A Study on the Use of Smartphones for Road Roughness Condition Estimation

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Abstract: Understanding condition of road surface is very important especially for road maintenance and asset management. There are many approaches to obtain road surface condition data, however almost all of them are either low speed with intensive human intervention techniques (visual inspection) or techniques that require advanced measurement equipment (sophisticated profilers), which usually comes with high costs and requiring skillful operators. Using smartphone to collect data is a promising alternative because of its low cost and easy to use features in addition to its potentially wide population coverage as probe devices. This paper explores features and relationship of acceleration vibration that may be useful to express or estimate road roughness condition, which is the main focusing road surface condition for this paper. Results from our experiment and analysis show that acceleration data collected by smartphone sensors at different driving speeds has different significant linear relationships with road roughness condition.

Keywords: Road Surface Condition, Roughness, Condition Estimation, Smartphones, Smartphone Sensors

1. INTRODUCTION

Road surface condition information is very useful for road users because with the availability of such information, road users can avoid or be cautious of the bad road ahead. In addition, for road authorities, the information is very important as it can be applied in decision making processes especially for strategic planning such as asset management planning, maintenance planning and programming.

Road surface condition or pavement condition is generally defined by the irregularity in the pavement surface that adversely affects the ride quality of a vehicle, thus the road users. The irregularities may be in the form of surface unevenness, potholes, cracks, etc. Bad road condition can cause damages to vehicles, increase fuel consumption, increase road user costs for vehicle maintenance, unpleasant driving comfort, and sometimes cause traffic accidents. For many decades, roughness is an internationally accepted indicator to which it is usually used to measure the ride quality of the pavement. International Roughness Index (IRI) is a measurement indicator that has been used internationally for road surface condition, Sayers *et al*. (2007). Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. This paper focuses mainly on road roughness as road surface condition.

Smartphones nowadays usually come with many useful sensors. A 3D or 3-Axis accelerometer is one of the most common sensors that can be found inside a smartphone. Accelerometer sensor gives us the acceleration measurements in m/s^2 along each of x, y, z axes. It can be used to recognize the motion activities. In smartphones, accelerometers are originally used for detecting the orientation of the screen as well as in some user interfaces and applications.

There are some researches and studies that have explored the use of standalone accelerometers and accelerometers that come with smartphones to detect road bumps and anomalies. However, majority of these studies focus mainly on identifying and locating anomalies. Gonzalez *et al.* (2008); use a standalone accelerometer to fit in a simulation car and use it to assess road roughness condition. Their simulations conclude that roughness of the road can be estimated from acceleration data obtained from the sensor. Eriksson *et al.* (2008); also develop a system that utilizes standalone accelerometers to successfully detect road anomalies. Mohan *et al.* (2008); use many sensing component from mobile phone such as accelerometer, microphone, GSM radio, and GPS to monitor road and traffic condition. By analyzing data from the sensors, potholes, bumps, braking and honking can be detected. The information is then used to assess road and traffic conditions. Mednis *et al.* (2011); and Strazdins *et al*. (2011); use an Android smartphone device with accelerometer to detect location of potholes. Their approach includes many simple algorithms to detect events in the acceleration vibration data. Tai *et al.* (2010); and Perttunen *et al.* (2011); analyze data obtained by smartphone accelerometers in frequency domain to extract features that are corresponding to road bumps.

For developing countries, where budget and infrastructure are still limited, high-tech approaches may still be a little out of reaches and as a result a low speed with intensive human intervention approach may be an unavoidable option. However, with the need to update the information regularly, this may put further pressure on already heavy-loaded road authorities in terms of budget for maintenance, particularly. Therefore, exploring the use of smartphones to estimate road surface condition may be a great help. On one hand, smartphones already have sensors that are capable of recording useful signal for road surface condition estimation similarly to those used in many high-tech profilers. On the other hand, number of smartphone users is rapidly increasing, meaning that chance of having plenty of data with inexpensive investment is huge. Furthermore, the approach may also be useful for continuous monitoring the soundness of road infrastructure as a whole. For this purpose, the approach is useful not only for developing but also for developed countries.

Therefore, this project tries to explore application of smartphones in estimating road surface condition, especially classifying roughness condition of road sections, by simple techniques. In our final goal, we expect to be able to estimate road surface condition (roughness) and/or soundness of road infrastructure continuously from data being sent to us from ordinary road users with smartphones. In other words, we expect to be able to estimate rough road roughness condition in the form of indexes, not exact IRI value, from a lot of data; therefore, simple techniques should be considered. With the estimated road surface condition being made available for Road Management System (a system used by many road authorities including Laos for instance), road maintenance programming and planning, in particular, are believed to be more efficient and updated. Conceptual image of our approach is shown in the figure 1 below.

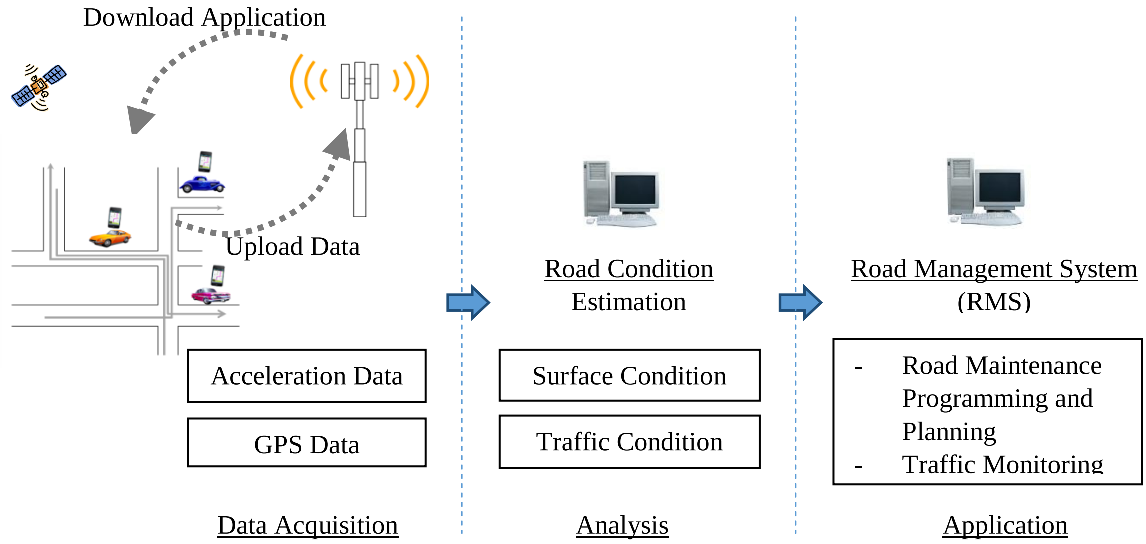


Figure 1. Conceptual image of continuous road condition monitoring system

To realize the final goal, in the first phase, which is the scope of this paper, it is important to find out and understand the relationship between acceleration data from smartphones and actual road surface condition. Furthermore, it is also important to understand to what extent different variables such as speed, vehicle type and smartphone setting may have on the mentioned relationship.

2. METHODOLOGY:

Assuming that different road surface conditions cause vehicles to vibrate differently, therefore by placing smartphones that come with acceleration sensors, the variation of the vibration is believed to be captured. In our experiment, we place two smartphones on two different vehicles. We then drive each vehicle with normal driving condition along many roads that have different surface conditions. Different approximately fixed driving speeds are also performed on four selected short sections (0.6 to 1km in length). The four short sections consist of different surface conditions such as good, fair, poor, and bad respectively. Sensors on the smartphones record acceleration and GPS data. To simplify our experiment, orientation of the smartphones is fixed. Thus, we assume that the acceleration coordinates of the vehicle and smartphones are the same. A video camera is also used to capture the road surface; this video footage is used for data checking and verification in case there is a need.

Two vehicles, a Toyota VIGO 4WD pickup truck and a Toyota Camry, are selected for our experiment. Vehicle Intelligent Monitoring System or VIMS (Vehicle Intelligent Monitoring System, 2012) is also used to estimate the road section selected for our experiment. Result from VIMS is used as a referenced road roughness condition data.

The experiment has been done in Vientiane Capital City, Lao PDR, from 16 to 21 November 2012. A total road length of more than 300 km has been covered. However, due to time constraint and different setting of the data collection, only 159 km of the total road length will be studies under the scope of this paper. Also due to time constraint, the total section length covered by the second experiment vehicle is approximately half of the total section length covered by the first experiment vehicle.

Table 1.Experiment under the scope of this paper

Date	Experiment description	
	Vehicle type	Section length
16-18 Nov 2012	Toyota VIGO 4WD Truck	110 Km
19-21 Nov 2012	Toyota Camry Sedan	49 Km

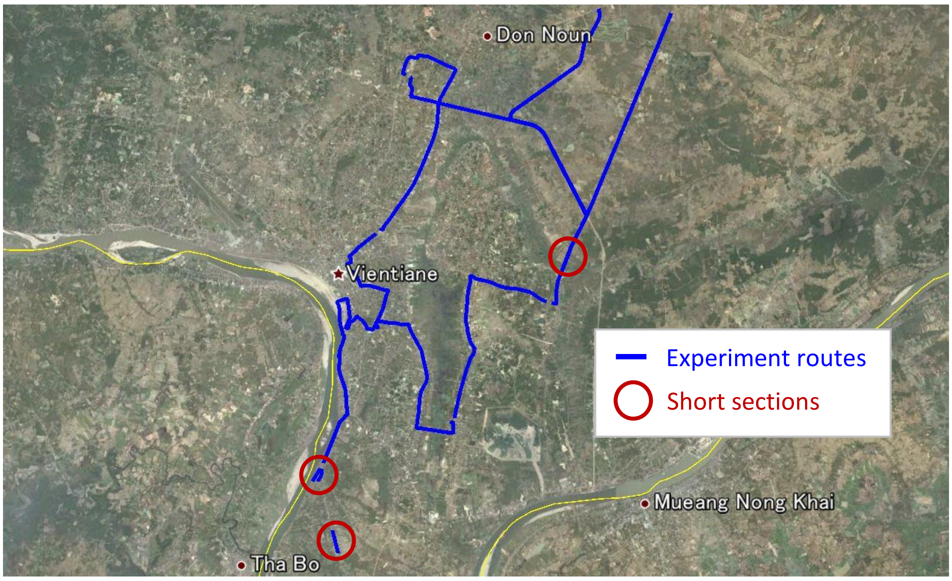


Figure 2. Experiment routes in Vientiane, Laos

After obtaining the data, analysis, which includes matching, sectioning of acceleration data into small files, and then each file is converted to analyze in frequency domain, has been carried out.

3. DATA COLLECTION

3.1 Equipment and Software

The experiment equipment includes: two Android smartphones (a Samsung Galaxy Note 2 and a Samsung Galaxy S3), a GPS logger and a video recorder.

Android smartphones

GPS logger

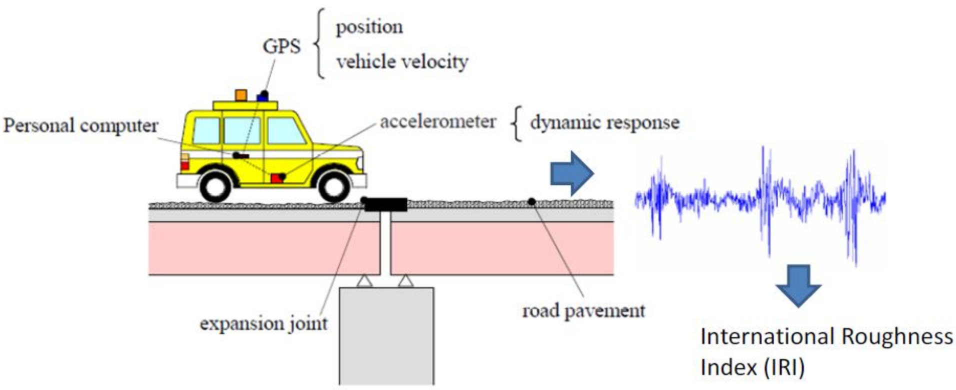
VDO Camera

Figure 3. Experiment equipment

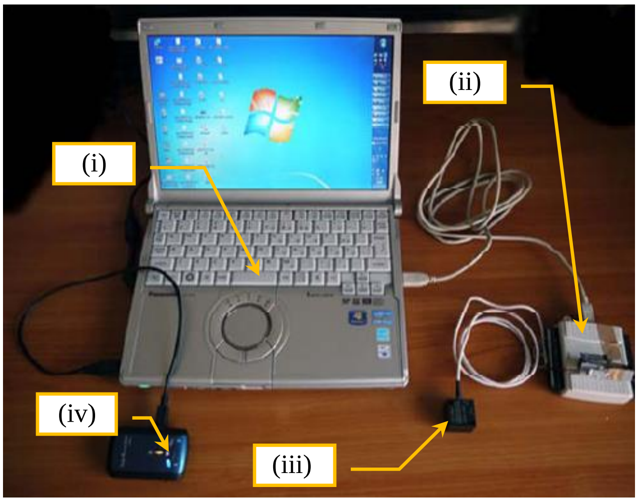
All two smartphones are pre-installed with an application called “AndroSensor“, AndroSensor (2012). AndroSensor is an application that can collect data from almost all of the sensors available on the handsets and it is available for free download in Google Play Store. For this experiment and studies, only acceleration data (x, y, z) from accelerometer; location data (longitude, latitude, speed…) from GPS are needed. Data recording is done at an interval of 0.01 second or at a frequency rate of 100Hz. Calibration is done for all 4 devices with AndroSensor by setting the devices in different orientations to collect data; after that data from the devices is compared against each other for validation purpose.

3.2 Referenced Road Roughness Condition Data

Referenced pavement condition data for this study is also obtained using VIMS. VIMS has been developed by Bridge and Structure Laboratory at the University of Tokyo, Japan. The system is now being deployed for road management purpose in Laos. For our experiment, VIMS is used with the experiment vehicles. To properly use VIMS, calibrations are carried out. VIMS data collection for the 2 vehicles is carried out at the same time of the smartphone data collection.



Source: VIMS Manual (2012)
Figure 4. VIMS approach



Source: VIMS Manual (2012)
Figure 5. VIMS component

VIMS deploys an accelerometer and a GPS on a vehicle. The vehicle then drives on a road and calculates the International Roughness Index (IRI) in a short time based on acceleration response of the vehicle. Figure 4 shows the concept of VIMS approach.

VIMS comprises of both hardware and software, VIMS Consortium (2012). The hardware includes (i) a laptop computer, (ii) a data acquisition module, (iii) an accelerometer and (iv) a GPS logger, see Figure 5. All the components are connected to each other via cables. For software, the system consists of two main programs, (1) An application for calibration and data collection; and (2) an application to carry out the analysis.

The system calculates IRI for every 10 meter road section. The result can be put in Excel spreadsheet as well as visual presentation on Google Earth. VIMS can only calculate IRI when driving speed of experiment vehicle is 20kph or faster.

Table 2. Example of VIMS result

VIMS	Date	IRI	Latitude	Longitude
	2012/12/10	8.46215	17.88805	102.6108
	2012/12/10	8.13753	17.88796	102.6108
	2012/12/10	7.808368	17.88788	102.6107
	2012/12/10	7.231083	17.8878	102.6107
	2012/12/10	6.931109	17.88772	102.6106
	2012/12/10	5.939928	17.88764	102.6106
	2012/12/10	6.177234	17.88756	102.6105
	2012/12/10	6.357153	17.88748	102.6105

3.3 Equipment Setting

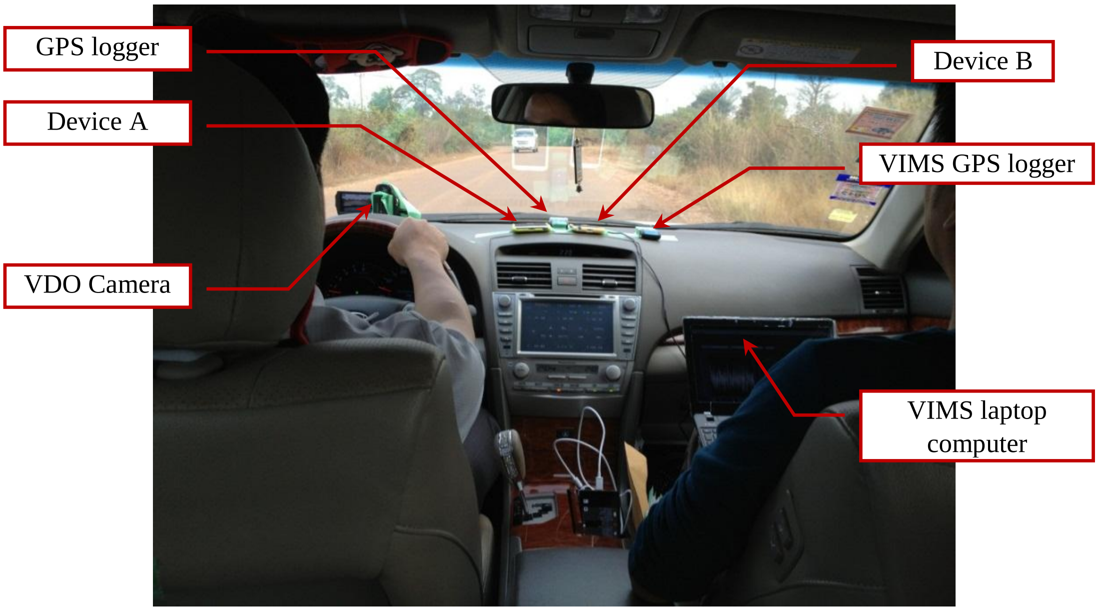


Figure 6. Equipment Setting

The two smartphones are glued closed to each other on the dashboard of the experiment vehicles with strong and thin adhesive tapes. The screens of the smartphones are facing up and the heads pointing towards the front of the vehicle. Therefore, the x, y and z axes of the accelerometer represent the motion along left-right, front-rear and up-down of the vehicle, respectively. Other equipment such as GPS and video camera are also placed on the dash board. VIMS components are also installed in accordance to the VIMS manual (2012).

4 DATA PROCESSING

Data from smartphones is uploaded into a desk top computer and converted to excel spreadsheets. The spreadsheets are carefully checked manually to select only road sections that have complete data sets, both data from smartphones and IRI data from VIMS. Sections with incomplete data set are the sections that have no data from VIMS, i.e. when the vehicle speed is too slow (<20kph) in traffic jam condition.

A simple high pass filter, a standard method used for Android device, Android Developer Reference (2012), is applied to remove unrelated low frequency signal, which usually causes by the effect of vehicle maneuver such as changing speed and turning as well as the contribution of the force of gravity, from all axes (x, y and z) of the acceleration data.

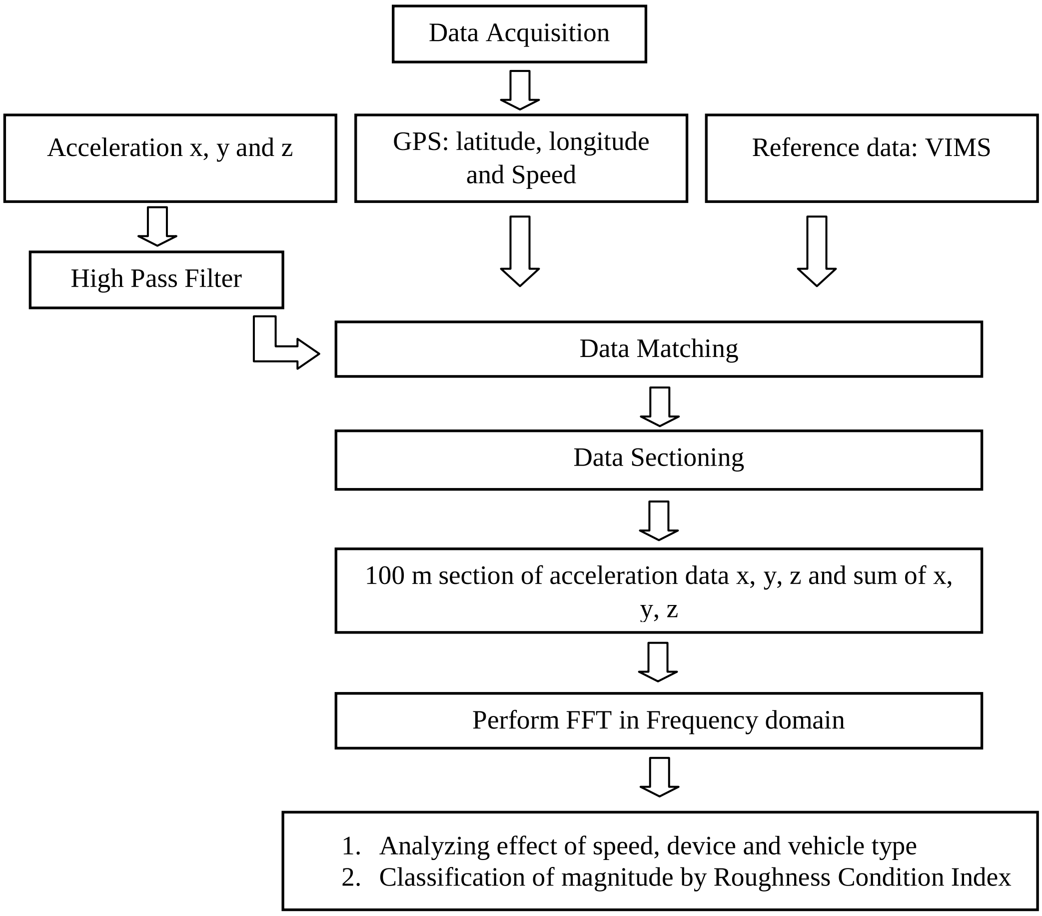


Figure 7. Data processing flow chart

Data matching by GPS coordinates is carried out. This process merges IRI data from VIMS with the acceleration data from smartphones for the same road sections. Then, the merged data files are cut into small 100 meter sections based on VIMS GPS coordinates. A 100 meter length of acceleration data is chosen as a unit for road surface estimation in this study. The reasons are (i) because Road Management System in Laos requires road surface condition to be estimated for every 100 meter section, therefore it would be more convenient for us to select the same unit so that it is compatible for future application; (ii) there is a concern on the accuracy of GPS position data, thus choosing a shorter section unit may cause some issues for data matching between VIMS and smartphone GPS data. In the sectioning process, road sections where experiment vehicles have stopped (checking from speed and VIMS results) are excluded since data at these sections cannot be used to estimate road roughness condition. In addition, sections that are less than 100 meters are also ignored.

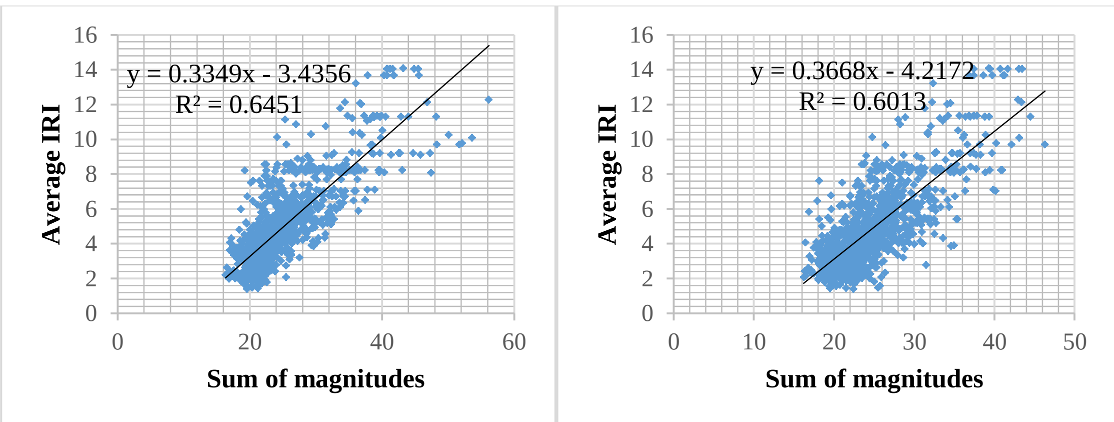
Table 3. 100 meter sections resulted from sectioning

	Total sections	Section omitted	Sections selected for analysis
Vehicle 1:			
Device A	1093	68	1025
Device B	1093	68	1025
Vehicle 2:			
Device A	485	23	462
Device B	485	23	462

All selected data sections are converted to frequency domain and perform Fast Fourier Transform (FFT). Magnitude from FFT is the amplitude or strength of the associated frequency component. For a specific frequency window, we assume that the total sum of magnitudes represents the total strength of the vibration at that frequency window. Therefore, sum of magnitudes from FFT is studied to find out features, effect and relationship that the acceleration data might have in connection with road roughness condition.

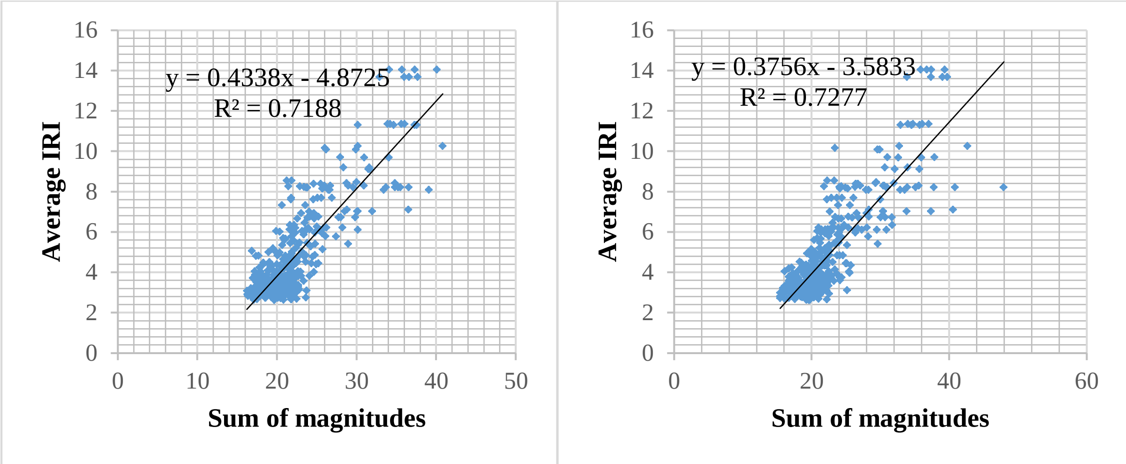
5. ANALYSIS RESULT

In our analysis, acceleration data generally has linear relationship with road conditions. Figure 8 and 9 below show linear relationship between sum of magnitudes of acceleration data and average road roughness (IRI). An average IRI is calculated from 10 VIMS IRI values (VIMS calculates IRI for every 10 meter road section) that comprises into a 100 meter road section. Sum of magnitudes is the total magnitude derived from FFT of the sum of acceleration x, y and z in 100 meter road sections.



a. Vehicle 1 Device A b. Vehicle 1 Device B

Figure 8. Relationship between acceleration data and road condition (Vehicle 1)



c. Vehicle 2 Device A
d. Vehicle 2 Device B

Figure 9. Relationship between acceleration data and road condition (Vehicle 2)

From the graphs above, the significant of relationship between acceleration data and road condition is quite different between the two vehicles, while there is slight different between the two smartphone devices that are fitted in the same vehicle.

At different speeds, acceleration data seems to show different usefulness in representing road roughness condition, if we judge from the coefficients of linear regressions, which differ by speed, from the scatter plots in Figure 10 and 11 below.

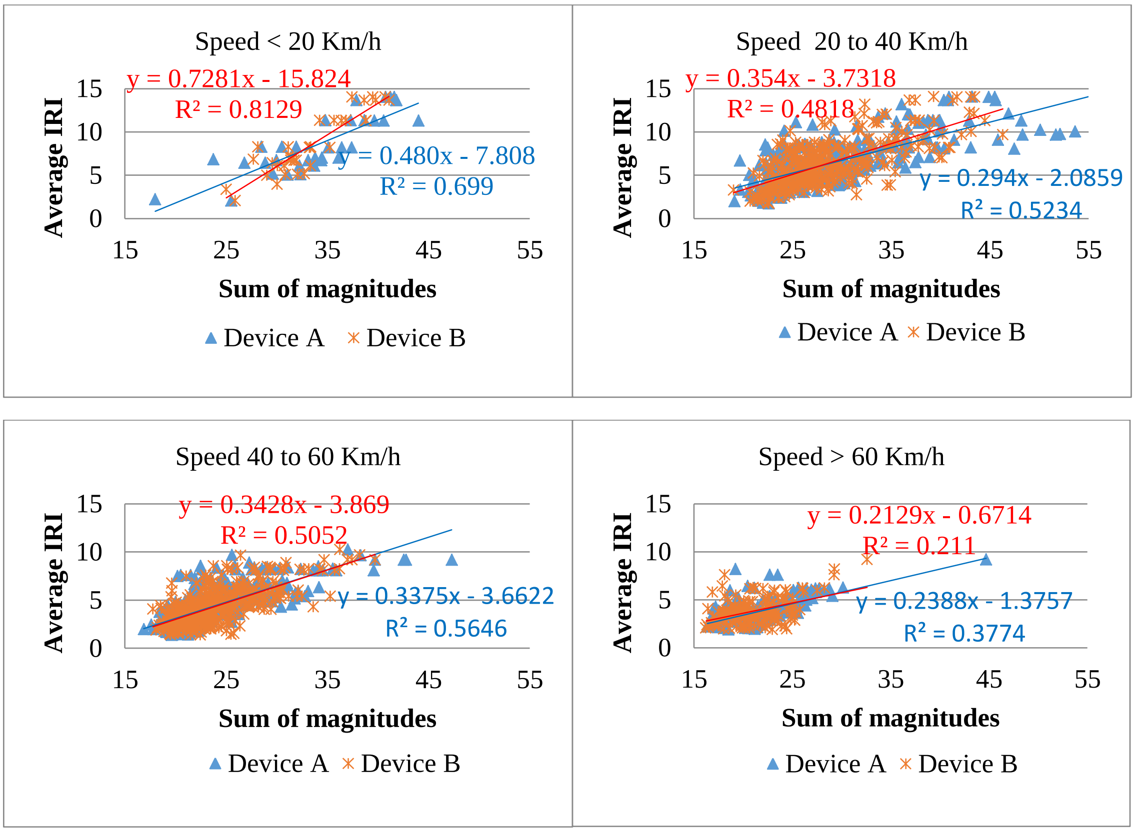


Figure 10. Effect of speed (Vehicle 1)

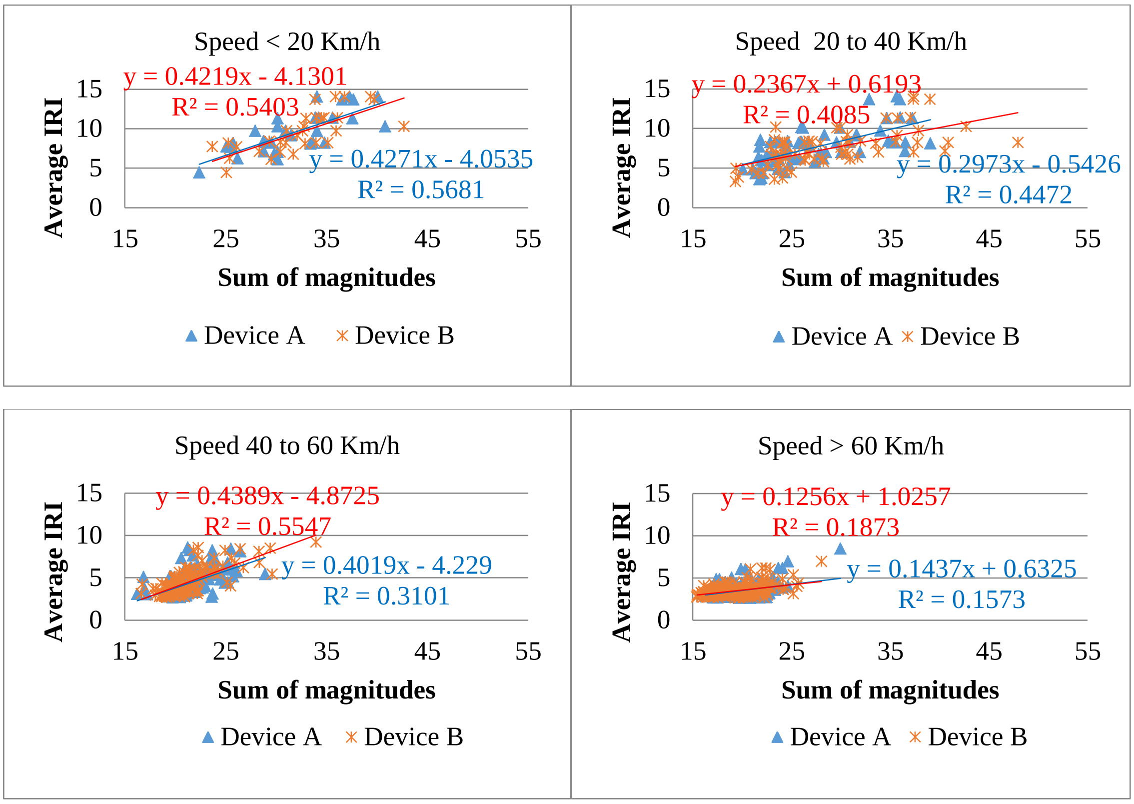


Figure 11. Effect of speed (Vehicle 2)

Therefore, we assume that speed may have some effects on the representation of acceleration vibration towards road roughness condition. To prove this we further investigate by implementing multiple regression analysis. The dependent variable is the sum of magnitudes and the explanatory variables are the average IRI and the average speed. Note that we set variables as mentioned above because road condition and running speed are considered as the cause of the vibration in the vehicle; although average IRI is the variable we would like to estimate.

Below is a summary of multiple regressions for each device in each experiment vehicle. Statically, for all tests presented below, it is clear that speed does have some influence on the way acceleration vibration represent road roughness condition.

Table 4.Summary of multiple regression analysis

	Vehicle 1				Vehicle 2			
	Device A		Device B		Device A		Device B	
Observations	1025		1025		462		462	
Multiple R	0.818		0.815		0.863		0.868	
R Square	0.669		0.665		0.744		0.754	
Adjusted R Square	0.668		0.664		0.743		0.753	
F Stat	1031		1014		667		704	
	Coeff.	*t Stat*	*Coeff.*	*t Stat*	*Coeff.*	*t Stat*	*Coeff.*	*t Stat*
Intercept	20.0	35.0	23.2	46.6	19.0	25.5	18.5	22.1
Avg IRI	1.70	33.6	1.32	29.4	1.31	19.1	1.53	19.6
Avg Speed	-0.0731	-8.49	-0.105	-13.9	-0.0549	-6.72	-0.0645	-7.03

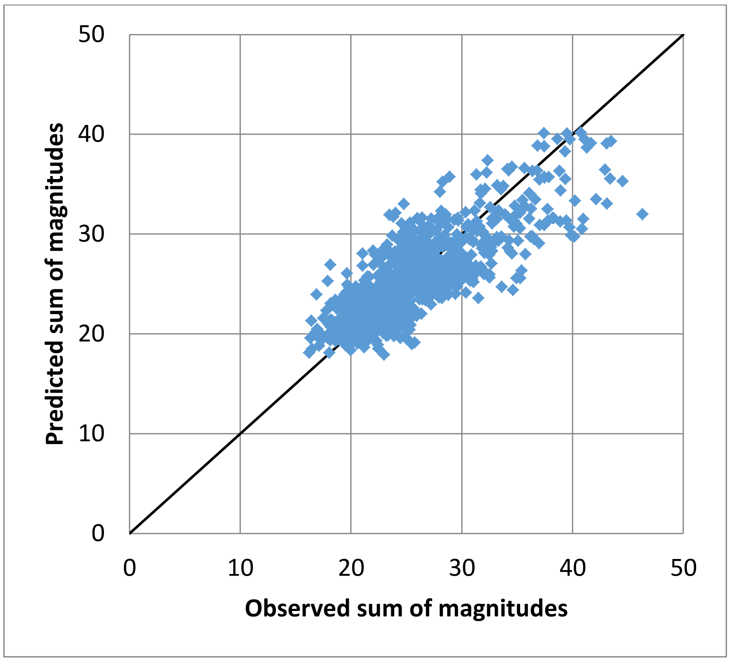


Figure 12. Observed and predicted sum of magnitudes by multiple regression model (Vehicle 1, Device A)

From the analysis above, it has been observed that the multiple regression yields a very good fitting (Figure 12). As summarized in Table 4, the intercept and coefficient of the average IRI and average speed are statistically significant. The coefficients of the average IRI is positive, meaning that the worse the road surface condition is, the larger the sum of magnitudes of vibration. On the other hand, coefficient of the average speed is negative. This implies that a speed increase would mean a smaller sum of magnitudes, which could mean better road surface condition. One of the reasons could be, however, in general, drivers tend to drive at a higher speed on good roads; and at a much slower speed on road with bad surface condition. In addition, although the order of the coefficients is very similar for all devices and vehicle, the difference of coefficient by vehicle type and devices is observed.

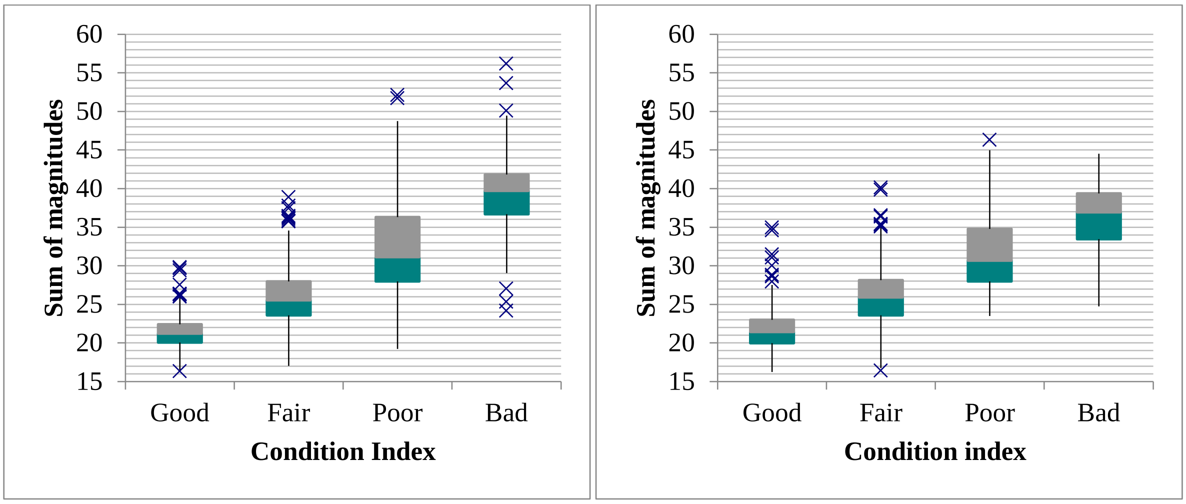
For the purpose of classifying road roughness condition, we propose 4 condition indexes of road roughness as summarized in Table 5.

Table 5: Condition index

Index	Average IRI
Good	0≤IRI<4
Fair	4≤IRI<7
Poor	7≤IRI<10
Bad	IRI≥10

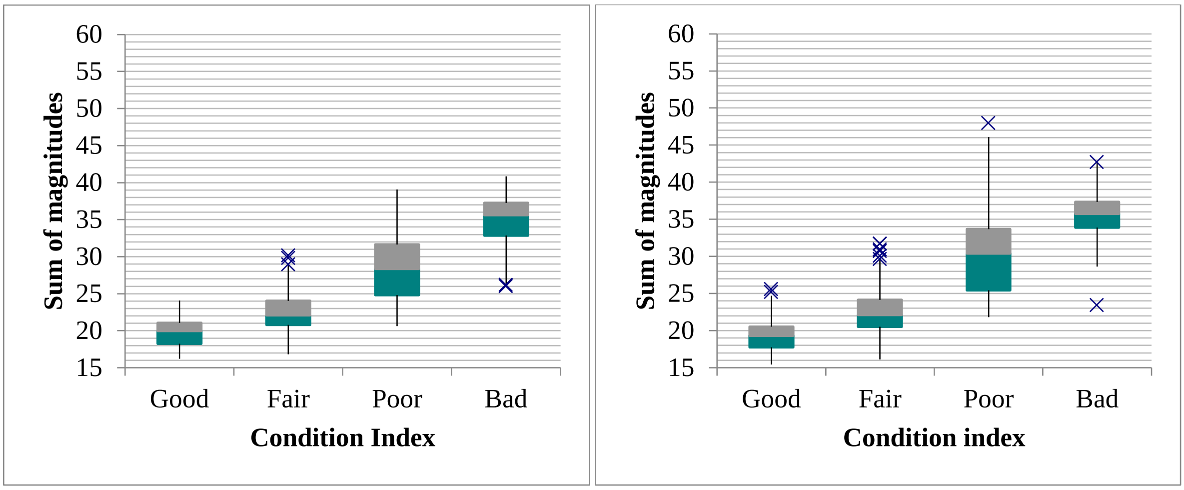
The above indexes are adopted from road roughness condition bands used in Lao Road Management System, where it uses 6 road condition bands: 1) Excellent (0≤IRI<2), 2) Good (2≤IRI<4), 3) Fair (4≤IRI<7), Poor (7≤IRI<10), 5) Bad (10≤IRI<18), and Failed (IRI≥18).

By plotting Box Whisker of the indexes and the sum of magnitudes we find some interesting result as shown in the graphs in Figure 10 and 11 below.



a. Device A   b. Device B

Figure 13.Classification of magnitude by condition index, Vehicle 1



a. Device A   b. Device B

Figure 14.Classification of magnitude by condition index, Vehicle 2

Figure 13 and 14 show quite clear classification of the sum of magnitudes in each road condition index. However, sum of magnitude ranges slightly differ by vehicle type and devices, especially between device A and B in vehicle 1 (Figure 13).

To sum up, from our analysis, it is clear that IRI can be expressed roughly as a linear function of magnitude of acceleration vibration. However, parameters (coefficients) of linear function are different by vehicle type and device. Speed range also has an effect on the relationship between IRI and magnitude.

The analysis also shows similar tendency in the classification of the sum of magnitudes by road condition indexes, suggesting that the same model for IRI estimation can be assumed as long as vehicle type and device do not change. However, in case vehicle type and device change, the parameters of the model should be calibrated.

In real use, it is very difficult to calibrate the parameters within solo data. However, by gathering so many data sets from so many vehicles and devices, the parameters might be estimated based on the commonality of road roughness for different vehicle types and devices. This is the advantage of the proposed approach.

6. CONCLUSION AND FUTURE WORKS

This paper explores features and relationships between acceleration data, collected by smartphones, and road roughness condition. With the assumption that rough estimation of road surface condition from smartphones would be helpful enough for road management and planning, provided that the approach is very low cost, easy to operate and can be implemented frequently.

An experiment is carried out to obtain data. The data is checked and matched with referenced data. The matched data then cut into sections representing many 100 meter road sections. Analysis is carried out in frequency domain to calculate magnitudes of acceleration data. An adopted group of road condition indexes have been proposed. From the analysis, it has been found that acceleration data from smartphones has linear relationship with road roughness condition. However, the significant of relationship depends on speed in which it is considerably significant when speed is less than 60kph. Furthermore the relationship also partly depends on vehicle type and device. Based on the condition indexes, similar tendency of the classification of the sum of magnitudes of acceleration vibration is observed.

Although we can conclude that a simple model may be sufficient to estimate road roughness condition from acceleration data obtain by smartphones, there are still many issues that have to be dealt with in our future works to make the approach practically applicable. Main focus in the future works includes:

- Detail studies on the features and the relationship of the acceleration data and road roughness condition. Realistic smartphones setting, not fixed coordinate, will also be considered.
- Explore approaches to estimate road surface condition from many anonymous road/smartphone users, who agree to participate. Plenty of data for many different road sections would enable us to build models to simulate and estimate road roughness condition and soundness of road infrastructure as a whole.

REFERENCES

Android Application (2012) *AndroSensor*. Google Play Store. Available at: https:// play. google.com/store/ apps/details?id=com.fivasim.androsensor&hl=en

Android Developer Reference (2012) *SensorEvent.* Android Developer Official Website. Available at: http://developer.android.com/reference/android/hardware/SensorEvent .html

Eriksson, J., Girod, L., Hull, B., Newton, R., Madden, S., Balakrishnan, H. (2008) The pothole patrol: using a mobile sensor network for road surface monitoring, Paper presented at the Sixth International Conference on Mobile System, Applications and Services, Breckenridge, Colorado, United States, June 17-20.

González, A., O'brien, E. J., Li ,Y. Y., Cashell, K. (2008) The use of vehicle acceleration measurements to estimate road roughness. *Vehicle System Dynamics*, 46(6), 483–499.

Mednis, A., Strazdins, G., Zviedris, R., Kanonirs, G., Selavo, L. (2011)Real time pothole detection using Android smartphones with accelerometers, Paper presented at the 2011 International Conference on Distributed Computing in Sensor Systems, Barcelona, Spain, June 27-29.

Mohan, P., Padmanabhan, V.N., Ramjee, R. (2008) Nericell: Rich Monitoring of Road and Traffic Condition using Mobile Smartphones. *Proceedings of the 6th ACM Conference on Embedded Network Sensor Systems*, 323-336.

Perttunen, M., Mazhelis, O., Cong, F., Kauppila, M., Leppänen, T., Kantola, J., Collin J., Pirttikangas, S., Haverinen, J., Ristaniemi, T. (2011) Distributed road surface condition monitoring using mobile phones. *Ubiquitous Intelligence and Computing*, 64–78.

Sayer, M. W., Gillespie, T. D., Queiros, C. A. V. (1986) *International Road Roughness Experiment*. The World Bank. Available at: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/3134/72773.pdf;jsessionid=2D55BF78AABCA31452E6A59CD28D17C1?sequence=2

Strazdins, G., Mednis, A., Kanonirs, G., Zviedris, R., Selavo, L. (2011) Towards Vehicular Sensor Networks with Android Smartphones for Road Surface Monitoring, Paper presented at the 2nd International Workshop on Networks of Cooperating Objects, Chicago, USA, April 11.

Tai, Y., Chan, C., Hsu, J. Y. (2010)Automatic road anomaly detection using smart mobile device, Paper presented at the 2010 Conference on Technologies and Applications of Artificial Intelligence, Hsinchu, Taiwan, November 18-20.

Vehicle Intelligent Monitoring System (2012) VIMS. Bridge and Structure Laboratory, the University of Tokyo, Japan

VIMS (2012) VIMS Manual. VIMS Consortium, Nagasaki University, Japan