Exploring the Use of Smartphone Accelerometer and Gyroscope to Study on the Estimation of Road Surface Roughness Condition

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Abstract: Smartphones are potentially useful to be adopted as a cost-effective and easy to implement tool for the measurement of road surface roughness condition, which is very essential for road monitoring and maintenance planning. In this study, an experiment has been carried out to collect data from accelerometers and gyroscopes on smartphones, which are placed at different locations inside vehicles running on road sections with different roughness conditions. The collected data is processed in the frequency domain to calculate magnitudes of the vibration. It has been revealed that at the considered frequency range of 40-50Hz, there is a very strong relationship between road roughness condition and the magnitudes of vibration, calculated from each axis of the accelerometers and gyroscopes; as well as the average speed. Road roughness condition that is modelled as a linear function of the vibration magnitudes, taking into account of both data from accelerometer and gyroscope as well as the average speed, achieves better estimation than the model that takes into account the magnitude from the accelerometer and the average speed alone. The finding is potentially significant for the development of a more accurate model and a better smartphone app to estimate road roughness condition from smartphone sensors.

1 INTRODUCTION

To properly monitor, plan for maintenance and manage road infrastructure, substantial amount of data is always needed, particularly time series and up to date road condition data. Road condition data changes over time; since it also usually requires considerably significant investment and time to collect the data on a regular basis, obtaining such data is often a challenge that many governments are facing, especially in countries where budget is limited and advance technology is still unaffordable.

Road surface roughness is regarded as one of the most important road conditions, because it affects vehicle maintenance costs, fuel consumption, comfort, and safety. International Roughness Index (IRI) is an indicator that is widely adopted as a measurement for road surface roughness condition. IRI measurement is normally done either by one or a combination of two main approaches, which include a subjective rating or a visual inspection, an approach that is labour intensive and very time consuming; and the use of sophisticated profilers, which are highly accurate but costly to obtain, operate and maintain, requires skilful operators as well as cumbersome calibration before deployment.

In the smartphone era, where the number of smartphone users is increasing steadily, using smartphones to collect road condition data and estimate road roughness condition could change the way the government monitor, plan for maintenance and manage the road infrastructure forever, because the chance of having plenty of up to date data with inexpensive investment is huge. On the other hand, today's smartphones usually come with sensors that are capable of recording useful signal for road surface condition estimation similarly to those used in many high-tech equipment.

There are some studies that are relevant to this work, such as the use standalone, mobile and smartphone sensors to assess and monitor road and traffic conditions, detect road bumps/anomalies and their locations, and analyse events/features of different road defects; in simulation and real-life traffic conditions (Gonzalez, et al., 2008; Eriksson, et al., 2008; Mohan, et al., 2008; Tai, et al., 2010; Menis, et al., 2011; Strazdins, et al., 2011; Perttunen, et al., 2011). Further development includes the

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introduction of smartphone apps that claim to work in detecting road bumps (BumpRecorder, 2013) and roughness condition (Roadroid, 2013). The final goal of this study, however, is to develop a significantly simpler app that does not require the smartphones to be fixed at a specific location, in a specific orientation, and a troublesome calibration before use.

Our previous studies (Douangphachanh and Oneyama, 2013a; 2013b; 2013c) suggest that there is a strong relationship between the magnitudes of the vibration from smartphone accelerometers, IRI, and the average speed. The strength of the relationship also differs at different frequency ranges, in which the strongest relationship is observed at the frequency range of 40-50Hz. Based on these findings, IRI is roughly modelled as a linear function of the magnitudes, from accelerometers, and the average speed.

The main objective of this study is to explore whether adding gyroscope vibration magnitudes, in the linear function, would improve the estimation results, in comparison to the function that only takes into account the magnitudes from accelerometers and the average speed, which is included in the scope of our previous studies. This study only focuses at the frequency range of 40-50 Hz.

2 APPROACH

2.1 The Experiments

To achieve the objective of this study, we use the data from the experiment that is conducted in Vientiane, Laos in November, 2012. In the experiment, many smartphones and equipment are set at different location inside experiment vehicles that run along selected roads to collect data for our analysis.

Main equipment used in this experiment includes 4 smartphones, 2 Samsung Galaxy Note 3 (GT-N7100), a Galaxy S3 (GT-I9300), and a LG 4X HD (LG-P880); a GPS trip recorder (747Pro), and a Sony video camera.

The smartphones are pre-installed with an application called AndroSensor (2012). The application is used to record data from accelerometers, gyroscopes and GPS. Data recording is done at an interval of 0.01 second or at a sampling rate of 100Hz. This sampling rate enables us to study the magnitudes of the vibration from the frequency range of 0-50Hz.

The roads selected for the experiment include various sections with diverse roughness conditions ranging from good ($0 \leq IRI < 4$), fair ($4 \leq IRI < 7$), Poor ($7 \leq IRI < 10$), and bad ($IRI \geq 10$). These condition classifications are based on condition indices used in Lao Road Management System.

We use Vehicular Intelligent Monitoring System (VIMS, 2012a) to measure the actual roughness condition of the selected road sections. VIMS comprises of both hardware, which includes a data acquisition module, an accelerometer and a GPS logger, all connected to a laptop computer via cables; and software, which includes two main programs, one for calibration and data collection, and another one for the analysis. The system calculates the International Roughness Index (IRI) for every 10 meter road section. The main limitation of VIMS is that it cannot estimate IRI of road sections where the travel speed of the experiment vehicle is less than 20km/h.

In our experiment setting, we place the smartphones at 3 different locations, on the dashboard, inside the driver's shirt pocket and in a box near the gearshift (Figure 1). On the dashboard, two smartphones are glued tightly assuming that the orientation of the smartphones is fixed (Smartphone A and Smartphone B), while the other two smartphones inside the pocket and the box are allowed to move freely (Smartphone C and Smartphone D, respectively). It is important to note that Smartphone C, though can move accordingly with the driver's movement, will not change its orientation. Smartphone D, which is inside the box near the gearshift, however, may change its orientation if the vehicles shake violently due to severe road surface condition. The violent vehicle shaking does not happen during the course of this experiment.

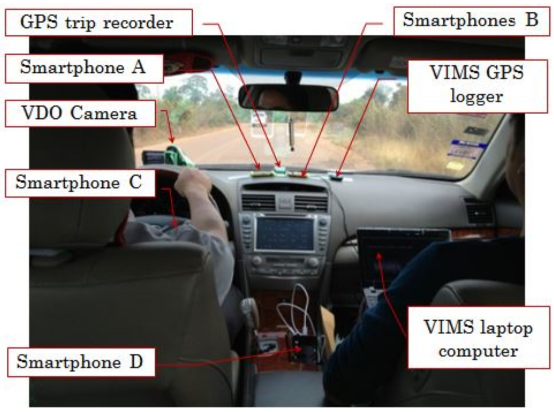


Figure 1: The experiment setting.

Figure 1 also shows the setting of the GPS and the video camera, which are also placed on the dash board. VIMS components are also installed in accordance to VIMS (2012b).

Four vehicles are used in this experiment, a Toyota Vigo 4WD pick-up truck as Vehicle 1, Vehicle 2 is a Toyota Camry sedan, Vehicle 3 is a Toyota Vigo 2WD pick-up truck, and Vehicle 4 a Toyota Yaris sedan.

Note that throughout the experiment, the two Samsung Galaxy Note 3 have been assigned as Smartphone A and C, the Galaxy S3 has been assigned as Smartphone B, and the LG 4X HD has been assigned as Smartphone D. For the Vehicle 1, Smartphone C and D have been switched their locations on one occasion during the entire course of the experiment. See Table 1 for details.

2.2 Data Processing and Analysis

Data processing for this study is similar to those described in our previous studies. The following figure (Figure 2) shows the data processing flowchart:

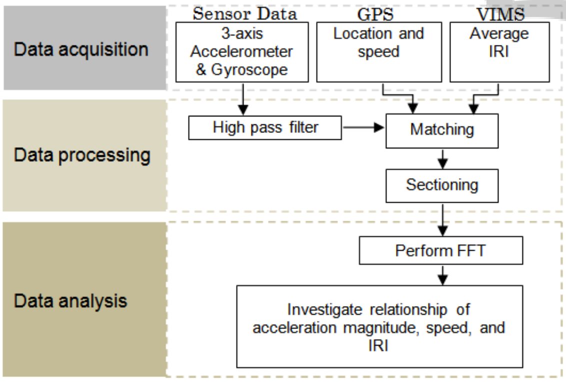


Figure 2: Data processing and analysis flowchart.

After data is obtained, it is checked and filtered (high pass) to remove irrelevant data and signal. Next, the qualified data will be matched with roughness data before dividing into 100 meter sections. A 100 meter length of sensors' data is chosen as a unit for road roughness estimation in this study because (i) Road Management System in Laos requires road pavement condition to be estimated for every 100 meter section as it is believed to be convenient for maintenance planning; (ii) there is also a concern on the accuracy of GPS position data, therefore choosing a shorter section unit may cause some issues in data matching between VIMS and smartphone GPS data.

Also similar to the previous studies, after sectioning, road sections that have incomplete data will be excluded from the analysis. The sections with incomplete data are those that have no data from VIMS, at the time when the experiment vehicle is travelling at a speed slower than that required by VIMS (less than 20km/h) in traffic jam condition, for instance; and sections that have no GPS data, as sometimes GPS would fail to record information due to some satellite signal obstruction. Road sections where experiment vehicles have stopped (checking from speed and VIMS data) are also excluded since data at these sections cannot be used to estimate road roughness condition. In addition, sections that have the lengths that are 10% less or more than 100 meters, less than 90 meters or more than 110 meters, are also omitted from the analysis.

Table 1: Number of road sections by smartphone, locations, and vehicles.

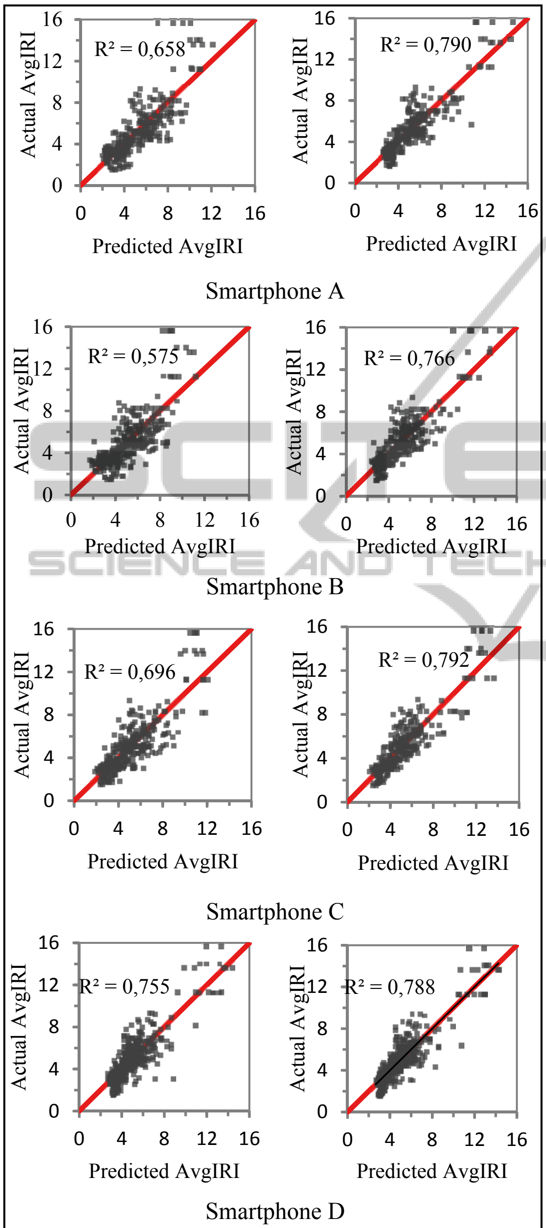
	Vehicle 1: Toyota VIGO 4WD Pick UP						Vehicle 2: Toyota Camry Sedan				Vehicle 3: Toyota VIGO 2WD Pick				Vehicle 4: Toyota Yaris Sedan			
	Smartphone						Smartphone				Smartphone				Smartphone			
	A	B	Ca	Cb	Da	Db	A	B	C	D	A	B	C	D	A	B	C	D
Number of sections selected for analysis	703	674	311	246	320	492	497	489	467	592	314	319	309	421	408	411	382	450
Location of smartphone	Dashboard	Dashboard	Pocket	Near gearshift	Near gearshift	Pocket	Dashboard	Dashboard	Pocket	Near gearshift	Dashboard	Dashboard	Pocket	Near gearshift	Dashboard	Dashboard	Pocket	Near gearshift

The analysis is carried out in the frequency domain using Fast Fourier Transform (FFT) to calculate magnitudes for every selected 100 meter section for each axis of the acceleration and gyroscope vibration. For the sampling rate of 100 Hz, FFT can calculate the magnitudes for each vibration axis from 0-50 Hz. FFT results allows us to study the relationship between the magnitudes and IRI at different ranges of frequency, to see whether the sum of magnitudes at a particular range of frequency is more useful in expressing the road roughness condition or not.

3 RESULTS AND DISCUSSION

The analysis shows that IRI can also be roughly modelled as a linear function of the magnitudes, calculated from both accelerometer and gyroscope data, and the average speed. By adding gyroscope vibration as an additional parameter in the function, significant improvement in the estimation of IRI is observed.

Figure 3 below shows a selected result of a comparison of IRI estimation for the function that is taking into account only the average speed and the magnitudes, from accelerometer (Function 1); and the function that considers the average speed and the magnitudes from both accelerometers and gyroscopes (Function 2).



Note: Graphs on the left hand side are the estimated by Function 1; while graphs on the right hand side are estimated using Function 2. The frequency range is 40-50Hz. AvgIRI is the average IRI.

Figure 3: Comparison of estimation results, for all smartphones in Vehicle 3.

As the figure shows, for all smartphones in vehicle 3, the R^2 values in the right hand side graphs are greater than the R^2 values in the left hand side graphs. This indicates that Function 2 is better than Function 1. Smartphone B, for instance, the R^2 improves significantly from 0.575 to 0.766 of the estimation predicted by Function 1 and Function 2, respectively.

Table 2: Summary of estimation results for both functions, all smartphones and all vehicles.

			R^2 derived from the estimation function that takes intoaccount the average speed and magnitudes from:	
			Accelerometer (Function 1)	Accelerometer and Gyroscope (Function 2)
Vehicle 4	Smartphone	A	0.735	0.817
		B	0.666	0.735
		C	0.790	0.804
		D	0.725	0.739
Vehicle 3	Smartphone	A	0.658	0.790
		B	0.575	0.766
		C	0.696	0.793
		D	0.755	0.788
Vehicle 2	Smartphone	A	0.616	0.764
		B	0.620	0.758
		C	0.550	0.694
		D	0.520	0.736
Vehicle 1	Smartphone	A	0.600	0.793
		B	0.545	0.736
		Ca	0.775	0.809
		Cb	0.602	0.618
		Da	0.718	0.806
		Db	0.594	0.625

Table 2 above summarises R^2 that are derived from the estimation of Function 1 and Function 2 for all smartphones and all vehicles. In general, it can be concluded that R^2 that are estimated by Function 2 are greater than that estimated by Function 1. Almost all R^2 estimated by Function 2 are greater than 0.74, while less than half of R^2 estimated by Function 1 reach that value. The greatest values of R^2 from Function 2 are as great as 0.8 in four cases (0.804, 0.806, 0.809, and 0.817 for Smartphone C Vehicle 4, Smartphone Da Vehicle 1, Smartphone Ca Vehicle 1, and Smartphone A Vehicle 4, respectively). In many cases, Smartphone B Vehicle 3, Smartphone D Vehicle 2, and Smartphone B Vehicle 1, for instances, there are significant differences between R^2 values estimated by the two functions (0.575 against 0.766, 0.520 against 0.736, and 0.545 against 0.736, respectively).

4 CONCLUSIONS

In our previous studies, we have investigated the use of smartphone accelerometers to estimate road surface roughness condition (IRI) in which promising results are observed. This study continues to explore the use of more smartphone sensors, including the accelerometers and gyroscopes, to estimate IRI with the final goal of obtaining an improved estimation model that is acceptably accurate, simple and easy to implement. An experiment is carried out to obtain data from the smartphone relevant sensors. After the data is processed, FFT is used to calculate the magnitudes of the vibration. Similar to the findings in our previous studies, IRI can also be modelled as a linear function of the average speed and the magnitudes, calculated from both accelerometers and gyroscopes. The function can be used to estimate IRI with an improved accuracy in comparison to the function that only considers the average speed and the magnitudes from the accelerometers alone, which is presented in the previous studies. The new estimation function is potentially useful for the development of a smartphone app, which may contribute to improve the efficiency of road authorities and government in obtaining needed data, and monitoring as well as maintenance planning of the road infrastructure.

In our ongoing studies, more focus is being put into the formulation, piloting, and improvement of the final and practicable estimation model. Additionally, in our future work, great emphasis will also be directed to the integration of the model into a smartphone app.

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