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An Improved Mobile Sensing Algorithm for Potholes Detection and Analysis

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Abstract

Potholes has been identified as one of the primary reasons for traffic fatalities as well as the wear and tear of vehicle tyres. Numerous efforts have been put into creating technologies that can automatically sense potholes. Notwithstanding, it is challenged with higher computational power. In this study, a mobile-based application for detecting and analyzing potholes is proposed using improved STDEV(Z) and Z-DIFF approach. In this study, an inbuilt mobile device that employs an accelerometer, GPS, and various Z-axis algorithms for potholes detection is presented. Potholes locations' data were compiled, analysed and transferred to the traveller's mobile software. Accuracy, precision and recall were used as the performance metrics for the algorithms. The performance evaluation results of the proposed improved algorithm for large potholes, small potholes and pothole cluster in term of sensitivity, specificity, precision and accuracy in percentage are: 81, 88, 82; 40, 58, 40; 86, 87, 94; and 76, 80, 79; respectively. Based on these results, the proposed improved algorithm outperforms the Z-DIFF and STDEV(Z) algorithms. With this approach, cost of vehicle maintenance and road accidents can be minimized as alternative routes can be used during mobility.

Keywords: *Potholes; STDEV(Z) algorithms; Z-DIFF algorithm; Z-axis algorithms; Accelerometer, GPS.*

1. Introduction

The presence of potholes on roads has over the years been a great source of concern to motorists. This can be frustrating as they lead to many deadly effects. Some have pavement's surface that have a minimal plan depth of 150 mm [1]. It has been identified as one of the primary reasons for traffic fatalities as well as the wear and tear of vehicle tyres [2, 3]. This has led to accident occurrences which could have been avoided. Also, vehicle owners have had to spend avoidable expenses on maintenance due to encounters with pot holes. This has been the case in many parts of Nigeria [4]. Additionally, as a result of climate change, there are more potholes on the sidewalk and heavier rain and snow in different geographic regions. This has led to increasing complaints about accidents caused by potholes [5]. There are internal and external factors that contribute to potholes. Internal factors include the deterioration of the pavement's materials and their responsiveness or durability to climate change factors like heavy rain and snowfall. External factors include a lack of quality and construction management. It is highly costly and requires lot of effort to manually find and assess potholes.

Numerous efforts have been put into creating technologies that can automatically find and identify potholes. This has tried to improve survey effectiveness and pavement quality through early detection and prompt action [6]. Notwithstanding, it is challenged with higher computational power, Table 1 shows the comparison of pothole sensing methods that have been used. Hence, an efficient pothole detection system is to alert drivers to uneven pavement and potholes in their routes [7]. This will enable the detection of potholes that can

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identify and gauge the size and depth of both dry and wet ones in order to warn [7].

With the easy access to mobile internet-based technologies, it makes it possible to build potholes detection systems with the aim of reducing the number of accidents caused by potholes. In this research, a mobile-based application for detecting and analyzing potholes is proposed by using improved STDEV(Z) and Z-DIFF approach. The algorithms employed applies inputs based on location detection and estimation of pothole depth. This makes it easy for motorist to make a choice on alternate routes or ply the path. Section 2 of this paper discusses some related works conducted in this research area by exploring methods and gaps. The method used for conducting this research is discussed in Section 3.

Table 1: Comparing Pothole Monitoring Techniques

Method	**Sensor cost**	**Comput-ational cost**	**Operati-onal cost (calibrat-ion, adjust-ent, etc.)**	**Accur-acy**
Vibration-based	Low	Low	Low	Low
3D-based	High	High	High	High
2D-based	Medium	Medium	Low	Medium

2. Related Works

Wang *et al.* [9] worked on the analysis, classification, and simulation of road surface profiles. The authors gave a universal categorization approach for the study of shock and vibrations associated with the process of road transport in a series of articles, together with a universal methodology for analysis of discretely sampled road profile data. With the help of a laser profilometer, the road profiles were recorded and they use 415 km of data, which represent a wide variety of road surfaces. They showed that the analysis of the spatial acceleration enables identification of transients using statistical tools such as skewness and kurtosis; and the crest factor. Additionally, they demonstrate a modelling method for stress and noises linked to variations in the road surface. Their approach re-lies on a statistical road surface profile model that detects the transient density, the probability distribution function (PDF), and the power spectral density (PSD) of the baseline stable credentials. Research work on remote monitoring of vehicle shock and vibrations were carried out by Nanthakumar *et al.* [10]. The authors introduced a technique for tracking shocks and vibrations produced by companies and manufacturing transportation vehicles.

Measurement of the acceleration levels is done using a four-accelerometer that is coupled to a microprocessor, and the results show how to distinguish short-duration vibration bursts and shocks, which typically take place against a backdrop of random vibrations. They take the strategy of first segmenting the signal and then calculating the root mean square of each segment. Then, the authors employ two variables to find the extreme values in-side the segments. First, determine whether the extreme value exceeds three to four times the RMS level, and then determine whether the extreme value exceeds a certain threshold. They also discussed problems with remote sensing, concentrating on three problems in particular: data transmission rates, communication expenses, and accessibility to wireless communication networks.

Also, Bernal *et al.* [11] extended research by working on Real-Time Pothole Detection using Android Smartphones with Accelerometers. Similar to the Pot-hole Patrol, the authors created and examined four alternative pothole-detecting algorithms utilizing acceleration levels. On a 4.4-kilometer test track they chose, their top algorithm, Z-DIFF, had a true positive hit rate of 92%. They took ad-vantage of four distinct Android-powered smartphone models to measure acceleration levels. They introduced some approaches to potholes detection. Z-THRESH was the incident detection method that was both the worst and the easiest to use. It limits acceleration amplitude at the Z-axis and is akin to the z-peak algorithm used in the Traffic Sense, Nericell, and Pothole Patrol systems. The algorithm implies that knowledge of the accelerometer's Z-axis position is pre-sent. Additional virtual reorientation of the accelerometer is available. They also suggested the Z-DIFF algorithm, a marginally more sophisticated method. This conducts a search for two sequential measurements with a difference between the values above the particular threshold level, in contrast to Z-THRESH. This algorithm thus quickly finds variations in data on vertical acceleration. Similar to the earlier method, the algorithm involves determining the Z-axis position.

The work done by Mednis *et al.* [12] titled "Distributed Road Surface Condition Monitoring Using Mobile Phones" was about the development of a pattern recognition system for detecting road surface anomalies that contribute to road roughness. The acceleration signals' characteristics were separated into several categories for the recognition, e.g. standard deviation, mean, peak-to-peak, root mean square, etc. Smartphones mounted to windscreens of moving vehicles were used to gather data, which included GPS location and acceleration levels. Additionally, a camcorder was used to corroborate any road anomalies.

A study on the use of smartphones for road roughness condition estimation was conducted by Perttunen *et al.* [13] where they performed an analysis on the features and the relationships between acceleration data and International Roughness Index (IRI). The acceleration data is collected using a mobile device. The Vehicle Intelligent Monitoring System (VIMS), a system created by the University of Tokyo's Bridge and Structure Laboratory for IRI calculations, is used to gather data on the standard surface state.

Douangphachanh and Oneyama [14] worked on Automatic Road Anomaly Detection Using Smart Mobile Device. The accelerometer was installed on a motorbike rather than a car, in contrast to prior research that have employed an accelerometer from a mobile device. Although the concept to identify road anomalies using acceleration data is the same as in other studies, they employed the vibration pattern to analyze the acceleration data to distinguish anomalous vibrations from ground vibrations. However, they classified the road section as a function of roughness, where the number of road anomalies per kilometer is used to determine roughness. Vibrations felt on smooth roads were recorded.

Tai *et al.* [15] proposed a method for pothole identification for offline data extraction. Using band-pass filters with a frequency range of 0.5–6.0Hz, a sliding window with various functions like Chebyshev, Hamming, and Taylor, and normalization in the range [0,1], accelerometer data (sampling rate 38Hz) is pre-processed. Then feature extraction, including wavelet packet seg-mentation, wavelet peak-to-peak ratio, root mean square, standard deviation, and variance. Backward and forward selection, genetic algorithms, and support vector machines with principal component analysis are used to reduce the number of features. Even though the suggested method performed well in tests, it cannot be fully implemented on a device with limited hardware and software resources. However, some of the outlined techniques might be helpful for processing data in real-time.

Ashwini *et al.* [16] proposed a method which includes Z-DIFF approach and the STDEV-Z approach. Some shortcomings were detected in these approaches. The position of the exact pothole has not been looked into, not real-time data collection and they are slow. Hence, a mobile application for pothole detection and analysis which will further strengthen the respective advantages of Z-DIFF and STDEV-Z approaches and also reduce their respective short-coming is therefore proposed in this work.

In view of the review of related works, it is evident that there is a need for a mobile sensing-based technique for real-time pothole detection (since it is considered as the most suitable method to detect potholes for mobile devices and the collection and normalization of accelerometer data from mobile devices for free angle determination does not require powerful computing resources). Additionally, for pothole detection accuracy improvement, the suggested pothole recognition system will consider a number of thresholds and combine a number of pothole detection approaches.

3. Research Design and Method

The objective of this research work is the implementation of a mobile application for pothole detection and analysis using an improved algorithm and the investigation of the efficiency of the implemented pothole detection system. To achieve this objective, the architectural design was implemented together with the re-search process steps, which are: accelerometer data gathering and collection. There are three components that make up the framework: a sensing subsystem, a communication subsystem, and a localization subsystem. These three subsystems operate separately from one another, but they all circle around the same thing: the data. The data is produced by the sensing subsystem; it is then distributed and collected by the communication subsystem; and, finally, it is used and produced by the positioning subsystem to provide information to the vehicle.

The mobile devices with the Android OS were incorporated into transportation vehicles. These smartphones check for travel-related anomalies and record the location information at the same time. It was linked to a web server where the info was transferred. It carried out the following functions: real-time vehicle monitoring and pothole detection. This inbuilt device employs an accelerometer, GPS, and various Z-axis algorithms to find potholes. Following the activation of each sensor, the accelerometer will use the algorithms to constantly record the Z-axis readings and identify potholes. When a pothole is found, a GPS sensor records the position details and sends them, along with a timestamp, to a server. The combination of two Z-axis algorithms were used in this system – STDEV(Z) and Z-DIFF. For real-time vehicle tracking, the pothole detection and warning system tracks the position of the vehicle using the GPS feature of the integrated mobile phone. Based on the speed of the vehicle, this position tracking was done over a specific period of time. The time interval and the vehicle's speed are negatively related.

The embedded handset captured data, which was transmitted to a web server. This information was stored in the web server's MySQL or MSSQL database. Two items are highlighted by the web server. To begin with, data regarding the locations of the potholes were compiled and analysed based on specific criteria to produce a list of potholes that require immediate attention. Second, using Google APIs, the data regarding the vehicle's current position was processed and dis-played on the map. This data is simultaneously transferred to the traveler's mobile software.

The Intelligent Transport System (ITS) was the foundation for the Traveler Program. Internet connectivity on the user gadget is the main prerequisite for the Traveler Application. The user will ask the web server for the vehicle's current position. The web server will then reply to the request with the location information and display this information on a map. These modules' general layout and that of their auxiliary modules are shown in Figure 1.

Figure 1: Proposed architectural design for pothole detection system

3.1 Accelerometer Data Gathering and Collection

The deviation on the X or Y plane is displayed by the accelerometer to indicate when a moving vehicle hits a pothole. The latitude and longitude of the pothole will then be sent to the cloud if the deflection meets the flow diagram's pre-stated conditions, as shown in Figure 1. In order to prevent collisions, an ultrasonic sensor measures the distance between two vehicles that are nearing one another closely. If the distance meets the criteria, the rider will be alerted by a buzzer.

3.2 Accelerometer Data Normalization

The three-axis accelerometer data in this investigation were normalised using the Euler angle formulas so as to overcome the drawback of the specific point acquired by current pothole detection methods. The three-dimensional Euclidean space vector set is expressed by the Euler angle formulas, which indicate a series of three elemental rotations. The specification of the accelerometer data's vector collection is $\{x', y', z'\}$. The x', y', z' system rotates about the $x'-axis$ by angle α. The $y'-axis$ is now at angle α with respect to the $y'-axis$, and the $z'-axis$ is now at angle α with respect to the $z'-axis$. The vector set used in the Euler angle calculations is $\{x', y', z'\}$. is calculable by utilising the vector set's numbers $\{x', y', z'\}$ and angle α. Additionally, when the device revolves about the $y'-axis$ by angle, the coordinate of each axis can be determined using the Euler angle equations

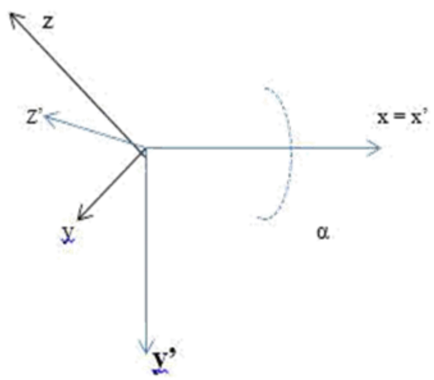

Figure 2: Euler angles (the x', y', z' system rotates about the $x'-axis$ by angle α)

β and $z'-axis$ by angle γ. Therefore, in this research, the coordinate of each plane with a 0-degree angle is referred to as the baseline as shown in Figure 2.

By using the vector set of the baseline and rotation angle for normalizing accelerometer data during runtime, the vector set $\{x, y, z\}$ can be computed as follows:

$$[x\ y\ z] = [x'y'z'], [1\ 0\ 0\ 0\ cos \propto\ -sin \propto\ 0\ sin \propto\ cos \propto],$$
$$x = x'$$
$$y = y' \times (cos\ cos\ \propto) + z' \times (sin\ sin\ \propto), \quad (1)$$
$$z = y' \times (cos\ cos\ \propto) + z' \times (sin \propto),$$
$$[x\ y\ z] = [x'y'z'][cos\ cos\ \propto\ 0\ sin\ sin\ \beta\ 0\ 1\ 0\ -sin\ sin\ \beta\ 0\ cos\ cos\ \beta]$$
$$y = y',$$
$$z = x' \times (sin\ sin\ \beta) + z' \times (cos\ cos\ \beta), \quad (2)$$
$$[x\ y\ z] = [x'y'z'][cos\ cos\ \gamma\ -sin\ sin\ \gamma\ 0\ sin\ sin\ \gamma\ cos\ cos\ \gamma\ 0\ 0\ 0\ 1],$$
$$x = x' \times (cos\ cos\ \gamma) + y' \times (sin\ sin\ \gamma),$$
$$y = x' \times (-sin\ sin\ \gamma) + y' \times (\gamma),$$
$$z = z'.$$

3.3 Methods for Sensing Potholes

In order to improve pothole detection, this research considers two different pothole detection methods and suggests a pothole detection algorithm to combine them.

The Z-DIFF Pothole Detection Approach. The Z-DIFF method uses the largest difference between two successive $z-axis$ accelerometer readings as the cutoff point for pothole detection. The velocity of variation of $z-axis$ accelerometer data between time t_1 and time t_2 is calculated and used to identify potholes due to the significant decreasing and increasing of $z-axis$ accelerometer data through a pothole. Therefore, in experimental runs, it gets i_{j-1}, i_j the greatest value of velocity of variation of $z-axis$ accelerometer data through a pothole. Additionally, the threshold is chosen to be able to detect potholes for each experimental run based on the minimum and maximum variation velocity values in each run. As of runtime, the value of $f_2(g_{a,i,j})$ is 1 when the value of $|g_{a.i,j} - g_{a.i,j-1}| / (t_{i,j} - t_{i,j-1})$ is larger than θ_2 for pothole detection. Regrettably, this method's drawback is that it is challenging to estimate the duration disparity in both $t_{i,j-1}$ and $t_{i,j}$ the temporal difference affects the accuracy of this method.

$$\theta_2 = \min \frac{|-|}{-} \quad (3)$$

Detention function is

$$f_2(g_{a,i,j}) = \left\{1, 0, others, if\ \frac{|-|}{-} \geq \theta_2\right\} \quad (4)$$

where,

$$a = 1,1 \leq i \leq n, \quad i \in N, j \geq 1, j \in N$$

The STDEV (Z) Pothole Detection Approach. In the STDEV (Z) method, the benchmark for pothole detection is based on the maximum standard deviation of the $z-axis$ accelerometer data. The standard deviation of $z-axis$ accelerometer data during K records is calculated and used to identify potholes due to the perturbation motion of $z-axis$ accelerometer data through a pothole. As a result, during experimental runs, it obtains the highest standard deviation of the $z-axis$ accelerometer data through a pothole. In addition, the threshold θ_3 is chosen as appropriate for the identification of potholes for each experimental run as the minimum and highest standard deviation values in each run. As of execution, the value of $f_3(g_{a,i,j})$ is 1 when the value of $\sqrt{\sum_{k=j-k+1} j}\ (g_{a,i,k}-\mu_{i,j})^2 \,/\, K$ is larger than θ_3 for pothole detection. The difficulty in figuring out the value of K, which stands for "time period," limits this method, and this time period affects how efficient it is. The value of threshold is

$$\sqrt{\frac{\sum_{k=j-k+1}^{j}(-)^2}{K}} \tag{5}$$

where

$$\theta_3 = \frac{\sum_{k=j-k+1}^{j}(-)^2}{K}$$

Detention function is

$$\sqrt{\frac{\sum_{k=j-k+1}^{j}(-)^2}{K}} \tag{6}$$

$$f_3\left(g_{a,i,j}\right) = \{1, 0, if \ \geq \theta_3\}$$

$$a = 1, \quad 1 \leq i \leq n, \quad i \in N, j \geq K$$

Establishing the Position of Potholes. This research employs the space interpolation method to determine the precise position of potholes. The space interpolation technique is used to locate the pothole using the two locations $L_1,$ L_2 and timestamps $t_1,$ t_2 retrieved from the GPS module. The distance for both points L_1 and L_2 is the definition of the function $d(L_1, L_2)$. Consequently, using the pothole position L_p can be done using

$$d\left(L_i, L_p\right) = (d(L_1, L_2)x\ (t_2 - t_1))/(t_3 - t_1) \tag{7}$$

$$d\left(L_2, L_p\right) = (d(L_1, L_2)x\ (t_3 - t_2))/(t_3 - t_1) \tag{8}$$

Algorithm for the pothole detection approach

INPUT: $g_{a,i,j}$

where $a = \{1, 2, 3\}, 1 \leq i \leq n, i \in N, j \geq 1, j \in N$

[1] ***OUTPUT: The value of output is 1 when the proposed pothole detection method supposes the car passed through a pothole***

```
Set check method = 0
Set check time = 0
while ( j ϵ N)
        if (t_{i,j} − check time) > ∈ sec then
        check method = 0
        check time = 0
end if
if f_1(g_{a,i,j}) = 1 then
        if check method = 0 then
        check method = 1
        check time = t_{i,j}
else if check method = 4 then
return 1
else
check time = t_{i,j}
end if
end if
if f_4(g_{1,i,j}) then
        if check method = 0 then
        check method = 4
        check time = t_{i,j}
else if check method = 1 then
return 1
else
        check time = t_{i,j}
end if
end if
end while
```

Technical Requirement. The mobile device's technological needs for the pothole detection, assessment, and monitoring systems were as follows:

a) The device is made to quickly identify potholes. Raw data gathering for offline post-processing is categorized as an extra function.
b) The identical details are published on a public website for the benefit of other travelers.
c) The hardware/software platform for the device is a generic Android OS-based handset with accelerometer sensors. The option to transfer data to other platforms is categorized as an extra feature.
d) The system is made to function on various smart-phone versions with a variety of settings. A list of the essential specifications for a smart phone was established and detailed during the system implementation process.

e) The device's native contact functions were hindered.
f) Both components and other apps had access to the data that was gathered by the components.
g) The program was created to prevent resource-intensive methods of making decisions.

3.4 *Performance Metrics*

Pothole segmentation and candidate extraction were carried out under identical conditions to evaluate the performance of the suggested strategy against that of the current approaches. The proposed criteria were then applied differently in each technique to determine the decision criterion for a pothole. Number of True Positives (TP, accurately identified as a pothole), False Positives (FP), and True Negatives (TN), and False Negatives (FN), wrongly detected as a non-pothole, were manually tallied in order to reflect accurate measurements for validation of the proposed method and the current method's accuracy, precision, and recall were computed.

4. **Results and Discussion**

4.1 *Data source*

The data used for the experiments were obtained by driving through a selected test track which was 18.9km (11.7miles) long. It included both important single-lane and minor multi-lane streets from Sango Ota, Ogun state to Agege, Lagos state. It was distinguished by a spectrum of uniformity in the road pavement.

4.2 *Experimentation*

A Walking GPS approach was used to mark the ground truth for the chosen test track, and irregularity potholes were classified into three groups based on size: large potholes, small potholes, and pothole clusters. Based on the depth, width, and whether the tyre contact the pothole's bottom when a vehicle is driving over it, potholes are classified as small or big. Small potholes are those in which the tyre won't hit the bottom and have a maximum horizontal dimension of more than 75mm and a depth of more than 20mm; large potholes are those in which the maximum horizontal dimension is more than 250mm and the depth is more than 40mm. Additionally, it describes those with a wide diameter so that the wheel. On the other hand, a pothole cluster refers to a group of potholes situated in a particular position. The actual ground truth parameters obtained for all pot-holes irregularities, that is, small potholes, large potholes, and pothole clusters is shown in Table 2. The actual ground truth parameters included forty-four (44) large potholes, fifty-two (52) small potholes and thirty-eight (38) pothole clusters summing up to a total of one hundred and thirty-four (134) pothole types. The road test session was conducted on the same day that the ground truth was deter-mined, and it consisted of eight consecutive laps on the chosen test track. Such a strategy guaranteed few mistakes in the data gathering processes. Four different vehicles, as well as a smartphone, were used during the test drive exercise.

Table 2: Ground truth parameters

Class	Number of detected pavement defects
Large potholes	44
Small potholes	52
Pothole clusters	38
Total	134

4.3 *Evaluation*

Three different algorithms (the Z-Diff, the STDEV(Z) and the Improved) were implemented to evaluate the performance of the results generated from the ground truth parameters for the evaluation analysis, the number of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) was generated. More specifically, the following statistical measures were used to assess each algorithm's performance:

a) **Accuracy**: A test can be said to be accurate when it is able to adequately measure what it is supposed to measure.
b) **Precision**: This is when repeated analyses on the same sample give similar results. It measures statistical variability, that is, description of random errors.
c) **Sensitivity**: This is a test of TP rate. This refers to a test's capacity to properly recognize and categorize a data item.
d) **Specificity**: This is a test of TN rate. Specifically, the capacity of a test to recognize and classify real negative data with accuracy.

The confusion matrix generated for the Z-Diff algorithm is depicted in Table 3. The results generated for TP, TN, FN, and FP for large potholes, small potholes and pothole clusters were 30 TPs, 6 TNs, 14 FNs, and 9 FPs; 33 TPs, 4 TNs, 19 FNs, and 8 FPs; 28 TPs, 1 TN, 10 FNs, and 4FPs, respectively. Averagely, the number of true positives, outweighs the number of false negatives generated. However, the number of generated true negatives is less than the number of false positives generated.

Table 3: Confusion matrix using the Z-DIFF algorithm

Evaluation metric	Large Potholes	Small Potholes	Pothole Clusters
Accuracy (%)	61	58	67
Precision (%)	77	80	88
Sensitivity (%)	68	63	74
Specificity (%)	60	67	80

The relationship between large potholes, small potholes and pothole clusters in terms of sensitivity, specificity, precision and accuracy is shown in Table 4. From Table 4, it is seen that sensitivity and accuracy is highest when dealing with pot-hole clusters and lowest when dealing with small potholes. However, in terms of specificity and precision, that value obtained is highest in pothole clusters and lowest in large potholes.

Table 4: Performance evaluation of Z-DIFF algorithm

Evaluation metric	Large Potholes	Small Potholes	Pothole Clusters
Accuracy (%)	61	58	67
Precision (%)	77	80	88
Sensitivity (%)	68	63	74
Specificity (%)	60	67	80

4.4 Results Analysis for the STDEV(Z) Algorithm

The confusion matrix generated for the STDEV(Z) algorithm is depicted in Table 5. The results generated for TP, TN, FN, and FP for large potholes, small potholes and pothole clusters were 34 TPs, 8 TNs, 10 FNs, and 7 FPs; 43 TPs, 4 TNs, 9 FNs, and 8 FPs; 28 TPs, 3 TN, 10 FNs, and 2 FPs, respectively. The confusion matrix clearly depicts that the number of true positives generated by this algorithm greatly outweighs the number of false negatives generated. Also, the number of generated true negatives outnumbers the generated false positives.

Table 5: Confusion matrix using the STDEV(Z) algorithm

Class	TP	TN	FN	FP
Small potholes	43	4	9	8
Large potholes	34	8	10	7
Pothole clusters	28	3	10	2

Table 6 shows the relationship between large potholes, small potholes and pot-hole clusters in terms of sensitivity, specificity, precision and accuracy. It is seen in table 6 that sensitivity and specificity is lowest when dealing with pothole clusters and highest when dealing with small potholes. However, in terms of precision, the value obtained is highest in pothole clusters and lowest in large pot-holes. In terms of accuracy, the value obtained is highest in smaller potholes and lowest in large potholes.

Table 6: Performance evaluation of STDEV(Z) algorithm

Evaluation metric	Large Potholes	Small Potholes	Pothole Clusters
Accuracy (%)	71	73	72
Precision (%)	83	84	93
Sensitivity (%)	77	83	74
Specificity (%)	47	67	40

4.5 Results Analysis from the Improved Algorithm

The confusion matrix generated for the improved algorithm is depicted in Table 7. The results generated for TP, TN, FN, and FP for large potholes, small potholes and pothole clusters were 36 TPs, 9 TNs, 8 FNs, and 6 FPs; 46 TPs, 5 TNs, 6 FNs, and 7 FPs; 31 TPs, 3 TN, 7 FNs, and 2 FPs, respectively. The confusion matrix clearly depicts that the number of true positives generated by this algorithm greatly outweighs the number of false negatives generated. Also, the number of generated true negatives outnumbers the generated false positives.

Table 7: Confusion matrix using the improved algorithm

Class	TP	TN	FN	FP
Small potholes	46	5	6	7
Large potholes	36	9	8	6
Pothole clusters	31	3	7	2

Table 8 shows the relationship between large potholes, small potholes and pot-hole clusters in terms of sensitivity, specificity, precision and accuracy. From the table, it is seen that sensitivity, specificity, precision and accuracy is highest in small potholes. Also, sensitivity, precision and accuracy are lowest in large pot-holes. However, specificity generates the same value for both large potholes and pothole clusters.

Table 8: Performance evaluation of the proposed improved pothole detection algorithm

Evaluation metric	Large Potholes	Small Potholes	Pothole Clusters
Accuracy (%)	76	80	79
Precision (%)	86	87	94
Sensitivity (%)	81	88	82
Specificity (%)	40	58	40

4.6 Comparative Analysis of the Algorithms

The comparison analysis further revealed the analysis of the results obtained from the improved algorithm and the existing algorithms used in these experiments. Three experiments were performed based on the different classification of the potholes. Also, a total of four metrics was used for the evaluation of the performance of the algorithm. As depicted in Figure 3, the efficiency of the Z-Diff algorithm in terms of sensitivity, precision, specificity and accuracy is more pronounced on pothole clusters than on large and small potholes. The Precision of the Z-Diff algorithm is higher in small potholes than on large potholes. The Z-Diff algorithm is more sensitive and more accurate in detecting large potholes than small potholes.

The Effect of pothole type on the performance of the STDEV(Z) Algorithm. The accuracy level obtained when the STDEV(Z) algorithm is applied on all pothole types is the same. However, higher precision is achieved using this algorithm on pothole clusters than on large and small potholes as seen in Figure 4. The precision achieved when this algorithm is applied on both large and small potholes are at par.

The Effect of pothole type on the performance of the Improved Algorithm. For the proposed improved algorithm, the precision level is higher when applied on small potholes and pothole clusters as depicted in Figure 5. The accuracy level achieved is at par across all pothole types. It is more sensitive on small potholes than on large potholes.

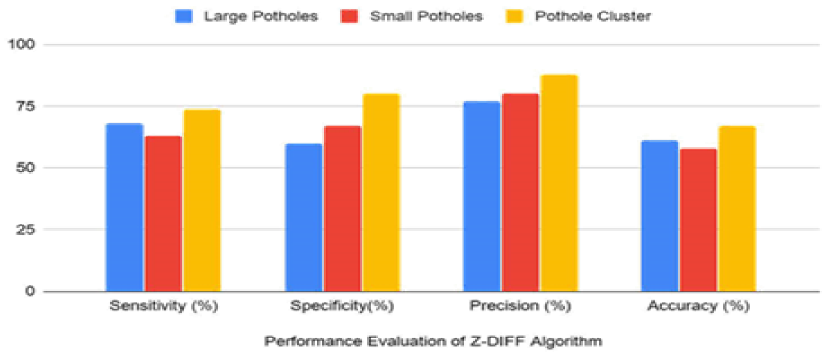

Figure 3: Performance evaluation of Z-DIFF algorithm on different pothole type

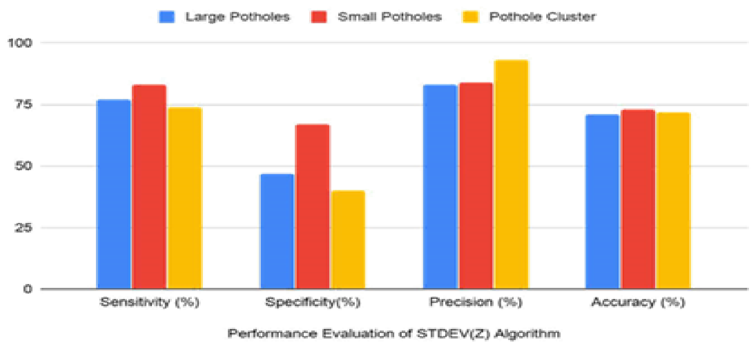

Figure 4. Performance evaluation of STDEV(Z) algorithm on different pothole type

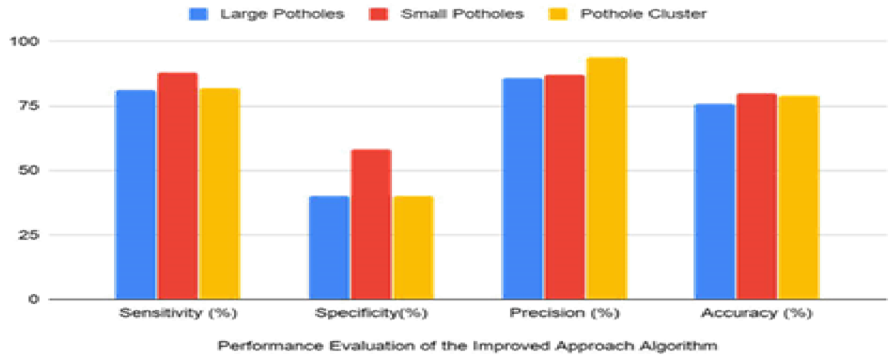

Figure 5: Performance evaluation of the improved algorithm on different pothole type

Performance Metrics Evaluation of Different Implementations of Pothole Detection System. As depicted in Figures 6, 7, and 8, the proposed improved algorithms out-perform the existing algorithms in terms of sensitivity, specificity, precision and accuracy irrespective of the pothole type.

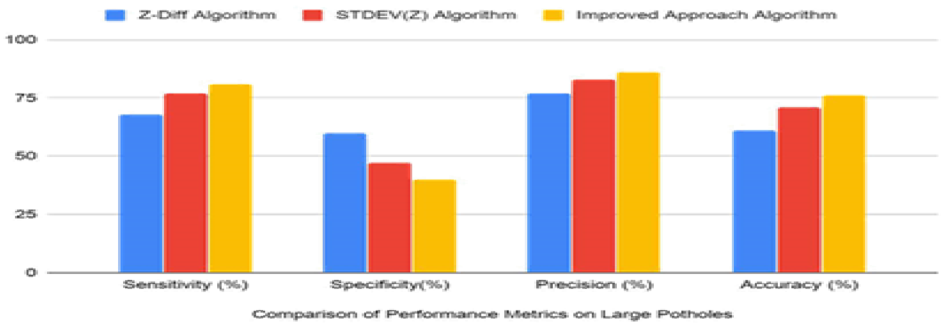

Figure 6: Evaluation of various algorithms' performance metrics of pothole detection system on large potholes

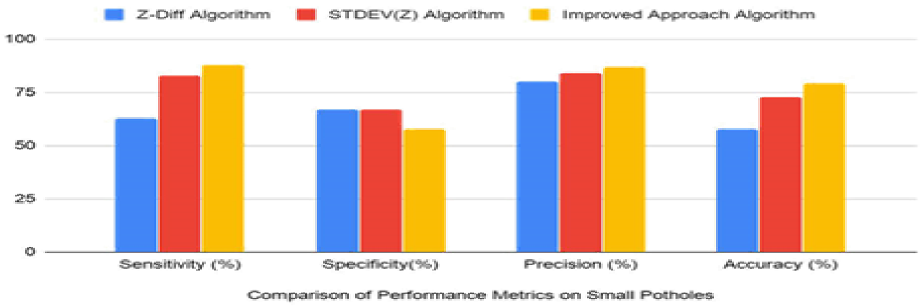

Figure 7: Evaluation of various algorithms' performance metrics of pothole detection system on small potholes

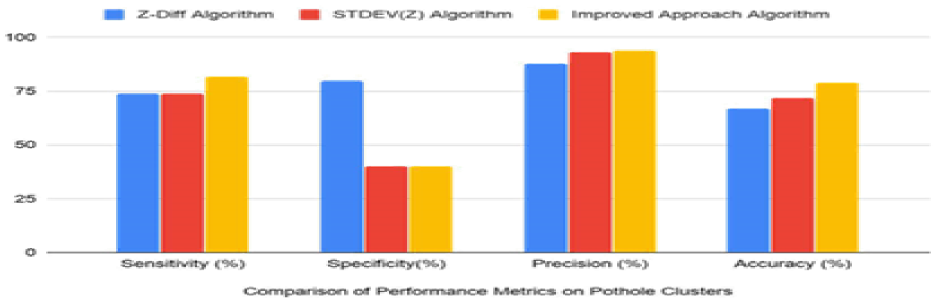

Figure 8: Evaluation of various algorithms' performance metrics of pothole detection system on pothole clusters

5. Conclusion

In this research, pothole detection systems based on accelerometer data are described, along with their assessment using actual data obtained using an Android OS-based smartphone for gadgets that have restricted hardware and software resources. It was detected that the depth and dimensions of potholes have an effect on the generated result. Three different algorithms were used in testing the proposed system and they are the Z-DIFF algorithm, STDEV(Z) algorithm and the proposed improved algorithm. The proposed algorithm adopted the interpolation method for getting the exact location where a pothole exists. The performance of each of the algorithm were evaluated using TP, TN, FN and FP. More so, evaluation metrics such as accuracy, precision, sensitivity and specificity were used to compare the results.

The evaluation results showed that the proposed improved algorithm outperform both the Z-DIFF algorithm and STDEV(Z) algorithm. This research demonstrated the use of mobile phones to take samples in real time, established the size and dimension of potholes as a factor to be considered in developing algorithms for pothole detection systems. With this approach, motorist can now minimize their cost of vehicle maintenance that could have been more as a result of their encounters with potholes on roads. Also, accidents on the roads can be minimized as alternative routes can be used during mobility. The proposed approach can be further improved to be faster. Other elements like notifying the user some distances to the location of the potholes can be included as a feature.

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