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Automated Pothole Detection and Notification System

Roy Francis Navea*, Patricia Bianca Celestial, Eirah Ritzel Paden, Paolo Pascual and Jose Ramon San Buenaventura
De La Salle University
**roy.navea@dlsu.edu.ph*

Abstract: Potholes are one of the obstacles present in roads that can possibly damage vehicles, slow down traffic and be a cause of accident. It is important to report and fix road imperfections before it worsen and require major renovations. This lessens exposure of motor vehicle drivers from any other driving hazards. Several studies were done which dealt with the detection of potholes. Common methods used are with computer vision or with on-board digital signal processors which require complex algorithms and fast computing peripherals.

In this study, simple on-board sensors, accelerometers in particular, were used and placed at the front and at the rear part of a car. Cruise vibrations, represented by the accelerometer readings, served as the basis of pothole detection. Accelerometer readings vary depending on road surface conditions. They vary when passing thru humps, potholes and flat surfaces. The speed of the vehicle, the number of passengers and whether the tires are fully and not fully immersed were considered when passing thru a pothole. A thresholding method was used to possibly differentiate vibration intensities when passing thru different road surface conditions. Aside from the accelerometers, webcam and GPS modules were also installed for notification purposes. When a pothole is detected, the webcam automatically takes a snapshot of the pothole while the GPS module acquires the coordinates of its location. The coordinates were used to determine the exact location in Google Maps where the car ran thru a pothole. All the gathered information can then be sent to an agency responsible for road works via electronic mail. Results show an average detection accuracy of 91.1% when it comes to pothole detection. Information gathering is fully automated as well as the sending of notifications.

Key Words: pothole; accelerometer; vibration; GPS coordinates; notification

1. INTRODUCTION

Potholes are cracks on the road which turned into holes in the pavement surface because of excessive use. Potholes come in different shapes, sizes, and depths. These road imperfections result to an uncomfortable ride and can possibly damage tires and vehicle suspension mechanisms which may lead to untoward incident. The heat produced by the friction of tires to the road causes it to expand leading to crack formation. The cracks on the roads become prone to being turned into potholes especially during the rainy season. If not repaired immediately, these road imperfections will further cause surface damage which is dangerous to the passing vehicles (Learning, 2017).

In the local setting, there are no automated road monitoring schemes in the country. Oftentimes, reports were made by concerned citizens through a TV network that relays the report and calls the attention of the concerned government agency on-air. If there are ways in which potholes can automatically be detected by passing vehicles and reports can be sent immediately to the government agency concerned with road maintenance and repair, speedy road fixtures can be expected and this could mitigate road deterioration and promote road safety.

Common methods of pothole detection either use computer vision-based techniques (Azhar, Muztaza, Yousaf, & Habib, 2016; Buza, Omanovic, & Huseinovic, 2014; Vigneshwar & Hema Kumar, 2017) or on-board digital signal processors (Chan, Gao, Zhang, & Dahnoun, 2014; Mikhailiuk & Dahnoun, 2016). Computer vision based techniques require complex algorithms and fast computing peripherals to process and analyze the images obtained. Processing takes long to produce results which may defeat the purpose of immediately reporting passed-thru potholes. Digital signal processors (DSP) are expensive as compared to simple sensors used for detecting cruise vibrations. In addition, DSP based devices are highly dependent on sampling rates with which if not enough will result to aliasing (Tan & Jiang, 2013). Data gathered from these methods can be shared through crowd sourcing techniques (Fox, Vijaya Kumar, Chen, & Bai, 2017) to possibly inform other motor vehicle drivers about the presence of a pothole. However, this cannot fix potholes unless the authorities are informed about its occurrence.

2. METHODOLOGY

2.1 System Overview

In this study, on-board accelerometers were used in the implementation of automated pothole detection equipped with a notification system. The block diagram of the automated pothole detection system is shown in Fig. 1. The system is composed of two accelerometers, a webcam and a GPS module. During a ride, the accelerometers continuously provide readings with which if the reading exceeds the identified threshold values, the webcam will be triggered together with the GPS module. The webcam takes a image of the pothole while the GPS module provides the coordinates. The coordinates provided by the GPS module serve as inputs to Google Maps for map display. A screenshot of the map from Google Maps will be stored and sent together with the snapshot image of the pothole via electronic mail to the recipient or say, a road works agency.

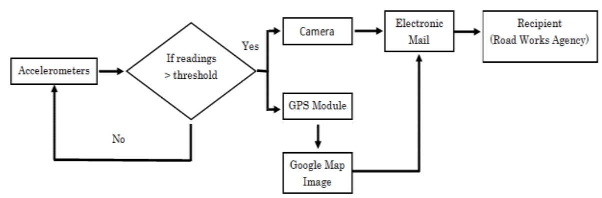


Fig. 1. Block Diagram of the Pothole Detection System

2.2 Sensors and Thresholding

Two capacitive accelerometers (MPU 6050) were used in the prototype. These accelerometers were placed at the front and rear bumpers (just below the plate) of a 2002 Nissan Exalta sedan. Two microcontrollers were used to link the sensors to a laptop computer for processing. Threshold values were obtained and used as bases whether the sensed vibration is from a pothole or not. There were 18 cases considered which came from 3 variations in speed, weight, and 2 types of potholes. Each case had 30 trials. The cases are shown in Table 1.

The mean and standard deviation of all trials for each case were calculated to determine the upper control limit (UCL) and the lower control limit (LCL) for thresholding using equations (Eq. 1) and (Eq. 2)

$$UCL = X + ZS \qquad \text{(Eq. 1)}$$
$$LCL = X - ZS \qquad \text{(Eq. 2)}$$

where:

X = mean
Z = number of standard deviations from the mean put the control limits
S = standard deviation

Table 1. Pothole Detection Cases

Case	Speed (kph)	Number of Passengers	Type of Pothole
1	10	1	Immersed
2	10	1	Not Immersed
3	10	2	Immersed
4	10	2	Not Immersed
5	10	3	Immersed
6	10	3	Not Immersed
7	20	1	Immersed
8	20	1	Not Immersed
9	20	2	Immersed
10	20	2	Not Immersed
11	20	3	Immersed
12	20	3	Not Immersed
13	30	1	Immersed
14	30	1	Not Immersed
15	30	2	Immersed
16	30	2	Not Immersed
17	30	3	Immersed
18	30	3	Not Immersed

2.3 Webcam Triggering

When the readings of the accelerometers exceed the threshold values, the webcam will be triggered to take a snapshot of the pothole. The image is stored in a specific folder with an auto-generated filename for referencing when sending reports. One of the webcams was placed at the trunk part of the car as shown in Fig. 2. The webcam is tilted at an angle of 45° to have a view of the road. Triggering of the webcam needs to be delayed relative to the speed of the vehicle.

Fig. 2. Field of View Alignment of the Webcam

2.4 GPS Module and Google Maps View Location

The GPS module is also triggered with the webcam. The GPS module used is the Skylab SKG25A equipped with an external antenna. The GPS module is connected to the laptop through a microcontroller. The module provides the coordinates of the location where it was triggered. These coordinates were used to find the location of the pothole using Google Maps.

2.5 Electronic Mail Notification

One of the features of this system is its ability to send reports to a designated e-mail address of for example, a government agency that handles road works. Once the webcam and the GPS module are triggered, the system will then notify the recipient by sending an electronic mail containing the image of the pothole, the coordinates of its location and a Google Map screenshot.

2.6 Testing Scenarios

The pothole detection system was tested when the tires are fully and partially immersed. The test sites are shown in Fig. 3.

A test was also conducted to differentiate accelerometer readings when passing thru a pothole, a hump, or a flat surface. The alignment of the maximum change in acceleration was used for this.

Speed, weight of the passengers and the tire immersion depth were considered. Three speed limits, 10 kph, 20 kph and 30 kph, were considered and monitored using Waze. The weight of the passengers varies from 51 to 60 kg, 101 to 110 kg, and 151 to 160 kg. For tire immersion depth, this is when they are fully or partially immersed in the pothole. The target accuracy is more than 81% (Buza et al., 2014) benchmarking from the accuracy attained by Buza et. al (2014).

The accuracy of the system was obtained using a 3-fold cross validation method. There were thirty trials conducted per case. Twenty of these trials were used in determining the threshold value, and ten were used in testing the threshold value whether potholes are detected or not. In each case, three combinations were used. The first combination used the first twenty trials in determining the threshold value and the last ten trials were used for testing. The second combination used the last twenty trials in determining the threshold value and the first ten trials for testing. The last and third combination used the first ten and last ten trials in determining the threshold value and the middle ten trials for testing. Using the threshold value obtained by the twenty trials, the ten trials remaining were used in determining if there is a pothole detected. The accuracy of the system was determined by getting the correct predictions over the total number of trials in each unique case as mentioned in Table 1.

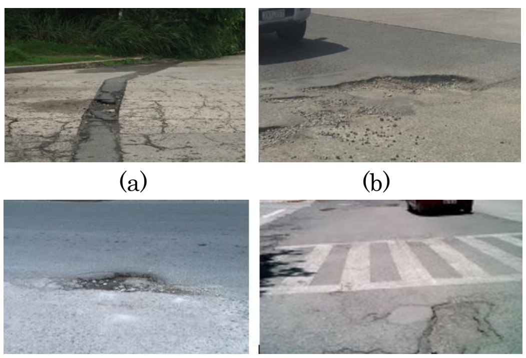


Fig. 3. Potholes in Different Locations: a) Immersed type of pothole located at San Lorenzo Road, Sta. Rosa, Laguna; b) Immersed type of pothole located at Paseo de Sta. Rosa; c) Immersed type of pothole located at Brgy. Malitlit, Sta. Rosa, Laguna; d) Partially immersed type of pothole located at Paseo de Sta. Rosa

3. RESULTS AND DISCUSSION

3.1 Accelerometer Reading Thresholds

Threshold values were obtained by using the 18 cases as shown in Table 1. The car was made to pass thru a pothole to determine the extent of vibrations that the accelerometer could produce. The maximum and minimum X, Y, and Z axes readings of each sensors were obtained as well as the mean and standard deviations for each case. Eq. 1 and Eq. 2 were used to determine the upper and lower cut-off limits. These threshold values are graphed in the Fig. 4 and Fig. 5. The upper threshold value (UTV) is the minimum value obtained per case. On the other hand, the lower threshold value (LTV) is the maximum value obtained per case. It is noticeable that the Z-axis has the highest threshold values as compared to the X and Y axes. This is because the Z-axis detects the vertical vibration which is most likely to occur when passing thru a pothole. Triggers in the X and Y axes are secondary as they refer to the forward-backward and right-left vibrations, respectively.

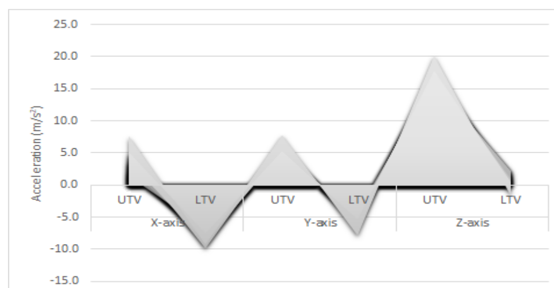


Fig. 4. Upper and Lower Threshold Values of the Front Accelerometer in m/s^2

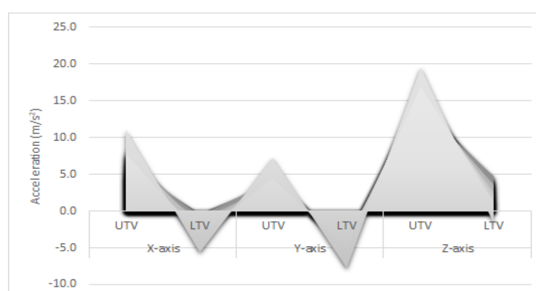


Fig. 5. Upper and Lower Threshold Values of the Rear Accelerometer in m/s^2

3.2 System Performance when Tires are Fully and Partially Immersed in a Pothole

The cases with the same weight and speed but have different types of potholes were compared with each other using ANOVA with an F critical value of 4.9646. Referring to Table 2 and Table 3, results show that for both mean and standard deviation of the accelerometer readings, the F-value is lower than its critical value. This is an indication that there is no significant difference in the accelerometer readings when the tires are fully or partially immersed as they pass thru a pothole. The system can possibly detect potholes in both scenarios.

Table 2. F-values for the Mean Accelerometer Readings

Case	F value	Case	F value
1 and 2	2.06E-04	11 and 12	7.69E-03
3 and 4	1.63E-04	13 and 14	2.38E-06
5 and 6	3.04E-05	15 and 16	1.31E-04
7and 8	7.89E-04	17 and 18	1.65E-03
9 and 10	5.09E-03		

Table 3. F-values for the Standard Deviation of the Accelerometer Readings

Case	F value	Case	F value
1 and 2	0.0640	11 and 12	1.2397
3 and 4	0.3034	13 and 14	0.7881
5 and 6	0.0537	15 and 16	0.9493
7 and 8	0.5628	17 and 18	8.5826
9 and 10	4.3232		

3.3 System Performance when Passing thru a pothole, a hump and a flat surface

Several tests were done to observe the location of the maximum change in acceleration as the car passes thru a pothole, a hump and a flat surface.

Ideally, when passing thru a pothole, the maximum change in acceleration happens at the same time in the X, Y and Z axis if the accelerometer. Thus, they should graphically appear vertically aligned. When passing thru humps and flat surfaces, it was observed that the maximum change in acceleration does not occur at the same instance which does not show vertical alignment across the X, Y and Z axis of the accelerometer.

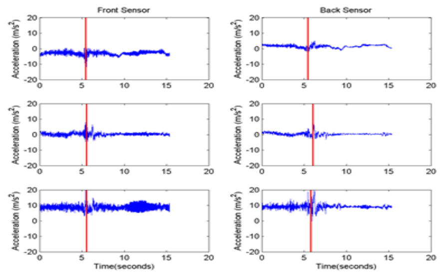


Fig. 6. Location of the Maximum Change in Acceleration when Passing thru Potholes

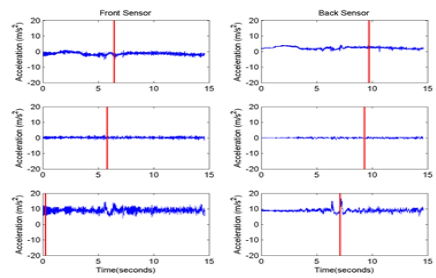


Fig. 7. Location of the Maximum Change in Acceleration when Passing thru Humps

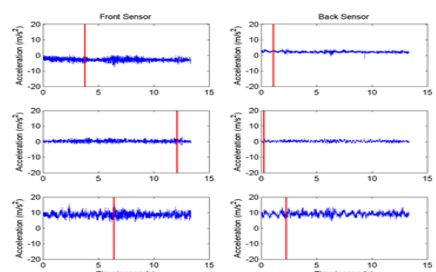


Fig. 8. Location of the Maximum Change in Acceleration when Passing thru Flat Surface

3.4 Detection Accuracy

The overall detection accuracy of the system is shown in Table 4. Odd-numbered cases are when the tires are immersed in the pothole while even-numbered cases are when the tires are partially immersed in the pothole. The average pothole detection accuracy is 91.1%.

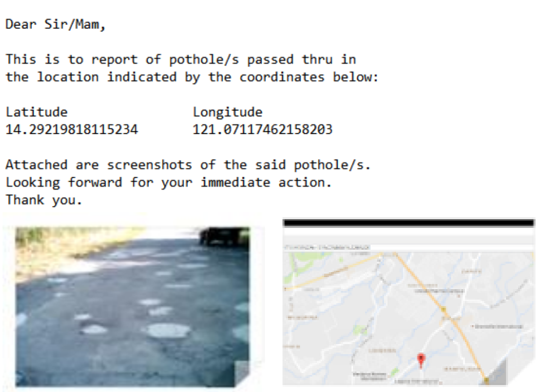
Table 4. Detection Accuracy

Case	Accuracy	Case	Accuracy
1	96.7%	10	96.7%
2	53.3%	11	100.0%
3	96.7%	12	80.0%
4	70.0%	13	100.0%
5	100.0%	14	100.0%
6	73.3%	15	93.3%
7	100.0%	16	100.0%
8	83.3%	17	96.7%
9	100.0%	18	100.0%
Sub	85.9%	Sub	96.3%

AVERAGE : 91.1%

3.5 Electronic Mail Notification

The system is equipped with a notification system. It will send an electronic mail to an agency reporting the detected pothole. As sample mail is shown in Fig. 9.



Dear Sir/Mam,

This is to report of pothole/s passed thru in the location indicated by the coordinates below:

Latitude 14.29219818115234 Longitude 121.07117462158203

Attached are screenshots of the said pothole/s.
Looking forward for your immediate action.
Thank you.

Fig. 9. Sample Electronic Mail with Attachments

4. CONCLUSION

An automated pothole detection and notification system using on-board sensors was proposed in this study. Accelerometers were used to sense cruise vibrations considering different scenarios as discussed.

It was proven that the set-up used performed well obtaining an average detection accuracy of 91.1%. When the system detects a pothole, it automatically takes an image of the pothole and sends an electronic mail notification indicating about its detection together with the GPS coordinates of its location.

5. REFERENCES

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