayed on the Arduino serial monitor. Based on the foregoing, it is easy to note that the Ultrasonic sensor will be capable of detecting a road defect at high speed. This can be explained as follows: For a car moving at a high speed, let us consider a velocity of 180 Km/hr (in reality, this rate might be dangerous for a car moving within a city). However, using this upper limit, and considering the transmit/receive interval of the Ultrasonic sensor to be 30ms, then, for a 10m range between the moving vehicle and the defect, the sensor would transmit and receive the signal about 7 times before reaching the defect! This number is sufficient to detect the defect at this speed (180Km/hr); thus, making it realistic.

C. Road Defect Alert Algorithm

In this section, an algorithm is presented for triggering an alarm using the detection and characterisation of the detected road defects. This alarm is a buzzer for notifying the driver of a possible pothole or bumps ahead. An alarm system was used as opposed to a display message to avoid distracting the driver towards reading a displayed message, which might lead to a possible road traffic accident. As observed in Figure 5, the input from the alternating voltage source is measured by the ultrasonic sensor in form of distance for decision making. This triggers an alarm when the computed distance lies within a certain range for either detected pothole or bumps. Thus, based on the set threshold distance of 40cm, any computed distance above this value is a pothole, while any distance below is a bump; otherwise, it is considered a smooth road.

III. RESULTS

The results obtained from several experiments were extracted from the memory card saved in CSV format. The results obtained are provided in Table 1. The location coordinates provided in the table indicate the location of defects at the time of experimentation. These defects were

located along the length of the road model. The distance between the sensor and each defect is provided in the table. For example (see Table 1), the distance between the car and the defect for the first run is 56 cm; thus, the detected defect was characterised as pothole. Subsequent results from other tests can be seen in Table 1, showing that bumps were detected when the threshold was less than 40cm, while those above this value were detected as pothole. By noting the actual type of defect on the road model, the result obtained showed that both potholes and bumps were detected accordingly.

IV. DISCUSSION

It should be noted that any distance above the designed threshold of 40cm corresponds to a detected pothole, while below corresponds to bump. These observations were logged as defect types, while their corresponding GPS coordinates were also recorded in Table 1. All defects were detected correctly according to the threshold value, indicating its practicality for real development. Despite the different approach used, this result showed similarity to that obtained by Lin *et al.* in [13]. Lin's results showed that potholes could be detected from acquired images similar to the use of Ultrasonic sensor in this paper. Mednis *et al.* also showed in their work [6] that defects could be detected by monitoring the road roughness with their results supporting that obtained in this work. Similarly, the results in Eriksson *et al.* [12] showed likewise to our results that potholes could be monitored using either mobile phones or Ultrasonic sensor (in our work). Our results are also consistent with that obtained by Seraj *et al.* [17], Douangphachanh *et al.* [16] and Vittorio *et al.* [19]. Generally, it has been demonstrated that defects can be detected using Ultrasonic sensor, different from the approaches used by Mednis *et al.* [6], Lin *et al.* [13], Seraj *et al.* [17], Douangphachanh *et al.* [16] and Vittorio *et al.* [19]. Thus, this laboratory model indicates that defect detection systems can be built and studied for larger scale development. However, due to the small dimensions of the laboratory model, the GPS coordinates were the same for all detected defects. Nevertheless, the system successfully logged the coordinates of the defects.

Table 1
Results Obtained from the Developed Simulated Environment

S/No	Latitude	Longitude	Distance (cm)	Type of Defect
1	9.531438	6.452013	56	Pothole
2	9.531438	6.452013	41	Pothole
3	9.531438	6.452013	35	Bumps
4	9.531438	6.452013	43	Pothole
5	9.531438	6.452013	44	Pothole
6	9.531438	6.452013	33	Bump
7	9.531438	6.452013	37	Bump
8	9.531438	6.452013	39	Bump
9	9.531438	6.452013	44	Pothole
10	9.531438	6.452013	34	Bump

V. CONCLUSION

This paper has presented an automated road defect detection system using an Ultrasonic sensor for pothole and bump detection. A model for determining the optimal tilt position of the ultrasonic sensor was used for design purpose. Experimental results showed that the developed system was able to detect and classify defects effectively. However, it was discovered that ultrasonic sensor is temperature dependent. Therefore, future work will consider these factors in the design process with the goal of improving the efficacy and performance of road defect detection towards implementing it on real vehicle.

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