Journal of Scientific Research & Reports
7(2): 108-116, 2015; Article no.JSRR.2015.192
ISSN: 2320-0227

SCIENCEDOMAIN *international*
www.sciencedomain.org

A New Measure for Analysing Accelerometer Data towards Developing Efficient Road Defect Profiling Systems

H. Bello-Salau[1*], A. M. Aibinu[2], E. N. Onwuka[1], J. J. Dukiya[3], M. E. Bima[2], A. J. Onumanyi[1] and T. A. Folorunso[2]

[1]*Department of Telecommunication Engineering, Federal University of Technology, P.M.B.65, Minna, Niger State, Nigeria.*
[2]*Department of Mechatronics Engineering, Federal University of Technology, P.M.B.65, Minna, Niger State, Nigeria.*
[3]*Department of Transport Management, Federal University of Technology, P.M.B.65, Minna, Niger State, Nigeria.*

Authors' contributions

This work was carried out in collaboration between all authors. Author HSB initiated the idea, designed the study, carried out data acquisition, and wrote the first draft of the manuscript. Authors AMA, ENO and JJD were responsible for supervising every stage of the research, and proof reading. Authors MEB and TAF were responsible for encoding and testing the protocol in LABVIEW, while author AJO participated in data acquisition, algorithm evaluation, manuscript proof reading, and handling of the review process. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2015/16840
Editor(s):
(1) Fabrício Moraes de Almeida, Federal University of Rondônia, Porto Velho, RO – Brasil.
(2) Pak Kin Wong, Department of Electromechanical Engineering, University of Macau, Macao.
(3) Luigi Rodino, Professor of Mathematical Analysis, Dipartimento di Matematica, Università di Torino, Italy.
Reviewers:
(1) Anonymous, P. R. China.
(2) Vaishali D. Khairnar, Information Technology, Terna Engineering College, Mumbai University, India.
(3) Anonymous, Hungary.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1126&id=22&aid=8961

Original Research Article

Received 16th February 2015
Accepted 11th April 2015
Published 27th April 2015

ABSTRACT

Aims: In this paper, we propose a new measure for analysing data obtained from an accelerometer with the aim of improving road surface condition monitoring and defect detection systems.
Study Design: The study consisted of an experimental setup involving the use of an

**Corresponding author: Email: adeiza1@yahoo.com;*

accelerometer embedded device connected to a laptop, all mounted in a vehicle for data acquisition and storage.
Place and Duration of Study: Data gathering was conducted within the campus of the Federal University of Technology, Minna, for a period of two months.
Methodology: The accelerometer was programmed to capture vibration signals along the x, y and z-axis with special interest in the z-axis because it monitors the up/down motion of the vehicle. Our algorithm uses what we call the "z-difference square" measure to analyse raw accelerometer data towards improving road defect detection. LABVIEW was used to configure the accelerometer device, while the algorithm for post data processing and statistical analyses were implemented in MATLAB.
Results: Inferences drawn from the raw data and other statistical measures indicate that the proposed measure provides the advantage of using single threshold values for detection, inherent averaging, and potential for spatial localization of potholes, as compared to other statistical measures.
Conclusion: The use of our proposed "z-difference square" measure for analysing accelerometer data will provide a simple yet efficient and effective statistical measure for improving road defect detection systems.

Keywords: Road Defects; potholes; smartphone; accelerometer; difference equation and profiling.

1. INTRODUCTION

Road defects are imperfections noticed on the surface of a road. These may be in the form of potholes, road bumps, rutting and pavement cracks. These defects are prominent on Nigeria roads, and this can be traced to poor or lack of drainage systems, excessive waterlogs, poorly maintained asphalt roads, excessive or unexpected traffic patterns and poor quality of roadway materials/construction, all contributing to the increase in the number of road accidents [1] in the country. This has further resulted in the loss of lives and properties, and has slowed down the rate of development in the country [2].

Efforts have been made to address these problems, and these include the enforcement of Law and order by the Federal Road Safety Corps (FRSC) [3] and Vehicle Inspection Officers (VIO) [4], training and retraining of drivers in compliance with safety tips [5,6], compliance with speed limit, making sure that vehicles are in good condition, durable road construction and repair of defect roads [2]. Nevertheless, the effectiveness of these solutions greatly depend on a number of factors, among which includes adherence to acceptable road construction and repair regulations/standards, time constraints and the availability of funds. Thus, while these constraints linger, it becomes necessary to develop alternate or supplementary solutions as considered in this article.

The main purpose of this paper is to propose the use of a new measure termed "z-difference square", towards enhancing accelerometer data analysis. The "z" acronym in the name of the measure is attributed to the z-axis of the accelerometer output. Existing methods based on normal difference equations, mean, variance or standard deviation require the use of a double-sided threshold for classifying portions of anomaly in the data set. This is because oscillations along the z-axis of the accelerometer output typically swing in a transverse manner across the mean 1g value calibration of the device. A double-sided threshold system increases the complexity of the system, coupled with the possibility of an increase in the false alarm or missed detection rate. Consequently, the concept behind the "z-difference square" measure is to ensure that the derived statistic is positive definite, which leads to the use of a single threshold system, and future possibility for threshold automation. In addition, the differencing factor in our proposed measure introduces a filtering effect which naturally reduces the noise content in the data. We note that this work is an initial effort in the course of developing an automated threshold system for an efficient road defect profiling system.

The rest of the paper is structured as follows: Section II presents related works on road defect detection using embedded systems, section III presents the proposed methodology, while result analysis and discussions are provided in section IV, and conclusion in section V.

2. REVIEW OF RELATED WORKS

This section provides review of related works, with particular emphasis on those that use sensor-embedded devices to detect road defects. In addition, we discuss the merits and demerits of these methods as they apply to road defect detection.

In [7], the relationship between acceleration vibration of different smart phones was used to estimate road roughness condition. Data was collected by placing two smart phones on two different vehicles, which were then driven with normal driving condition on different roads with varying surface conditions. These conditions were classified as good, fair, poor and bad respectively. The sensors on the Smartphone usually log acceleration and GPS data respectively, while a video camera installed on the vehicle was used to verify the acceleration data logged by the phones. It was assumed that the acceleration coordinates of the vehicle and phones are the same. The proposed method has a merit of low cost and wide coverage potential as a result of the number of users acting as probe devices within the population. Also, data obtained from experimental results shows that there is a linear relationship between accelerometer data and road roughness condition. However, accuracy of acceleration data obtained depends on the type of smart phone used, vehicle speed and the type of vehicle itself. Furthermore, there seemed to be no realistic smartphone setting used by authors due to their assumption that the acceleration coordinates of the vehicle and smartphone are the same.

In [8], three android smart phones with GPS and accelerometer sensor software were used to monitor and evaluate road surface quality. The smartphones were placed on the dash board of a car and drive tests were performed while the phones acquired road surface smoothness data. An empirical event detection using the standard deviation of the Z-axis data set, Z-Diff, Z-thresh and G-Zero were used in analyzing detection. Preliminary results obtained confirmed the possibility of using smart phones to monitor road surface condition. However, the accuracy of the sensor software used phone was not validated. Also, smart phones with the same accelerometer software installed on it gave different GPS and accelerometer data acquisition accuracy, which reveals the uncertainty in using a single data acquisition system.

Authors in [9] proposed a novel means of driving event recognition using smart phone. Associated data from various sensors were combined into one classifier together with a dynamic time warping algorithm to recognize, detect and record offensive driving. The proposed system identifies portion of the recorded video segment, sends an alert to an external system and notifies the driver. The driver's driving behavior was determined from the number of potential aggressive driving events recorded. Results obtained show the possibility of using smart phones to detect, record and alert both the driver and an external system of aggressive driving behaviors. A major drawback of this approach is the inability to differentiate or determine the vibration acceleration as a result of noise from vehicle interior vibration, while considering the speed of the vehicle and road conditions.

In [10], readings from a GPS and mobile phone accelerometer were used for pattern recognition towards detecting road anomalies. The proposed system involved 3 stages namely preprocessing, classification and visualization. A program written in java was used for data collection from the accelerometer reading in Nokia N98 8Gb, where samples were taken at 38Hz and the GPS reading at 1Hz. Performance evaluation showed that the proposed system performed better when compared to similar approaches in the literature, and sampling errors were reduced by preprocessing the GPS and acceleration signals. However, experimental results show unsatisfactory speed estimate irrespective of how the filter was tuned. Also, limited available data made it difficult to cluster data with road anomaly from multiple drivers during clustering experiment. This reduced the performance of the proposed method. We also note that the accuracy of the proposed system depends on the type and model of the mobile phone used.

A collaborative road surface condition monitoring system using a mobile application and a geo-referenced data base was proposed in [11]. An algorithm which runs on a mobile device with an android application was used to process the roughness parameter signal captured. A mathematical model used for computing road roughness index was presented. The road roughness estimate was derived from sampled points using linear predictive coding. Results obtained showed that a mobile device running on the customize application can be used to detect road surface anomalies. But there is need to improve the mathematical modelling.

The focus of authors in [12] was to estimate the gravity component of accelerometer measurements and develop new sets of accelerometer features to capture key characteristics of vehicular pattern. Their results showed an improvement of over 20% in transportation mode detection over current accelerometer based systems. In similar light, the work of [13] proposed the application of a combinatorial optimisation technique for the characterisation of pavement roughness. Particularly, the technique aided in determining the profile height from measured accelerations at and above the vehicle axle. The flashpoint of this work was the overall reduction in general cost of this method, and the validated performance from simulated road profiles.

Authors in [14] provided a review on the use of acoustic signal techniques for improving intelligent transportation systems. Focus was on classification of such signals associated with the vehicle, which can suffice from engine noise, tyre noise, or general mechanical effect noise. Other interesting deductions included vehicular speed estimation and density estimation in different environments. Another interesting application was found in [15] which presented dynamic analysis of a tank with particular three-axle road tank for loose material transportation. Several simulations of models for several speeds were conducted. By using finite element method along with some frequency analysis, authors were able to show how maximum responses of the observed truck can be deduced at different speeds. Their research output finds significance in fatigue analyses of road tank in real traffic conditions. Similarly, the main purpose behind the work of [16] was to prove that some coherent relationship exists between horizontal and vertical curves, and the number and severity of accidents on a specific road termed Road Nr. 82. Authors developed techniques for detecting straight sections, arcs, and arbitrary curves of the observed road. They used accident data from the road of interest to evaluate their methods, and concluded that a close relationship existed in support of their hypothesis.

All these works though related to either the use of accelerometers, or typical approaches to road surface profiling leads us to the conclusion that while most works focus on direct interpretation of the raw accelerometer data, others provide statistical measures which require specialized thresholding systems to achieve classification. It is thus necessary to develop new measures that avail to simple thresholding rather than complex double-side thresholding systems.

3. METHODOLOGY

3.1 Experimental Overview

A Myrio accelerometer embedded device was used for the data acquisition process. It was placed on the dashboard of a Toyota Siena car, used for the drive test (as shown in Fig. 1). The accelerometer embedded device was programmed using LABVIEW to actualise acquisition and filtering of data. A view of the physical experimental setup can be seen in Fig. 1. Recall that the x, y and z vibration axis usually monitor the turning (left and right) motion of the vehicle, the slope of the road and the upward and downward movement of the vehicle, respectively. The required number of samples per second was initially set in the LABVIEW environment before we commenced acquisition. Numerical datasets we acquired were logged in Excel and subsequently transferred to MATLAB for further statistical analysis.

3.2 Using Other Statistical Measures

The accelerometer data was analysed to obtain the mean, standard deviation and the variance. The expression for mean of a time series is given in (1), with the signal samples expressed from x_0 to x_{N-1} as

$$\mu = \frac{1}{N}\sum_{i=0}^{N-1} x_i \tag{1}$$

where, μ is the mean, and N is the total numbers of samples. The standard deviation is a measure of how far the accelerometer's measured signal fluctuates around the mean, while the fluctuation power is known as the variance. These statistical measures were computed using (2) and (3) respectively,

$$\sigma = \left(\frac{1}{N}\sum_{i=0}^{N-1}\left(x_i - \mu\right)^2\right)^{\frac{1}{2}}, \tag{2}$$

$$\mathrm{var} = \sigma^2, \tag{3}$$

where, σ is the standard deviation and *var* is the variance.

The energy content (*E*) of the measured time series signal *x(n)* was computed using (4). We note that areas with road defects will have higher energy content than other anomaly free portions of the dataset. Please note that threshold values were manually set to identify portions of higher energy content, and hence, indicating of the presence of possible road defects within the dataset.

$$E = \sum_{i=0}^{N-1} \left(|x(n)| \right)^2 . \quad (4)$$

For computing the difference, the model used is expressed in (5). However, equation (7) was used for a non recursive system as obtainable in a typical accelerometer system, where the present output *y(n)* of the time series signal is computed from the present input *x(n)* and the previous input *x(n-i)* for *i*= 1,2,3 .. n..

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) - \sum_{j=1}^{N} a_j y(n-j) , \quad (5)$$

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) . \quad (6)$$

where, *M* is the number of previous data points, and b_i *and* a_j are the coefficients that characterize the system. However, we consider a second order difference equation with an initial condition of *x(n) = 0,* and rewrite (6) as

$$y(n) = b_1 x(n-1) + b_2 x(n-2) , \quad (7)$$

3.3 The Proposed "z-difference Square" Measure

The model to compute the newly proposed "z-difference square" measure, (Z-diff2), is given in (9). We consider a second order difference equation, with initial condition x(n) = 0, and hence compute Z(n) as the output of the difference between the present accelerometer time series input signal x(n-1) and the previous input signal x(n-2), with the Z-diff2 being the square of Z(n). Also note that for data already measured by the accelerometer, the coefficients of (8) simply have values b_1 = 1, and b_2 = -1, respectively. The squaring operation in (9) is proposed to remove the negative components of the signal and to achieve a single threshold value for anomaly detection. The flowchart of the proposed methodology is shown in Fig. 2.

$$Z(n) = b_1 x(n-1) + b_2 x(n-2) , \quad (8)$$

$$Z\text{-}Diff^2 = (Z(n))^2 . \quad (9)$$

The raw accelerometer data was first windowed with a percentage overlap to enhance spectral analysis, and the window size (Win) was set at 10 samples, along with a sampling rate of 20 Samples/s. Also note that an overlap percentage (Ovp) of 60% was used during our analysis.

Fig. 1. Experimental setup within the vehicle, and the actual vehicle used

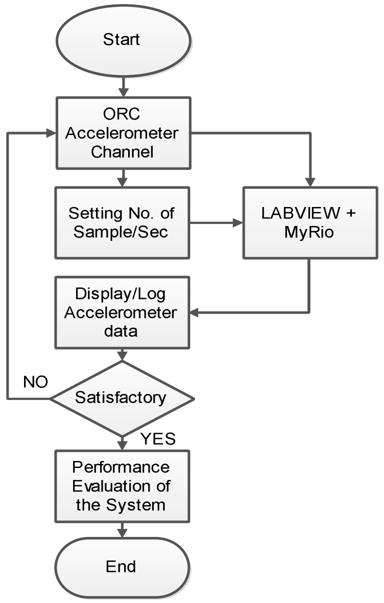

Fig. 2. Flowchart of the proposed methodology

The pseudocode of the proposed algorithm as implementable in MATLAB is as follows:

Step 1: Obtain dataset x_i
Step2: Set Win, Ovp
Step3: If 100 ≤ Ovp ≤ 0
do; Ovp=100
Step4: Ovl = (Ovp/100)*Win
Step5: L = length (x)%Obtain length of input data
Step6: N = L/Ovl
Step7: LL = N×Win
Step8: xx = zeros(1, LL) %Initialize memory to zero
Step9: xx(1, 1:L) = x
Step10: R = zeros (N, Win); h = 0;
Step11: for a = 1:N;
PP = xx(1+h*ovl:win+h*ovl);
% Compute the mean, standard deviation,
% variance, and Energy Spectral Density of
%PP using equations (1) – (4);
h = h+1;
end
Step12: for b = 1:L-1
zdiff(:,b) = xx(:,b+1) - xx(:,b);
%Compute proposed measure
Zdiff_square(:,b) = (xx(:,b+1) - xx(:,b))^2;
End

4. RESULTS AND DISCUSSION

In this section, we provide results of accelerometer data captures, statistical measures, and the proposed measure, and use them to discuss how each measure contributes towards enhancing road profiling systems. The raw accelerometer data obtained along the z-axis is shown in Fig. 3a, while the mean, standard deviation and variance of the same data are shown in Fig. 3b.

By observing the raw data of Fig. 3a. it can be visually seen that some road anomalies exist between the 25th – 50th sample, 180th – 200th sample, and the 360th – 370th sample, as such; we focus our discussion on these segments. The mean data in Fig. 3b. offers little in observing these anomalies as can be seen in the figure. We note that though the standard deviation and variance provide some information (as can be seen in the extrusions), it remains difficult to make important inferences from these measures – such as information on the spatial location of these anomalies. Fig. 4a gives us a frequency

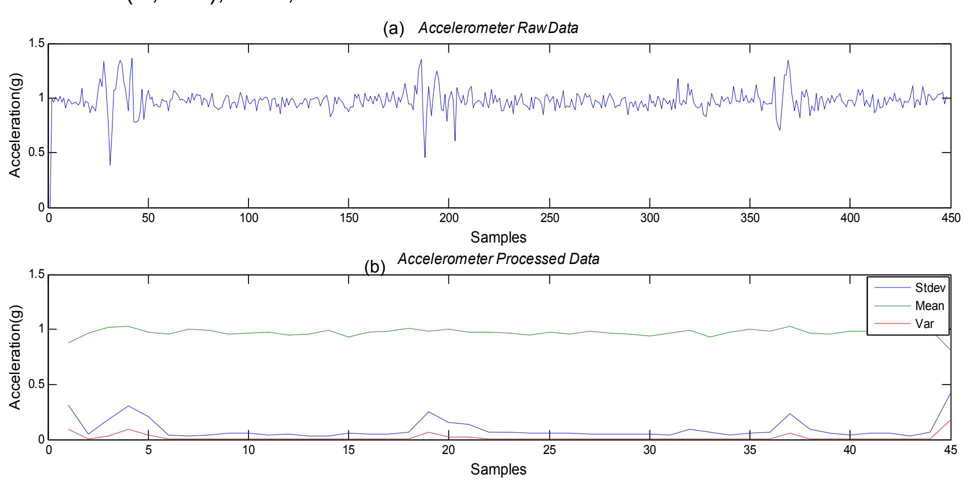

Fig. 3. (a) Accelerometer vibration signal (top plot); (b) The mean, standard deviation, and variance of the vibration signal (bottom plot)

domain perspective of the same accelerometer dataset of Fig. 3a.

The motive behind frequency analysis is to ascertain how much information on road anomalies can be obtained from the dataset in this domain. Consequently, by using a threshold value of 11 W.s, it can be observed in Fig. 4b that the three anomalies were detectable, using their energy content alone. However, little can be inferred with respect to spatial location, depth, width, or characterisation of these anomalies.

By considering the difference measure of Fig. 5a, it can be seen that a one sample difference of the data produces a measure quite similar to the original raw dataset. Consequently, nothing much can be deduced, except for some little filtering effect achieved by the differencing. We also note that thresholding this measure will require two values for both the upper and low portions of the data. However, by using the proposed difference square of Fig. 5b, it can be seen that the difference measure is made positive definite. All anomaly effects are translated appropriately, hence making it easy to apply a single threshold for detection. Also note the filtering effect achieved by the measure, which reveals clearly, only areas of road anomaly. Finally, because the difference square measure is computed directly from the samples,

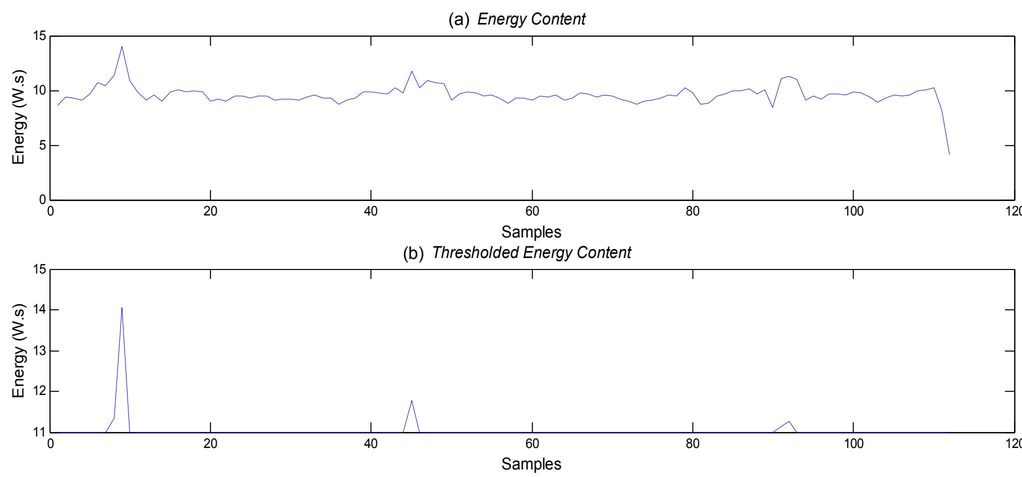

Fig. 4. (a) Energy content of vibration signal; (b) Threshold spectrum of the energy content

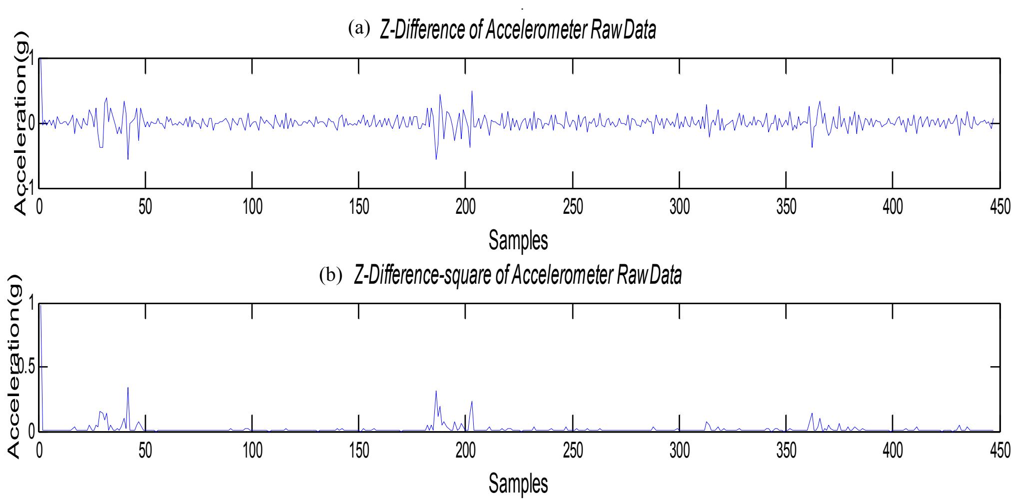

Fig. 5. (a) One sample difference of the vibration signal of Fig. 3a; (b) Our proposed one sample difference square measure of the vibration signal

i.e. as a function of the sample index, it becomes straightforward to deduce spatial details. This can be done by correlating the samples obtained with either the respective GPS location, or with actual distance (measured in metre).

5. CONCLUSION

The main purpose of this paper is to propose the use of a "z-difference square" measure for analysing accelerometer datasets towards improving road condition monitoring systems. Several other statistical measures normally used for analysis were considered here to include time and frequency domain features, e.g. mean, standard deviation, variance, energy spectral density, and normal difference measures. By implementing all these measures on a particular dataset, we have been able to discuss some of their merits and demerits. In addition, we inspected the newly proposed measure, and discussed its merits. This measure presents us with some advantages, such as the opportunity to use a single threshold system, rather than double if the normal dataset or ordinary difference measure is used. The proposed measure introduces an inherent averaging (filtering) effect which effectively emphasises the defects from noise, and it provides us with the opportunity to infer spatial related information, owing to its direct relationship with the sample indices themselves. Our effort in this article forms an initial step in a long term project geared towards developing an autonomous real-time road condition profiling system. This future direction will involve developing new algorithms for threshold automation, and also seeking new ways to deduce spatial information from the accelerometer data.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FRSC, "Report on Road Traffic Crashes involving Cars, Buses, Tankers and Trailers in Nigeria. Abuja: Federal Road Safety Corps," ed. Abuja; 2011.
2. Bello-Salau H, Aibinu A, Onwuka E, Dukiya J, Onumanyi A. Image processing techniques for automated road defect detection: A survey in Electronics, Computer and Computation (ICECCO). 2014 11th International Conference on. 2014;1-4.
3. FRSC. Safety Guidelines for Articulated Lorries [Online]. Available: frsc.gov.ng/publications
4. Habibu AS. Safety Auditing on Urban Roads with Special Emphasis to Intersections in a Case Study in Kano in Kano, Nigeria; 2014.
5. Femi SA. Building sustainable policy framework for transport development: A review of national transport policy initiatives in Nigeria. Journal of Sustainable Development Studies. 2013;2.
6. Femi A. Road crashes trends and safety management in Nigeria. Journal of Geography and Regional Planning. 2013; 6:53-62.
7. Douangphachanh Viengnam, Hiroyuki O. A Study on the use of Smartphones for road roughness condition estimation in Proceedings of the Eastern Asia Society for Transportation Studies; 2013.
8. Strazdins G, Mednis A, Kanonirs G, Zviedris R, Selavo L. Towards vehicular sensor networks with android smartphones for road surface monitoring in 2nd International Workshop on Networks of Cooperating Objects (CONET'11). Electronic Proceedings of CPS Week; 2011.
9. Johnson DA, Trivedi MM. Driving style recognition using a smartphone as a sensor platform in Intelligent Transportation Systems (ITSC). International IEEE Conference on. 2011; 1609-1615.
10. Perttunen M, Mazhelis O, Cong F, Kauppila M, Leppänen T, Kantola J, Collin J, Pirttikangas S, Haverinen J, Ristaniemi T. Distributed road surface condition monitoring using mobile phones, in Ubiquitous Intelligence and Computing, ed. Springer. 2011;64-78.
11. Alessandroni G, Klopfenstein LC, Delpriori S, Dromedari M, Luchetti G, Paolini BD, Seraghiti A, Lattanzi E, Freschi V, Carini A. Smart road sense: collaborative road surface condition monitoring, in UBICOMM 2014, The Eighth International Conference

on Mobile Ubiquitous Computing, Systems, Services and Technologies. 2014;210-215.

12. Hemminki S, Nurmi P, Tarkom S. Accelerometer-based transportation mode detection on smartphones. *In ACM Conference on Embedded Networked Sensor Systems*, 2013;13. Doi:10.1145/2517351.2517367
13. Harris NK, Gonzalez AÃ, Obrien EJ, Mcgetrick P. Characterisation of pavement profile heights using accelerometer readings and a combinatorial optimisation technique. Journal of Sound and Vibration. 2010;329(5):497–508. Doi:10.1016/j.jsv.2009.09.035
14. Borkar P, Malik L. Review on vehicular speed, density estimation and classification using acoustic signal. Int. Journal for Traffic and Transport Engineering. 2013;3(3)
15. Peňáz J, Voltr O. Dynamic Analysis of behavior of three-axle semi-trailer road tank going on special waved roadway. Periodica Polytechnica Transportation Engineering. 2013;41(2):139-142. DOI: 10.3311/PPtr.7115
16. Sipos T. Coherence between horizontal and vertical curves and the number of the accidents. Periodica Polytechnica Transportation Engineering. 2014;42(2): 167-172. DOI: 10.3311/PPtr.7224.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1126&id=22&aid=8961