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Smartphone Applications for Pavement Roughness Computation of Sri Lankan Roadways

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Abstract: Pavement Roughness can be expressed as the anomalies in a pavement surface, which will affect the ride quality of a vehicle. Roughness can be expressed as International Roughness Index (IRI). In Sri Lanka, fund allocations for road rehabilitation have become a major issue for government authorities. In this research two android applications were used to estimate the road roughness which can be used to collect road condition data cost effectively. The study was performed on 20 national roadway sections in Sri Lanka. The statistical analysis showed linear regression model, R^2= 0.754 based on the relationship between estimated and existing IRI values which were obtained from Road Development Authority (RDA) of Sri Lanka. Based on result from the experiment smartphone application can be determined as an alternative that can be used to determine the surface roughness of pavements, as it provides data efficiently and with technical benefits.

Keywords: Smartphone sensors, Pavement roughness, Pavement condition, Android applications

1. INTRODUCTION

This section aims to show the theoretical foundations of International Roughness Index. Basically this section shows the definition of IRI, background, factors affecting roughness of pavements, measuring equipment, among others. Factors that greatly influences the state of road infrastructure are flaws or surface deterioration of the pavement. These factors influence the life of the pavement and in the service provided to the public, it is important to evaluation in flexible pavements, which shows that the deterioration process starts immediately after construction. The causes are external stresses produced by traffic and weathering. Consequently, pavement deterioration is a progressive process, so it is necessary to perform maintenance management based on conservation or rehabilitation; depending on whether the faults are affecting the functional or structural pavement condition. IRI is a statistical indicator of the irregularity of the pavement and represents the difference between the longitudinal profiles of a particular pavement surface relative to a planar theoretical surface. What dynamic effects of road irregularities, may be reflected not only in vehicles but also in changes of state of stress and strain in the pavement structure, which can increase costs in maintenance and rehabilitation activities. For these reasons, knowing the evenness of the pavement at any time since the start of their period of service life, will define the actions necessary for conservation or rehabilitation at the relevant time. As IRI was proposed by the World Bank in 1982 as a statistical standard roughness and has served as a benchmark for measuring the quality of road internationally. This paper will focus on evaluating IRI by an effective and economical alternative using smartphone applications called “Roadroid” and “Androsensor.”

1.1 Research Background, Approach and Overall Objective

Characterization and measurement of pavement roughness is a major concern of highway authorities throughout the world (Douangphachanh and Oneyama 2014). American Society for Testing Materials (2012) defined pavement roughness as the "deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality". Pavement roughness is an expression of the irregularities in a pavement surface that adversely affect the ride quality of a vehicle. Roughness also affects vehicle delay costs, fuel consumption and therefore emission (Islam *et al*. 2014).

In developing a country like Sri Lanka, the funds allocated to local authorities are largely insufficient to maintain road network at good condition. To optimize the funds available, it is essential to have a proper cost effective method that can be used to monitoring the condition of roadways and up to date road condition information. A proper inventory of the road network can be used to optimize fund allocations to achieve better overall network performance. Therefore, the overall objective of this research is to estimate the road roughness using smartphone applications, which can be used in the maintenance and planning process.

1.2 Pavement Roughness

Roughness is a non-destructive evaluation of pavement surface and can be converted into IRI which can be recognized as an indicator to road roughness condition. IRI value can be got from measuring longitudinal road profiles according to its introduction in 1986 (Sayers *et al*. 1986). The given scale in Figure 1 can be recognized as a valid calibration scale for roughness which was established by Sayers *et al*. (1986). And this IRI value can be used to classify roads which is a major advantage for road authorities as mentioned above.

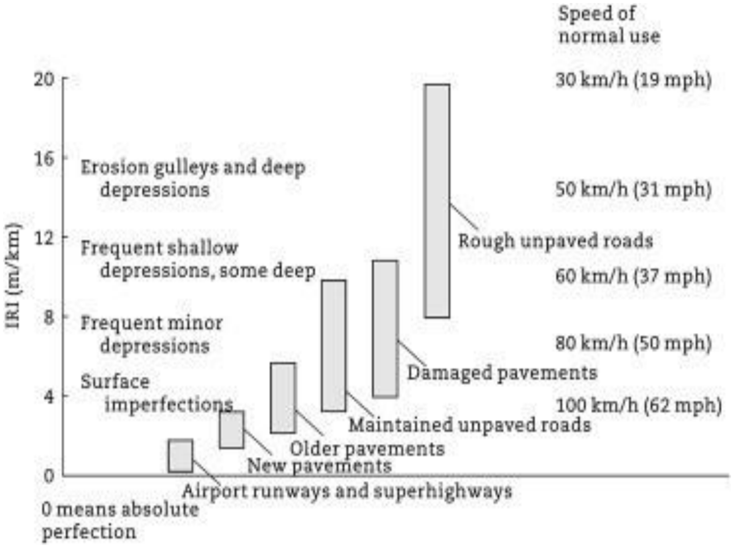


Figure 1. IRI calibration scale for roughness
(After Sayers *et al*. (1986) cited in Schlotjes *et al*. (2014))

Four Generic classes of road roughness measuring methods are:

- Class 1 – Precision profiles,
- Class 2 – Other profile – metric methods,
- Class 3 – IRI estimates from correlation equations, and
- Class 4 – Subjective ratings and uncalibrated measures

The IRI summarizes the roughness qualities that impact on vehicle response, and is most appropriate when a roughness measure is desired that relates to: overall vehicle operating cost, overall ride quality, dynamic wheel loads (that is, damage to the road from heavy trucks and braking and cornering safety limits available to passenger cars), and overall surface condition.

1.3 Existing Roughness Measurement Systems

There is a large variety of equipment that has been developed over the years to measure pavement roughness. Those devices can be categorized into the following five categories (Jhonston 2011);

- Response Type Road Roughness Measuring Systems (RTRRMS),
- High- speed inertial profilers/inertial profilers (Laser),
- Profilographs,
- Light weight profilers, and
- Manual Device.

A sliding straightedge (viagraph) as depicted was the very first instrument to measure the roughness of the road with the difficulties faced during sliding eventually the equipment has developed to a rolling straightedge. Even though rolling straightedge tuned to certain wavelength some of the wavelengths did not record to overcome this situation the concept was improved by establishing a reference plane as Profilograph. With the time this equipment developed as a Rough meter and then Road meter with standardized all dimensions, mass properties, and tire and suspensions properties to compare properties among all existing devices (Gillespie 1992). Later González *et al.* (2008) have modelled two - axel vehicle as a “four degree of freedom suspension system which has named as a half - car” and a standalone accelerometer can be used to evaluate road roughness condition successfully by obtaining acceleration data from the sensor.

But for developing countries like Sri Lanka these high-tech methods may still be a little out of the reach. Douangphachanh and Oneyama (2013) used 3 Axis accelerometer which is one of the most common sensor in the smartphone and obtained acceleration computation in m/s2 along each x, y, z, axis, by using an already developed android based application called “AndroSensor”. The connection between obtained acceleration statics and road roughness condition was explored and found that the relationship depends on the vehicle type and device used. Roadroid has been developed since 2002, initially using accelerometer, Global Positioning System (GPS) and a laptop personal computer (PC) to now using a smartphone. Roadroid supports different cars, speeds and phone models. The information obtained can directly guide pothole fixing and urgent patching. And Roadroid can work as an early warning system to see when where a road is changing state. Forslöf and Jones (2015) have done the case study in Deir AL - Balah City.

The Roadrod smartphone solution has two options for roughness data calculations;

I. Estimate IRI (eIRI) - based on a Peak and Root Mean Square (RMS) vibration analysis - the setup fixed but made for three types of cars and is thought to compensate for speed between 2-100 km/h.
II. Calculated IRI (cIRI) - based on the quarter-car simulation (QCS) for sampling during a narrow speed range such as 60-80 km/h when measuring cIRI, the sensitivity of the device can be calibrated by the operator to a known reference.

1.3.1 Quarter Car Model

According to Sayers and Karmihas (1998) Figure 2 shows a quarter-car model, where the vertical movements of the body can be captured. The model includes the major dynamic effects that determine how roughness causes vibrations of the car body. It includes tire compliance, suspension stiffness and damping, and two masses. The equations are derived from Newton's second law, force = mass acceleration. For the sprung mass, the vertical acceleration is related to vertical forces.

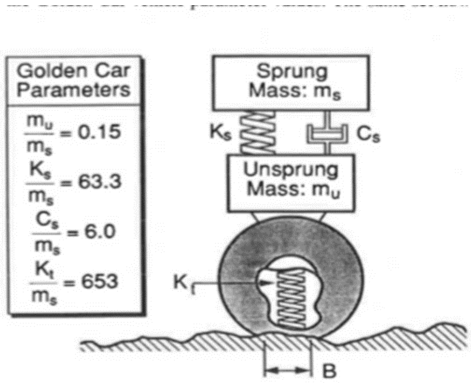


Figure 2. Quarter Car Model and parameters
(after Sayers and Karmihas (1998))

$$(\ddot{z_s} - g) = f_{susp} - f_g \tag{1}$$

Where;

$\ddot{Z_s}$= vertical;
m_s = sprung mass (portion of mass of car body supported by one wheel);
g = gravitational constant;
f_{susp} = suspension force in addition to static load due to gravity; and
f_g = static load due to gravity = $m.\ g$

Gravitational force and acceleration in the equation 1 will be removed, as they are constants; and simplified equation 1 can be written as equation 2.

$$m_s\ddot{z_s} = f_{susp} \tag{2}$$

For the simplified mechanical system shown in the Figure 2, the suspension force is the sum of a spring force and damper force. Using simple linear spring and damping components, k_s and c_s, respectively, gives in equation 3.

$$f_{su} = k_s(z_u - z_s) + C_s(\dot{z_u} - \dot{z_s}) \tag{3}$$

Combining Equations 2 and 3, an equation of motion is obtained as shown in equation 4.

$$m_s\ddot{z_s} + C_s(\dot{z_s} - \dot{z_u}) + k_s(z_s - z_u) = 0 \tag{4}$$

A similar equation is obtained for the unsprung mass by considering the force from the suspension and the tire (modeled as a linear spring with rate kt) and wrote in equation 5.

$$m_s\ddot{z_s} + C_s(\dot{z_u} - \dot{z_s}) + k_s(z_u - z_s) = k_t(z_p - z_u) \tag{5}$$

In Equation 5, m, is the unsprung mass, defined as the mass of the wheel, tire, and half of the axle. Equations 4 and 6 are the equations of motion for the quarter-car model shown in the Figure 2. As input, this model requires wheel track elevation as a function of time, designated by the variable z_p. As output, it predicts the displacement, vertical velocity, and vertical acceleration of the sprung and unsprung masses.

IRI can be calculated using equation 6.

$$IRI = \frac{1}{L}\int_0^{L/V} |\dot{z}_s - \dot{z}_u| \, dt \tag{6}$$

Where;

L=longitudinal distance, and

V=speed of the vehicle.

Present Serviceability Index (PSI) as a pavement performance parameter. The PSI is used to formulate decision matrices that support the roadway treatments selection process. depends on the pavement condition index (PCI), rutting, and IRI as explanatory variables to estimate PSI of state roadway segments (Aleadelat and Ksaibati 2017).

1.3.2 Relationship between PSI and IRI

Gulen *et al*. (1999) found that there were no significant differences between the models for different states and pavement types. The following nonlinear model in equation 7 fits the boundary conditions is recommended (Gulen *et al*. 1999).

$$PSI = 9 \times e^{-0.008784 \times IRI} \tag{7}$$

Where IRI is in inches/mile.

1.4 Pavement Roughness Estimation in Sri Lanka

The RDA in Sri Lanka is using a Laser profilometer Class 1 Inertial Profiler and conforms to ASTM-E950, which is known as Hawkeye 2000 Network Survey Vehicle as depicted in Figure 3. Quarter Car Model concept has been used in laser profiler. It has capability of collecting 13 points to estimate roughness across the road. It estimates IRI values in 100 m intervals. Speed limit should be maintain between 20km/h – 110km/h during the testing period.

Figure 3. Overview of Hawkeye 2000 Network Survey Vehicle (Source: RDA(2010))

1.4.1 Limitations of the Laser Profiler

- In Sri Lanka RDA has only one survey vehicle, which is shown in Figure 3. The cost of its in 2010 was Rs.100 million. Moreover, the estimated cost for 10-year upgrade is Rs.200 million in year 2020.
- Backup vehicle should be there, the red color vehicle as depicted in Figure 3 in order to avoid any interruption from outside vehicles.
- Since the width of the survey vehicle is 3.6m as shown in Figure 4, the minimum lane width will be limited to 3.6 m, therefore some roads which are maintaining by Provincial Road Development Authority (PRDA), cannot be covered using this vehicle.
- Because it is cost intensive to do survey on the total road network, the surveys were done on A-Class and B-Class roads only. The latest data available in Colombo district is during August of 2017 but for some other roads data in 2016 or 2015 were used.

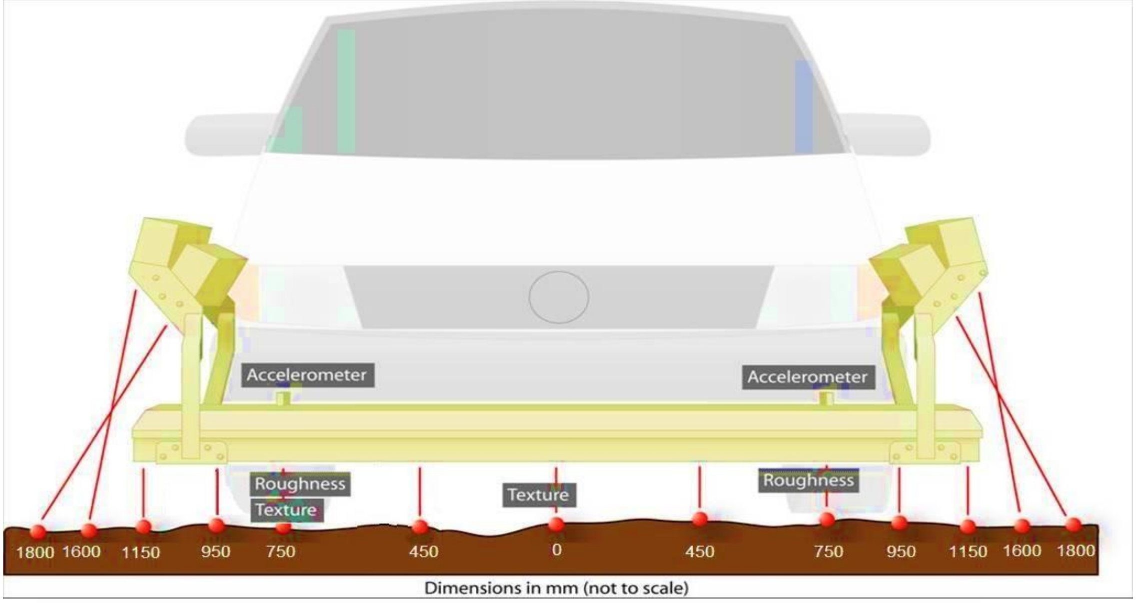


Figure 4. Typical Front Layout of a Laser Profiler (Source : RDA(2010))

2. LITERATURE REVIEW

2.1 Recommendation of Acceleration to Evaluate IRI

Sayers *et al*. (1986) stated that pavement condition data are an essential component of any pavement management system (PMS), and is required to determine existing pavement condition, to setup the pavement maintenance. There are four main pavement condition evaluation methods (1) distress survey, (2) roughness, (3) structural capacity, and (4) skid resistance. IRI has defined simply and conveniently by Sayers *et al*. (1986) in order to have a single standard roughness measurement information which can be used to compare directly and they have studied and established valid calibration scale for roughness by conducting an International Road Roughness Experiment in Brazil in May 1982 measures from Response - Type Road Roughness Measuring Systems (RTRRMSs) operated at 80 km/h speed.

The IRI is essentially a numerical representation of a road profile designed to replicate the traditional roughness measures obtained from response type measuring systems. IRI uses a mathematical model known as the quarter car to filter the suspension deflection of a simulated mechanical system with a response similar to a passenger vehicle Brown *et al.* (2010). The components used in this mathematical process are illustrated in Figure 2.

Characteristics and speed of the operating vehicle means they are not able to provide a roads longitudinal profile for spectral analysis. This is one area that limits RTRRMS measurements over profile based system measurements (Brown *et al.* 2010). The most modern roughness measurement devices are noncontact profile measuring systems (Islam *et al.* 2014). These devices measure deviations in longitudinal pavement profile using acoustic or light probes. For their study they have used ProVAL software to estimate roughness by computing IRI value. The main objective of the project as stated was to demonstrate a new cellphone application to capture pavement roughness by using smartphone accelerometer capabilities and concluded that data collected using smartphone application were similar to data collected by inertial profiler system which has also conducted by this research team as a part of their project.

González *et al.* (2008) modelled two - axel vehicle as a four degree of freedom suspension system that has named as a half – car and a standalone accelerometer has fit to the vehicle in order to measure the road roughness as the main aim of their research. It was concluded that road roughness can be estimated from acceleration data which were obtained by the sensor. Moreover, Bidgoli *et al.* (2019) developed an automated, cost-effective Road Roughness Monitoring System (RRMS), using accelerometer and GPS sensors mounted on an additional wheel carried by a vehicle to measure the pavement roughness.

2.2 Introduction of Smartphone Applications

Nowadays, smartphone have many valuable sensors inside of them. A 3D or 3 Axis accelerometer is one of the most common sensor which can be found in them from the accelerometer we can obtain acceleration measurements in m/s2 along each x,y,z, axis by using an already developed android based application called “AndroSensor”(Douangphachanh and Oneyama 2013) explored the relationship between obtained acceleration data and road roughness condition; and found that the relationship depends on the vehicle type and device used.

Roadroid has been developed since 2002, initially using accelerometer GPS and a laptop personal computer (PC) to now using a smartphone. Forslöf and Jones (2015) stated using a case study which was conducted in Deir AL – Balah City, that Roadroid supports different cars, speeds and phone models. The information obtained can be directly used in pothole fixing and urgent patching. And Roadroid can work as an early warning system to see when and where a road is changing its condition. Zang *et al.* (2018) explored that IRI values which measured using smartphone sensors are strongly and positively correlates with those measured by professional instrument (car mounted laser pavement scanner) on pedestrian and cycle lanes, by conducting road roughness measuring experiment using bicycle mounted smartphone on selected 10 cycle lane sections in Banqiao Town, southwest of Nanjing, China. Bisconsini *et al.* (2018) assessed the potential of smartphone to estimate pavement roughness with the use of androsensor and accelerometer analyzer applications, by comparing the results with IRI values which were obtained from Rod and Level method and revealed that data acquisition rate can affect for the calculation of IRI values.

2.3 Application of “Roadroid” and“Androsensor”

Since previous studies have shown that road, surface conditions are an important factors for road quality, Aydin *et al.* (2017) explored utilization of Roadroid, an android based simple application by collecting data using acceleration and GPS properties of a smartphone in a specific (passenger car) vehicle type in Turkey. In addition, confirmed that Roadroid have a great potential to evaluate road surface roughness condition correctly, even under obstacles like potholes, manholes and decelerating marks.

Schlotjes *et al*. (2014) studied the performance of the Roadroid android application as a low cost solution for road condition surveys. The study was done in Kiribati and the main objective was to demonstrate the applicability of the device in the Pacific Region and to study the effectiveness of the device in the Pacific environment and evaluate the performance of the IQL -3/4 device in Kiribati. The study concluded the device is potentially vehicle dependent, but this dependency could be within the limits of an Information Quality Level (IQL) ¾ device and will not be a practical issue.

Jhonston (2011) researched whether the Roadroid system can represent the roughness felt by a road user in the Auckland network. Tests were conducted by surveying 20 roads of variable characteristics. The results were compared with industry accepted measurement systems to determine accuracy and wavelength energy to determine response. It was found that Roadroid has an 81% similarity to Laser data and can represent the roughness felt by a road user to a ‘good’ level. Gamage *et al*. (2016) demonstrated how smartphone application can be used in the measurement of roughness in low volume roads in Sri Lanka. Use of road roughness information can give the road agencies useful information for decision-making process in maintenance planning and programming of low volume roads. The experiment has been conducted using “two android applications to get accelerometer readings: Roadroid Classic and Androsensor and a Toyota Hilux 4 - Wheel Drive (4WD) cab. As the conclusion by analyzed collected data, they found that acceleration data from smartphones has linear relationship with road roughness condition and results depended on the speed and vehicle type.

New descriptive variables can be measured using smartphone sensors when estimating Present Serviceability Index (PSI) (Aleadelat and Ksaibati 2017). The objective of this research was to reduce the cost of measuring pavement conditions of county roads by evaluating PSI directly without the reliance on the direct measurement of pavement condition parameters. Two smartphones attached to the dashboard in order to identify new variables, were used to capture the vertical vibration while driving the testing vehicle using an application called “Androsensor” which operates using smartphone sensors such as gyroscopes, magnetometers, GPS receivers and three dimensional accelerometers. The observed results demonstrated the ability of smart phone sensors in returning variables that could work as good explanatory variables to predict the PSI of country roads. Aleadelat *et al*. (2018) compared observed results with a standard profiler (South Dakota profiler) and showed the capability of smartphone accelerometers for measuring pavement roughness as a part of an actual local county road’s pavement management system (PMS).

3. MATERIALS AND METHODS

This study explores the use of smartphone sensors to determine the pavement roughness on 20 roadway sections in national road network which include A-class roads, B-class roads and Expressways in Colombo District, Sri Lanka, as a cost effective alternative to obtain road condition data. As the methodology, smartphone sensors such as internal accelerometer, GPS receiver, Gyroscopes have been used to capture the vertical vibrations while driving over roads that can be considered as a reflection of roughness and distress of roads. Two applications were selected for cross checking validation as “AndroSensor” which can be freely download from Google Play Store and “Roadroid Classic” application were installed. Two identical smartphones One Plus X with OS 3.4.1, as shown in Figure 5.a, as proposed by Aydin *et al*.

(2017) were used. Smartphones were attached to the front window (windshield) horizontally/landscape mode and standing vertically from road (this is the most suitable position for the using GPS function), using two identical car mounts as recommended in application manual as shown in Figure. 5.b.

a. Identical One Plus X phones b. Car Mounts

Figure 5. The smartphones used for data collection

Testing vehicle was a standard passenger car BMW E90 318I SPORT model. The investigations were done road sections which given in Table 1. The test vehicle maintained a speed around 80 km/hr, and data collection was done during off peak hours from 10.00 p.m. to 12.00 midnight.

Table 1. Selected Road sections

Road Class	Road Sections	Distance (km)	Number of Lanes
A001	Peliyagoda Interchange – Kadawatha Interchange	10.00	4
AA002	Gall Face Roundabout- Kollupitiya	2.20	4
AA004	Homagama Town – Nugegoda Bus Stop	13.70	4
AB010	Welivita Junction – Kaduwela town	2.50	2
AB015	Parliament Junction – Junction near end of the Parliament ground	1.80	4
B 452	Homagama – Diyagama Junction	3.80	2
B 047	Battaramulla – Pannipitiya	5.40	4
B263	Malabe Junction- Kaduwela Junction	5.00	2
B240	Koswatta Junction- Parliment Junction	2.10	4
B 239	kottawa to pinhena junction	0.93	2
B 267	Pinhena Junction – Piliyandala bypass Road	6.06	2
B 084	Piliyandala -Borelasgamuwa Junction	10.80	4
B 094	Maharagama – Borelasgamuwa Junction	7.50	4
B 639	Piliyandala By Pass	2.70	2
B291	Nawinna – Jubilee Post	3.30	2
B120	Nugegoda – Pita Kotte	2.70	4
B 307	Nawala Junction – Nugegoda (Near Supermarket)	1.70	4
E001	Kottawa Interchange –Gelanigama Interchange	58.00	4
E002	Kottawa Interchange - Kothalawala Interchange	13.00	4
E003	Colombo Entrance – Ja Ela Expressway Entrance	26.00	4

Data collection was done by selecting the "Start / stop sampling" option in AndroSensor and in Roadroid by selecting video, photo or non –video mode with the defined route. It is observed that the Roadroid application directly generates two IRI values for the respective vibration, such as the eIRI (estimated IRI) and the cIRI (calculated IRI) for each 100m of road length; the cIRI based on the quarter –car simulation is considered in this research. Since the values compared with RDA results have obtained using laser profilometer, which is based on quarter car simulation model. From AndroSensor application Z-axis acceleration data were obtained from the application and IRI values were calculated using MATLAB software and ProVAL (Profile Viewing and Analysis) program, which is a free engineering program that allows visualizing and analyzing pavement profiles in different ways respectively.

Then the IRI values estimated by Androsensor and Roadroid were compared using population hypothesis analysis called z- test and a relationship was developed between two applications using linear regression model. And the IRI values obtained by the RDA of Sri Lanka using a laser profiler were compared with calculated IRI values.

4. RESULTS AND DISCUSSION

Table 2 shows the z-test results from the analysis between two android applications Androsensor and Roadroid. Since the Sample size (N) = 765 which is greater than 40, it is recommended to do z-test as population hypothesis test to illustrate that the relationship between of IRI values from the two android applications. This z-test analysis is used to determine if there is a statistically significant difference between two sets of scores when the population variance is known.

Table 2. z-Test results Significant at 5% level.

Population Variance	
Androsensor	2.901294973
Roadroid	2.901870001
Mean	
Androsensor	4.463816993
Roadroid	4.475477124

z-Test: Two Sample for Means **Alpha =0.05**

	Androsensor	Roadroid
Mean	4.475477124	4.463817
Known Variance	2.90187	2.901295
Observations	765	765
Hypothesized Mean Difference	0	
z	0.133875676	
P(Z<=z) one-tail	0.446750442	
z Critical one-tail	1.644853627	
P(Z<=z) two-tail	0.893500885	
z Critical two-tail	1.959963985	

Since the z-actual value was 0.133875676 which was lower than the z-critical value (1.959963985) and the probability was 89.3500885 % (> 5 %), it can be confirmed that IRI values from the two android applications are very similar.

Also, the relationship between of IRI values from the two android applications could be seen as very similar according to Equation 8 and Figure 6.

$$y = 1.0001x + 0.0113; R^2 = 0.978 \tag{8}$$

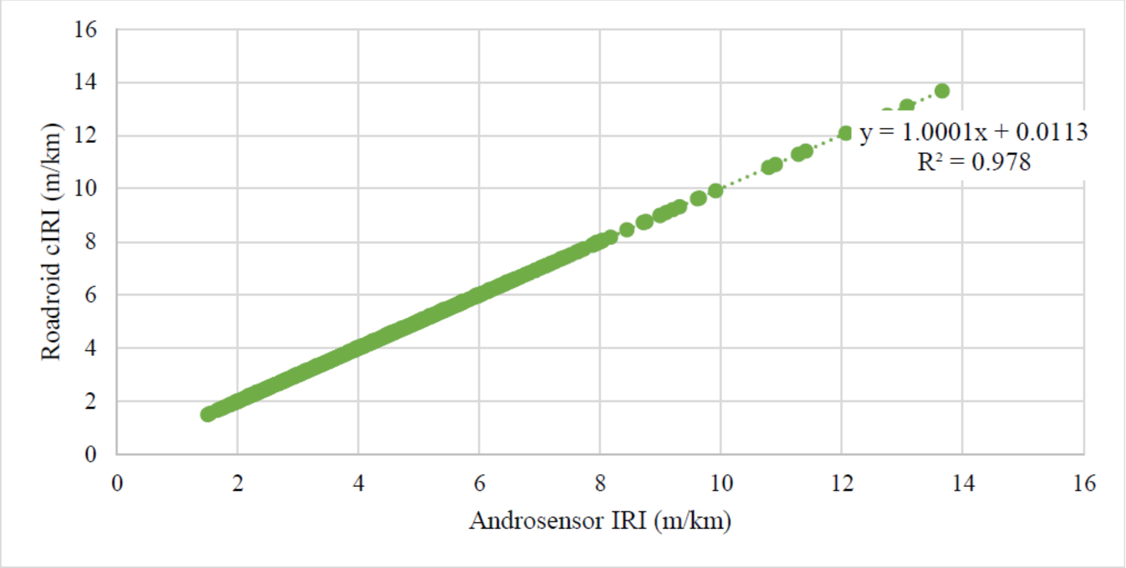


Figure 6. Relationship between obtained IRI values from AndroSensor and Roadroid applications

Figure 7 shows the linear relationship between IRI values obtained from Roadroid application and laser profiler. The obtained linear relationship between Roadroid application and Laser Profiler was express as;

$$y = 0.8232x + 2.4612;\ R^2 = 0.754 \tag{9}$$

There was a 24.6% difference associated to several factors such as the data collection technique of each team, while that with the inertial profiler takes the data directly by means of elevations, thus measuring the deformations, the Roadroid application takes the data indirectly by means of the mobile accelerometer. Also, at the time of sampling with the Roadroid application curves are a problem; as the vehicle tends to decelerate, finally resulting in frequent human errors.

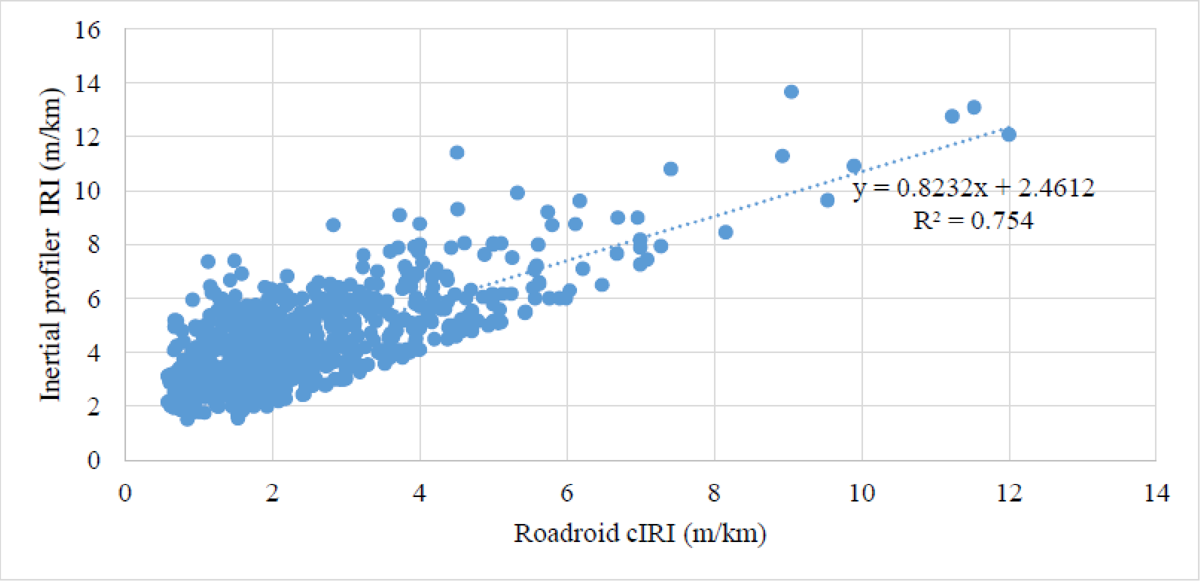
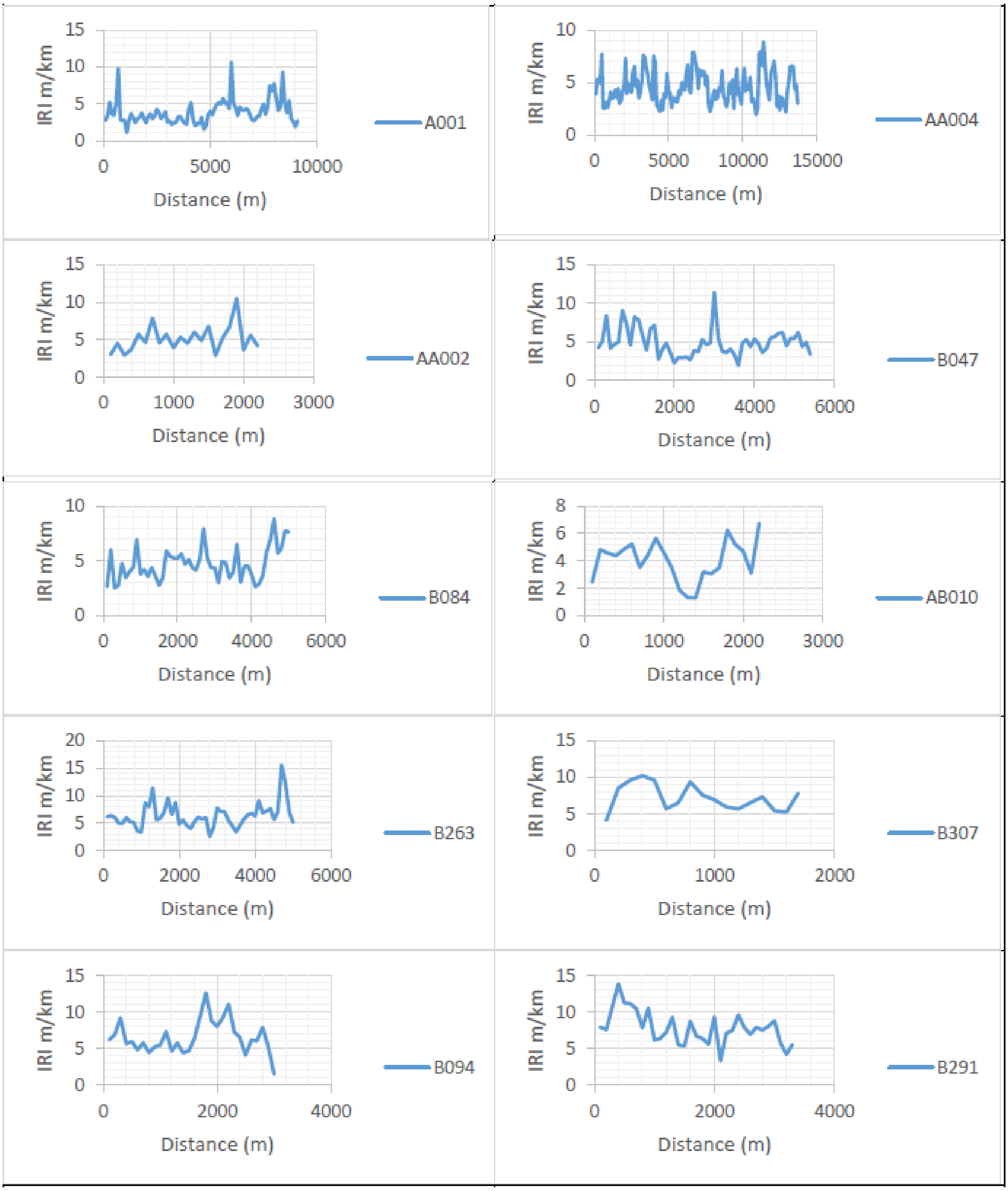


Figure 7. Relationship between LaserProfiler and Roadroid IRI values

In Figure 8a and Figure 8b, IRI values in 100m intervals were illustrated as line graphs for each individual road to show that how the IRI values varying along the road, which can be used for spatial distribution, with the use of GPS navigation system in smartphone. When investigating the line graph of individul road segments, it can be make the disions which road segment is critical and what prirority should be given for maintence and rehabilitations.

As the next step of the study, repeatability tests were conducted for Roadroid IRI measurements in Outer Circular Expressway. Figure 9 gives the IRI Roadroid measurement plots at every interval of 100m of 4 runs on the same roadway conducted in four different days.



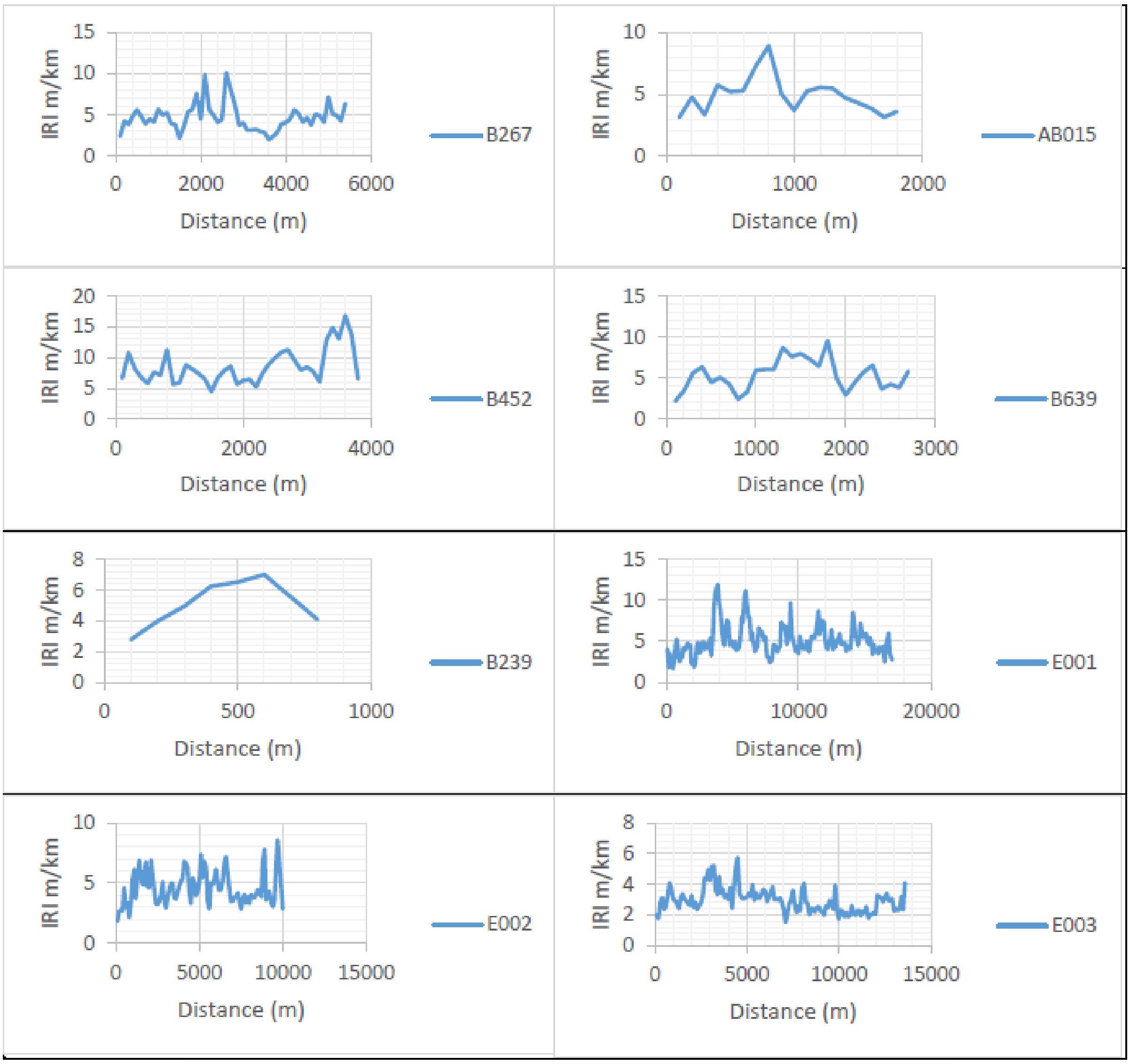


Figure 8.b. Interpretation of IRI values for 20 Individual Roads

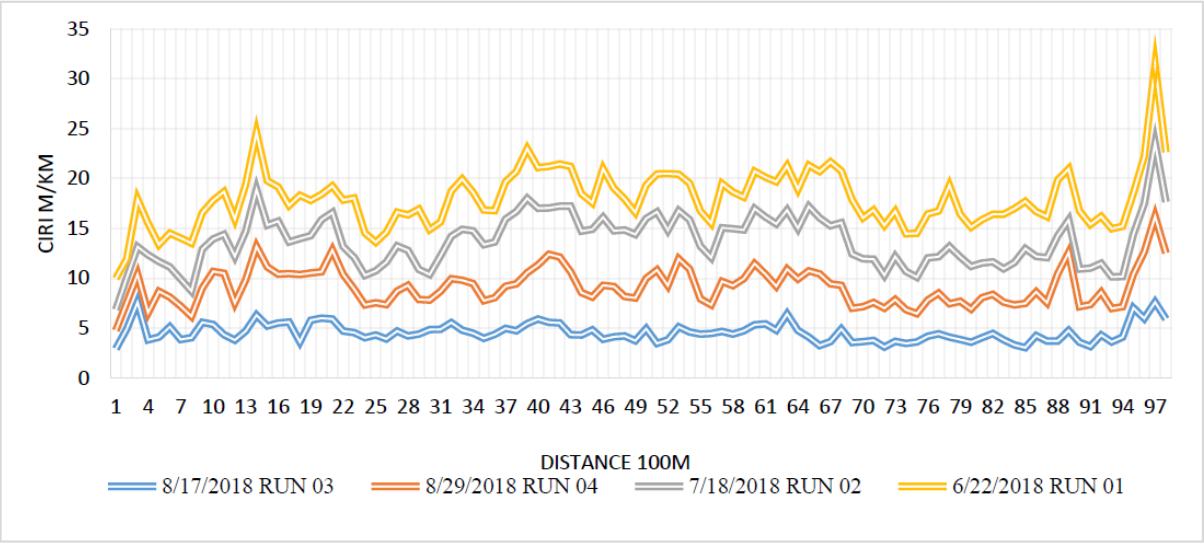


Figure 9. Presentation of Repeatability test

Runs were approximately in the same roughness range, as shown in Figure 9, despite deviations due to differences in lead in length during the start of the runs and failure to maintain constant speed throughout survey. The cost of the proposed method and Laser Profiler method (which is using by the RDA) were compared. The data collection with the Roadroid application of the 20 roads under study, was carried out with two people; the driver and the operator of the application. Within a day around IRI values of 100 km can be obtained. On the other hand, the data collection using Laser Profiler should carried out with the support of three people for the survey vehicle, and backup vehicle with a driver and an officer. It also can be covered around 100km of small road sections within one day. Table 2 shows the initial and operating cost comparisons between these two methods.

Table 2. Cost Comparison

	Smartphone Application			**Laser Profiler**
	Application	Smartphone	Vehicle	
Initial Cost (Rs.)	17,000. per unit/month	30,000.00.	5,000,000.	100,000,000 in 2010
System Operational Cost (Rs.)/km		100.		1,750.

According to Table 2, cost comparison can be shown that both categories initial and operational costs are comparatively very high in the initial laser profiler.

5. CONCLUSIONS

This paper has demonstrated a relationship between IRI values, collected by two android-based smartphone applications and IRI values obtained from Laser Profiler by RDA, as reference and analysis of the performance of Roadroid application. With the assumption that pavement roughness measurement from smartphone would be more affordable, efficient and more economical alternative for road conditioning survey.

The study was carried out to obtain data using acceleration and GPS properties of a smartphone in a passenger car vehicle type. The experiment was done on outer lane of different 20 flexible road segments in Colombo district, Sri Lanka. A total of 179.188 km has been covered in the study. The analysis was carried out to check the relationship between captured data from smartphone against referenced data obtained from Laser Profiler and to the performance was analyzed by doing a repeatability test. From the analysis it has been found that there was a linear relationship between IRI values from application and Laser Profiler. The percentage of similarity of the results of the measurement of evenness pavement roads; between two smartphone application is 97.8% similarity, was illustrated in linear regression model and it was confirmed by using z- test analysis (89.35%), and using the Roadroid application with respect to laser profiler determined a similarity of 75.4%; demonstrating that the values obtained with the Roadroid application were very close to the referenced IRI of the pavement. Repeatability was observed where the variation in IRI recordings at the same range in different speeds. It was found that estimated IRI values from application had lower value than the values from laser profiler in some roads that is because even though those particular roads were rehabilitated IRI values available from laser profiler have been captured before the rehabilitation process.

The main conclusion drawn from this study is Roadroid application can be used as an equipment that can be used to determine the surface roughness of pavements, since it provides data efficiently and with large technical benefits. Since the pavement roughness data is playing a vital role in road maintenance management, and it costs millions of rupees annually to perform road survey, it can be concluded that this simple method may be sufficient to estimate road conditions in developing country like Sri Lanka. Similarly, it was confirmed that the performance and cost are the most important benefits of the Roadroid application with respect to the laser profiler. There are still many limitations such as the accuracy of data depending on speed of the vehicle when the speed is less than 80km/h, type of the vehicle and smartphone devices.

6. RECOMMENDATIONS

As recommendations for further validation of roughness capture, since the simplicity of IRI computation process, it is recommended to use Roadroid application over the Androsensor as it is more time consuming to compute IRI with the assistance of MATLAB and ProVAL software. For measurements performed with the mobile application Roadroid is recommended to maintain speed between 60km/h - 80km/h in the manual, therefore it is recommended that data collection in time, where traffic is not intense. In the meantime it is recommended to use hypothesis testing to show similarities of collected data between two android applications in order to be more clear and intuitive than a linear model.

As this study has based on flexible pavement, the future research could be focused for different types of pavements. Also, different type of smartphones, different type of vehicles, and different lanes such as outer and inner lanes due traffic load variations could be considered to evaluate how they could influence on final outcome. A crowdsourcing feasibility study will also be considered which will lead to gather data that are more accurate. In addition we would like to expand this work towards to implement a web platform allowing motorists to upload their recorded GPS and IRI data, and to provide other effective information, like vehicle type, installation position of smartphones and type of smartphone used in order to obtain more precise IRI values with GPS locations to have a spatial distribution of IRI values. This will be a great help in road pavement management.

It is further recommended to use latest IRI values obtained by the laser profiler to analyze while continuing the investigations. As mobile technologies and sensors get more advanced, it is recommended to be used this method in the future. This way it will enable to estimate road roughness conditions cost effectively and more efficiently while acquiring reliable data to support asset management for maintenance and rehabilitation of road network.

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REFERENCES

Aleadelat, W. and Ksaibati, K. (2017) Estimation of Pavement Serviceability Index through Android-Based Smartphone Application for Local Roads. *Transportation Research Record: Journal of the Transportation Research Board,* (2639), pp.129-135.

Aleadelat,W., Ksaibati,K., Wright, C. H. G., Saha, P. (2018) Evaluation of Pavement Roughness Using an Android-Based Smartphone. *Journal of Transportation Engineering, Part B: Pavements*, 2018, 144 (3): 04018033.

American Society for Testing Materials (2012) E867 *Standard terminology relating to vehicle- pavement systems*. ASTM, Pennsylvania.

Aydin, M.M., Yildirim, M.S. and Forslof, L. (2017) September. The Use of Smart Phones to Estimate Road Roughness: A Case Study in Turkey. In International Conference on Advanced Engineering Technologies Vol. 21, p. 23.

Bidgoli, M.A., Golroo, A., Nadjar, H.S.,Rashidabad, A.G., Ganji, M.R. (2019) Road roughness measurement using a cost-effective sensor-based monitoring system. *Automation in Construction*, 104 (2019), 140–152.

Bisconsini, D.R., Núñez, J.Y.M., Nicoletti, R., Júnior, J.L.F. (2018) Pavement Roughness Evaluation with Smartphones. *International Journal of Science and Engineering Investigations*, Volume 7, Issue 72, January 2018.

Brown, D., Liu, W. & Henning, T. (2010) *Identifying pavement deterioration by enhancing the definition of road roughness December 2010*. NZ Transport Agency research report,Wellington, New Zealand, 66pp.

Douangphachanh, V. & Oneyama, H. (2013) A Study on the Use of Smartphone for Road Roughness Condition Estimation. Proceedings of the Eastern Asia Society for Transportation Studies, Vol.9, 2013.

Douangphachanh, V. & Oneyama, H. (2014) A study on the use of smartphones under realistic settings to estimate road roughness condition. *EURASIP Journal on Wireless Communications and Networking*, p. 2014:114.

Forslöf, L. & Jones, H. (2015) Roadroid: Continuous Road Condition Monitoring with Smart Phones- Paper presented at SARF/IRF 2015 Better Roads Moving Africa,CSIR conference centre Petoria,September 2-4.

Gamage, D., Pasindu, H. & Bandara, S. (2016) Pavement Roughness Evaluation Method for Low Volume Roads Paper presented at Conference: 8th International Conference on Maintenance and Rehabilitation of Pavements,Singapore.

Gillespie, T. D. (1992) Everything You Always Wanted to Know about the IRI, But Were Afraid to Ask!. Road Profile Users Group Meeting, Volume no.15, pp. 22-24.

González, A., O'Brien, E. J., Li, Y. & Cashell, K. (2008) The use of vehicle acceleration measurements to estimate road roughness. Volume 46 (6), pp. 483-499.

Gulen, S., Woods, R. and Weaver, J. (1999) Correlation of Present Serviceability Ratings with International Roughness Index. Transportation Research Board, Volume No.1435, p. 20.

Islam, S., Buttler, W. G., Aldunate, R. & Varik, W. R. (2014) Measurement of Pavement Roughness Using an Android-Based Smartphone Application. Transportation Research Board, 93rd Annual Meeting, Volume No. 2457, p. 30-38.

Jhonston, M. (2011) Using Cell-Phones to Monitor Road Roughness. Engineering Sciences (NWSAENS), 13(3): 247-257, DOI: 10.12739/NWSA.2018.13.3.1A0416 Volume 2.1, p.10.

RDA (2017) *Road Development Authority*. [Online] Available at: http://www.rda.gov.lk/source/rda_roads.htm#ClassB [Accessed 14 March 2018].

Sayers, M. W., Gillespie, T. D. & Queiroz, C. A. V. (1986) The International Road Roughness Experiment Establishing , Correlation and a Calibration Standard for Measurement. World Bank technical paper, Volume no. 45, pp. 15-85.

Sayers, M. W. & Karmihas, S. (1998) In: *The Little Book of Profiling*. s.l.:The Regent of the University of Michigan, p. 98.

Schlotjes, M. R., Visser, A. & Bennett, C. (2014) Evaluation of a Smartphone Roughness Meter. Proceedings of the 33rd Southern African Transport Conference, 2014 Pretoria, South Africa.

Zang, K. , Shen, J. , Huang, H., Wan, M., Shi, J. (2018) Assessing and Mapping of Road Surface Roughness based on GPS and Accelerometer Sensors on Bicycle-Mounted Smartphones. *Sensors* 2018, 18(3), 914.