Study of Pavement Unevenness Using Sensor-Based Smartphone Software

Mandeep Kaur Arora, Mahesh Ram Patel, and Abhyuday Titiksh

Abstract Pavement surface monitoring has been a challenging activity historically in transport infrastructure management. Many researches have proposed a solution to check and control the pavement profile automatically. Mostly heavy sensors are employed in vehicles, like bump integrator or other class-1 profilers, resulting in an expensive measure. In developing countries detection of pavement irregularities also focuses on use of Merlin Cycle. This paper is based on monitoring a specific road surface using Merlin Cycle and Android-based smartphone mounted on a motor vehicle, that is, bike at a varying condition of speed and type of bike used. The overall architecture consists of the integration of a smartphone application (ROAD-ROID), a georeferenced database system, a visualization front-end (MS EXCEL) and a regression analysis software (SPSS, i.e. Statistical Package for Social Sciences). Pavement quality is summarized through roughness parameters (i.e. estimated international roughness index (EIRI) and calculated international roughness index (CIRI)) computed using in-built accelerometer and global positioning system (GSM) technique on mobile devices. The roughness values captured were wholly transmitted in a back-end geographic information system that gave the value of road condition in terms of international roughness index (IRI). Then comparison of the two values obtained from two sources, that is, Merlin Cycle and smartphone application was done, and a correlation and regression analysis was also done using SPSS software.

Keywords Smartphone application · Software · IRI · Merlin · Motor bike · Correlation and regression

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1 Introduction

Developing countries like India have shown an enormous increase in its road network since last century. According to the data of Annual Report 2015, around 100,000 km of roads has been built in last 15 years in India. As soon as the new roads have been developing, there is a major challenge of maintaining the old roads. Moreover, the freshly laid roads are also getting patches of holes in it because of uncertain climate change, use of less durable building materials and cheap technologies for construction.

Potholes have been provably responsible for causing serious hazards and also lead to vehicular damage. Such damaged roads also lead to lowering of highest possible traffic speed causing more congestion, higher fuel consumption, and finally causing pollution. Some tests have concluded that the alteration in road roughness parameter and the fluctuating speed of the vehicle can significantly decrease heartbeat of the driver which impact driver's response significantly [1]. There is a need of characterizing roughness of the pavement profile so that a proper check of ride comfort as well as safety can be achieved.

IRI is a roughness measurement unit, represented as cumulative vertical distance travel in unit horizontal length. It stands for international roughness index, expressed in mm/km, or in./mi. It describes road roughness used for evaluation and management of road system. It is reproducible, stable, and applicable for every terrain. IRI measuring devices are categorized into following classes on the basis of its accuracy:

- Type 1 profiler—these give exact profile with high precision;
- Type 2 profiler—these are the non-biased type of profilers, e.g., Merlin;
- Type 3 profiler—these are the response-type devices with 80% accurate results, e.g., smartphone apps;
- Type 4 profiler—these are the least accurate profiler based on subjective ratings.

IRI is correlated with the following variables:

- Pavement characteristic (a statistical quantity)
- Vertical vibration (pavement quality)
- Tire load (safety and control ability) [2].

Historically, there has been various equipment and techniques for determining pavement quality. One of such equipment is a towed fifth wheel bump integrator that is very popular in developing countries like India. Its composition is same as quarter car model dynamically, where the spring system supports the upper part and the wheel helps to protect against unexpected excitations, but this is really a tedious and expensive technique and the instrument is too heavy to handle. Similarly, dipstick can be used for determining IRI and also for measuring road roughness, but cracks cannot be sensed through it. While Merlin Cycle works on the speed of a cycle towed by hand, so the data collection is again a time-taking phenomenon. Conclusion is that every profiler has its certain limitations.

One of the emerging technologies to find IRI is based on Android-based smartphone applications. Smartphones are the mobile applications equipped with the technologies like global positioning system (GPS), sensor, gyroscope, data collection and storing potentiality, image-capturing potentialities, and fast processability. These features enable it to be used as a pavement surface classification instrument. In this paper, the variation of the roughness value, that is, IRI value obtained using smartphone at a varying speed and vehicle type is being discussed and correlated. The standard value of IRI is obtained using standard profiler, that is Merlin equipment, and comparison is made.

2 Literature Review

Many research works have been done in pavement profiling since nineteenth century. Most of those techniques proved to be reliable in estimating unevenness. Some of the research works related to pavement profiling are summarized below.

2.1 Literature Review on Profiling Parameters

Michael W. Sayers, Thomas D. Gillespie, and Cesar A. V. Queiroz (1986) characterized the pavement unevenness in a universal, consistent, and relevant manner and evaluated standard indices based on the geometric characteristics, road simulation, vehicular characteristics, and spectral analysis of the roughness recorder output. Response-type pavement unevenness measurement system based on vehicle simulation was used to calibrate profile [3].

Michael W. Sayers (1998) wrote a little book of profiling for understanding and determining road profile. In this book three basic questions were answered, that is, (1) How profilers are used? (2) How it helps? (3) How we can reduce errors? He described three basic parameters of a profiler, that is, a certain elevation, a height with respect to that elevation, and a horizontal length, where rod and level were defined as static profiler and dipstick as a dynamic profiler. He proposed the use of power spectral density (PSD) function as a high-speed profiling system, which is based on the classification of voltage, and applied the same mathematical function for profile measurement. He also elaborated that longitudinal acceleration and vertical vibration experienced by the rider while moving in a high seat vehicle like truck is higher than that experienced by the rider of a passenger car due to road roughness leading to a situation of discomfort.

Peter Mucka and Johan Granlund (2012) dealt with estimating the effect of the contents of the wavelength on IRI. It was found that the IRI corresponding to a velocity of 20 kmph is twice sensitive to velocity of 80 kmph for a local obstacle [4].

Peter Mucka (2016) proposed velocity-related IRI limit curves. He observed the large range of RMS values on the basis of vibrational response corresponding to an IRI value and quantified comfort level and safety of the ride along with the dynamic pressure [5].

2.2 Literature Review on Different Profiling Techniques

M. A. Cundill (1991) devised a simple low-cost pavement roughness data measuring machine, that is, MERLIN, which stands for a machine for evaluating roughness using low-cost instrumentation. This device has been well correlated with the pavement roughness data measuring machine known as bump integrator. Also the roughness output obtained is correlated to get the roughness value in terms of IRI (m/km).

Oldrich Kropac and Peter Mucka (2009) proposed an indicator defining about the pavement unevenness on the basis of the response of the vehicle on vertical vibration caused by the waviness of the pavement profile. Also they proposed modified IRI values which are affected by speed, and assessment of subjective rating methods [6].

Manish Paul and Rumi Sutradhar (2014) derived a generalized equation to get the values of IRI using bump integrator at any speed corresponding to 32 kmph speed by using SPSS software [7].

$$(\mathrm{BI})_{32} = 0.956(\mathrm{BI})V + 0.842V - 25.544 \left(R^2 = 0.958\right) \tag{1}$$

Marwan Hafez, Khaled Ksaibati, and Richard Anderson-Sprecher (2016) used statistical technique and old PMS data and then developed uni-variable regression multiple accusation. It was concluded that by the use of historical data, a good estimation of pavement data can be obtained [8].

2.3 Literature Review on Smartphone-Based Profiling Technology

Kasun De Zoysa, Kasun Chamath, Keppitiyagama chamath (2007) designed a road surface observing system which worked on a sensor-based network Bus Net. Bus Net is an ideal approach to monitor data network using a public transport because public transport uses the road that we want to monitor and the most economical attempt for monitoring road condition [9].

Shahidul Islam, William G. Buttlar, Roberto G. Aldunate, and William R. Vavrik (2014) collected IRI values at two test sites using smartphone technology and validated those values with the help of values of standard inertial profiler. They found that in 37 out of 40 tests, values were within 15% of the standard results. A linear correlation can bring the close result which can be implemented, if required [10].

Trevor Hanson, Coady Cameron, and Eric Hildebrand (2014) calculated IRI values from different smartphones to compare the value of IRI by varying type of device, vehicular speed, type of vehicle, and also mounting arrangement with respect to a class-1 profiler.

They concluded that significant factor causing variation in IRI values are type of smartphone used, mounting arrangement, and type of vehicle [11].

Rajiv Kumar, Abhijit Mukherjee, and V.P. Singh (2016) performed crowd sourcing, that is, distributed smartphones to the people for gathering road roughness parameter; used a fuzzy system and characterized the roughness parameter; presented road surface condition on web mapping service platform by different patterns of surface classes; and the roads were monitored visually for justification of the smartphone technology [12].

3 Objective and Scope

It is already concluded above that the emerging smartphone technologies determine pavement profile in a very short time. So, the objective of this paper was to detect pavement unevenness of a certain test section using smartphone application and correlating the obtained IRI values with the most reliable value of IRI obtained using a standard equipment at the same section. The smartphone values were determined at a varying condition of speed and type of bike used to understand the variation in IRI values with the respective variations. The standard equipment used was a type-2 profiler, that is, Merlin Cycle.

4 Methodology

In this paper, before performing any experiment, some basic components of the experiment need to be understood well. Following are the basic requirements:

4.1 System Architecture

System of pavement roughness data analysis consists of the following parameters:

Smartphone: Smartphone embedded with Android OS > 5.0 is to be taken, so in this paper MOTO G^5 Android version 8.1.0 had been taken as a smartphone platform.

Smartphone Application: ROADROID mobile application as shown in Fig. 1 installed in smartphone with the following features in it:

- Analyze vehicle vibration in 100–200 Hz

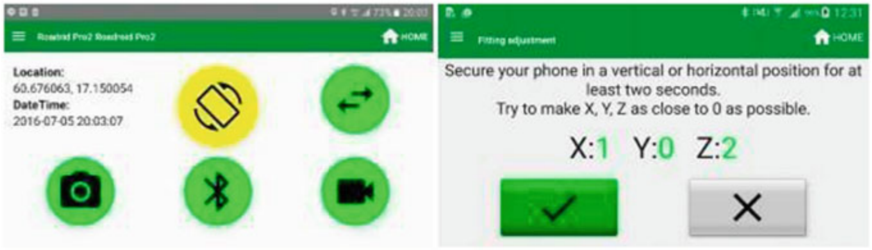


Fig. 1 ROADROID application installed in smartphone

- Calculate two IRI values, that is, calculated IRI (CIRI) and estimated IRI (EIRI) and GPS
- Sensitivity and segment length adjustment
- Degree of accuracy 80% of type-1 IRI measuring equipment
- ROADROID is a type-3 IRI measurement equipment, that is, a response-type survey system
- EIRI value is calculated from quarter car formula
- CIRI value uses a smothering filter, hence reported as the required IRI [13].

Vehicle: In this study, two motor bikes have been selected for performing experimental study. One of them is shown in Fig. 2 (Table 1).

Survey Speed: A constant speed needs to be maintained as the speed considerably affects the vertical vibration. In this paper, two speeds were maintained and values had been recorded in 25 and 30 kmph speed.

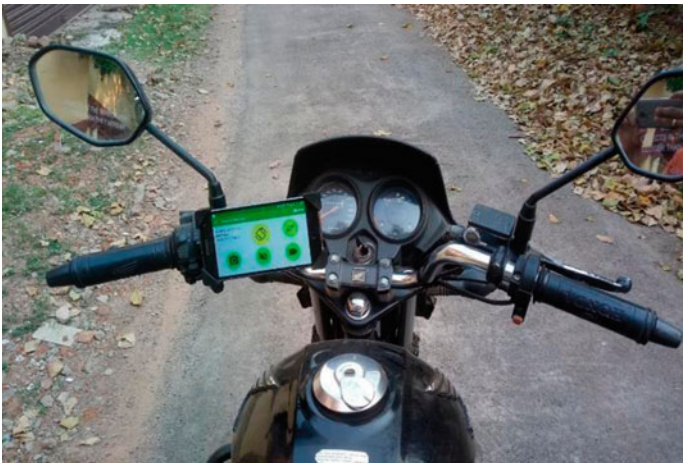


Fig. 2 Image of the smartphone mounted on bike

Table 1 Profile of test vehicle

S. no.	Vehicle type	Engine type	Chassis type	Front-suspension	Rear-suspension
(1)	Honda LIVO	110 cm^3	Diamond	Telescopic fork	Spring loaded hydraulic type
(2)	Honda CB Shine	125 cm^3	Diamond	Telescopic fork	Spring loaded hydraulic type

Test Section: Since Merlin equipment was available in NIT Raipur campus; therefore, a 400 m test section was taken from NIT Raipur campus, as shown in Fig. 3.

Software: Using SPSS software, data obtained from experimental results are represented graphically and a correlation between different observations is made. A snapshot is shown in Fig. 4 [14].

Mounting Arrangement: A stable mount is necessary to get an accurate profile and vertical vibrations.

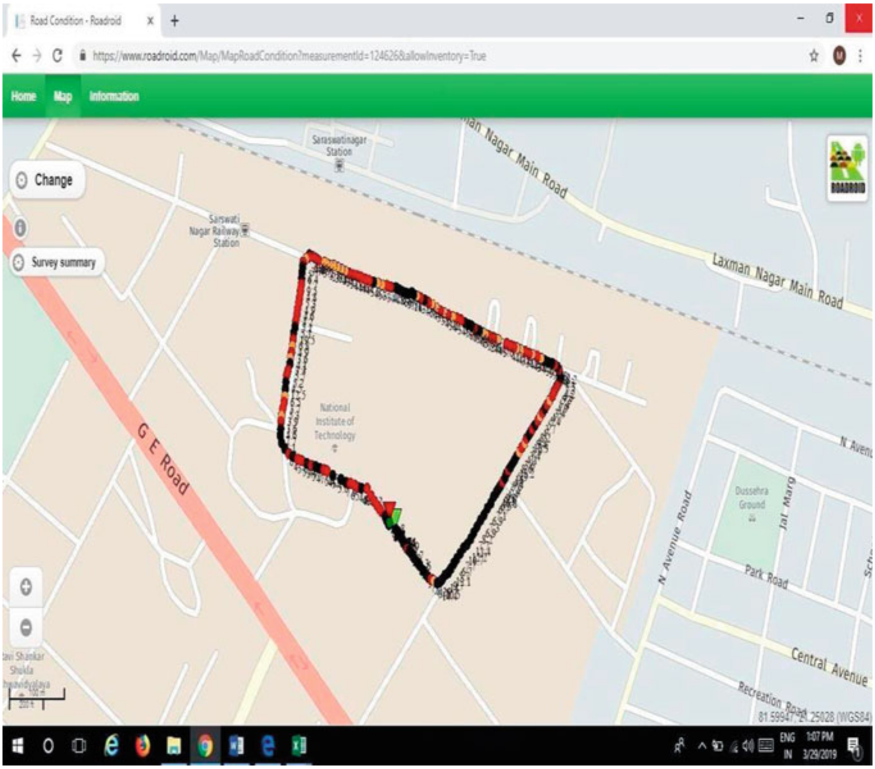
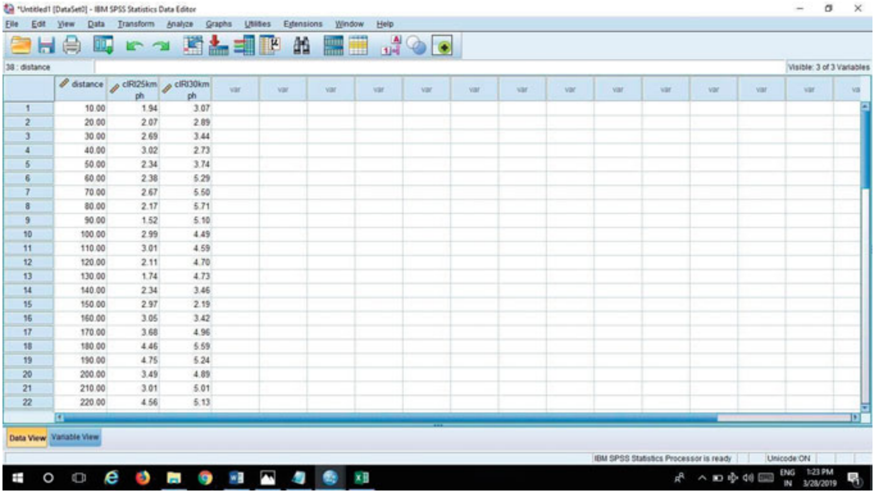


Fig. 3 Test section snapshot taken by using Google Map

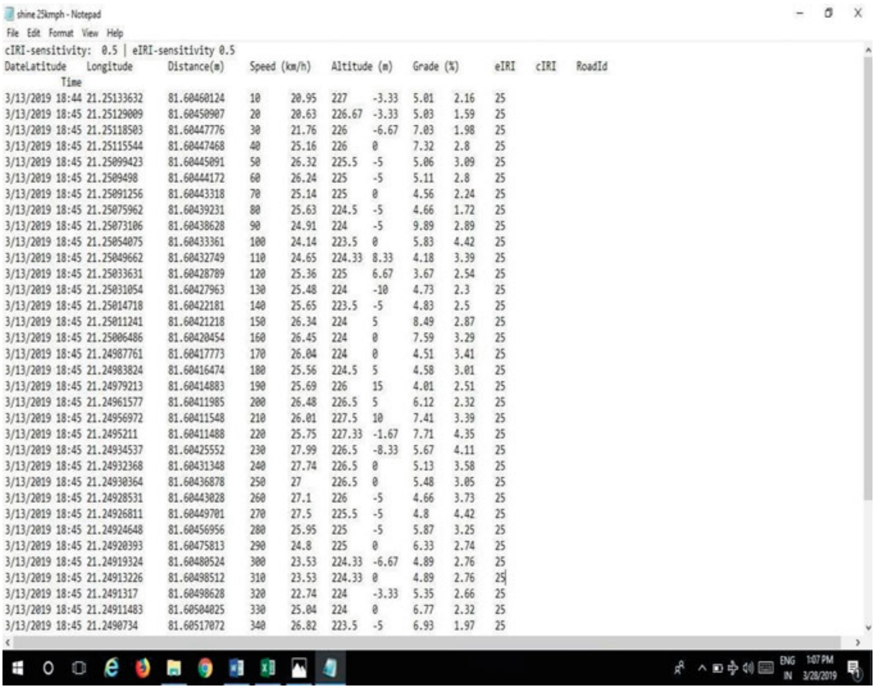


	distance	cIRI25kmph	cIRI30kmph
1	10.00	1.94	3.07
2	20.00	2.07	2.89
3	30.00	2.69	3.44
4	40.00	3.02	2.73
5	50.00	2.34	3.74
6	60.00	2.38	5.29
7	70.00	2.67	5.50
8	80.00	2.17	5.71
9	90.00	1.52	5.10
10	100.00	2.99	4.49
11	110.00	3.01	4.59
12	120.00	2.11	4.70
13	130.00	1.74	4.73
14	140.00	2.34	3.46
15	150.00	2.97	2.19
16	160.00	3.05	3.42
17	170.00	3.68	4.96
18	180.00	4.46	5.59
19	190.00	4.75	5.24
20	200.00	3.49	4.89
21	210.00	3.01	5.01
22	220.00	4.56	5.13

Fig. 4 Data view in SPSS software (snapshot)

Merlin Equipment: It is a class-2 profiler which gives accurate IRI value. MERLIN stands for machine for evaluating roughness using low-cost instrumentation. It consists of a graph paper in which displacements are plotted as a histogram. A working equipment has been shown in Fig. 5. In this equipment, the probe is connected to an arm such that it is moving close to the probe. To the next side of the arm, a pointer is attached such that 1 mm movement of the probe moves the pointer by 1 cm over the prepared data chart. The chart consists of column divided into 5 mm boxes [15].

Fig. 5 Merlin equipment while working (author Mandeep Kaur Arora along with co-author Mahesh Ram Patel recording data)



cIRI-sensitivity: 0.5 | eIRI-sensitivity 0.5

Date Time	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	Grade (%)	eIRI	cIRI	RoadId
3/13/2019 18:44	21.25133632	81.60460124	10	20.95	227	-3.33	5.01	2.16	25
3/13/2019 18:45	21.25129009	81.60450907	20	20.63	226.67	-3.33	5.03	1.59	25
3/13/2019 18:45	21.25118503	81.60447776	30	21.76	226	-6.67	7.03	1.98	25
3/13/2019 18:45	21.25115544	81.60447468	40	25.16	226	0	7.32	2.8	25
3/13/2019 18:45	21.25099423	81.60445091	50	26.32	225.5	-5	5.06	3.09	25
3/13/2019 18:45	21.2509498	81.60444172	60	26.24	225	-5	5.11	2.8	25
3/13/2019 18:45	21.25091256	81.60443318	70	25.14	225	0	4.56	2.24	25
3/13/2019 18:45	21.25075962	81.60439231	80	25.63	224.5	-5	4.66	1.72	25
3/13/2019 18:45	21.25073106	81.60438628	90	24.91	224	-5	9.89	2.89	25
3/13/2019 18:45	21.25054075	81.60433361	100	24.14	223.5	0	5.83	4.42	25
3/13/2019 18:45	21.25049662	81.60432749	110	24.65	224.33	8.33	4.18	3.39	25
3/13/2019 18:45	21.25033631	81.60428789	120	25.36	225	6.67	3.67	2.54	25
3/13/2019 18:45	21.25031054	81.60427963	130	25.48	224	-10	4.73	2.3	25
3/13/2019 18:45	21.25014718	81.60422181	140	25.65	223.5	-5	4.83	2.5	25
3/13/2019 18:45	21.25011241	81.60421218	150	26.34	224	5	8.49	2.87	25
3/13/2019 18:45	21.25006486	81.60420454	160	26.45	224	0	7.59	3.29	25
3/13/2019 18:45	21.24987761	81.60417773	170	26.04	224	0	4.51	3.41	25
3/13/2019 18:45	21.24983824	81.60416474	180	25.56	224.5	5	4.58	3.01	25
3/13/2019 18:45	21.24979213	81.60414883	190	25.69	226	15	4.01	2.51	25
3/13/2019 18:45	21.24961577	81.60411985	200	26.48	226.5	5	6.12	2.32	25
3/13/2019 18:45	21.24956972	81.60411548	210	26.01	227.5	10	7.41	3.39	25
3/13/2019 18:45	21.2495211	81.60411488	220	25.75	227.33	-1.67	7.71	4.35	25
3/13/2019 18:45	21.24934537	81.60425552	230	27.99	226.5	-8.33	5.67	4.11	25
3/13/2019 18:45	21.24932368	81.60431348	240	27.74	226.5	0	5.13	3.58	25
3/13/2019 18:45	21.24930364	81.60436878	250	27	226.5	0	5.48	3.05	25
3/13/2019 18:45	21.24928531	81.60443028	260	27.1	226	-5	4.66	3.73	25
3/13/2019 18:45	21.24926811	81.60449701	270	27.5	225.5	-5	4.8	4.42	25
3/13/2019 18:45	21.24924648	81.60456956	280	25.95	225	-5	5.87	3.25	25
3/13/2019 18:45	21.24920393	81.60475813	290	24.8	225	0	6.33	2.74	25
3/13/2019 18:45	21.24919324	81.60480524	300	23.53	224.33	-6.67	4.89	2.76	25
3/13/2019 18:45	21.24913226	81.60498512	310	23.53	224.33	0	4.89	2.76	25
3/13/2019 18:45	21.2491317	81.60498628	320	22.74	224	-3.33	5.35	2.66	25
3/13/2019 18:45	21.24911483	81.60504025	330	25.04	224	0	6.77	2.32	25
3/13/2019 18:45	21.2490734	81.60517072	340	26.82	223.5	-5	6.93	1.97	25

Fig. 6 A snapshot of downloaded aggregated file (obtained through smartphone application)

4.2 *Data Collection*

Using Smartphone App: This was the first step of pavement roughness measurement in this paper. As shown in Fig. 2, the smartphone, that is MOTO G[5], was stably mount in the handle of the bike. Such a fixing was done so that there was no self-movement of the smartphone. Bike was ridden at a constant speed and the recording of the values was carried out in smartphone app simultaneously. In this experiment two values of speed, that is 25 and 30 kmph, were taken for recording values. Recording was done in both of the bikes separately, one at a time. Specifications related to application, smartphone, and motor bike are already mentioned in the above section. Finally, the readings were uploaded from the application which was opened further by logging in ROADROID website for getting the readings in terms of IRI.

Using MERLIN Equipment: To measure roughness of road using MERLIN equipment, 200 observations were made. Each observation was taken by resting the machine on road when the wheel was in stable position and the probe, stabilizer, and back end foot in contact with the pavement. Then the pointer was recorded in the graph and a tally box with a cross-sign in the respective column is shown in Fig. 7, to keep an observation of the records. Then the handle was elevated such that the wheel

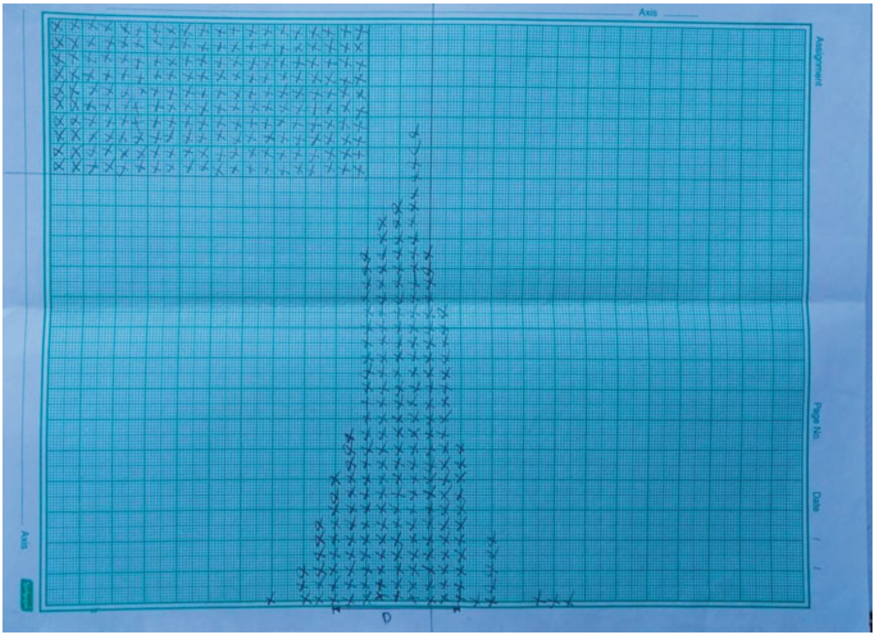


Fig. 7 Chart obtained from Merlin equipment

was only in contact with the pavement surface and then was taken ahead for the next normal position and the same procedure was repeated. After 200 observations were made, chart was removed from the MERLIN.

4.3 Data Analysis

Smartphone Data: The downloaded data are available in .txt format, as shown in Fig. 6. The readings corresponding to CIRI were exported to SPSS software and average IRI was calculated and also a graphical representation of the roughness was plotted as shown in Fig. 9. Further, there was also a correlation and regression analysis made between two values of IRI corresponding to 25 and 30 kmph speed, using SPSS software.

MERLIN Data: The chart obtained after the experiment was observed and the position from the both sides of the chart after 10th cross was marked. The distance between the two cross was measured in mm and calculated as D mm, that is, 45 mm in this experiment. This value was the roughness in terms of MERLIN scale. Then pavement unevenness in terms of IRI was obtained with the help of this relation

$$\text{IRI} = 0.593 + 0.0471D \tag{2}$$

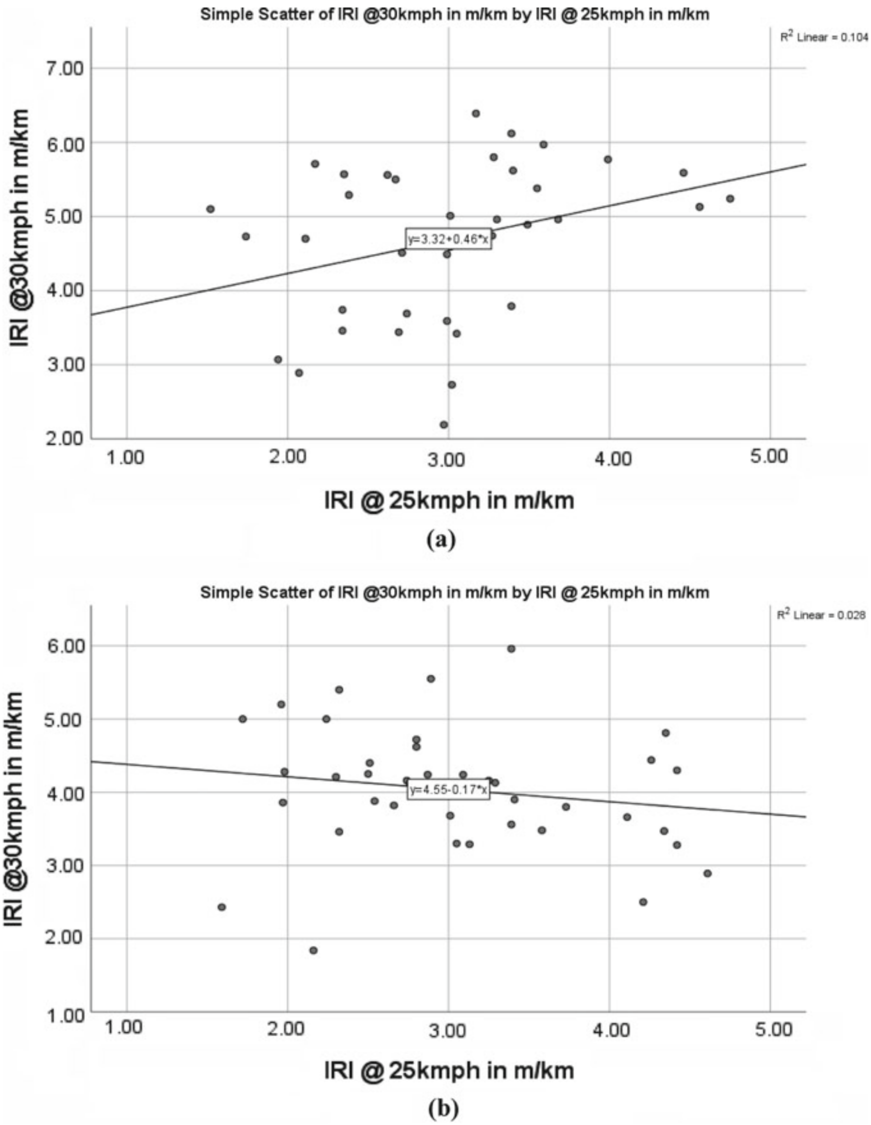
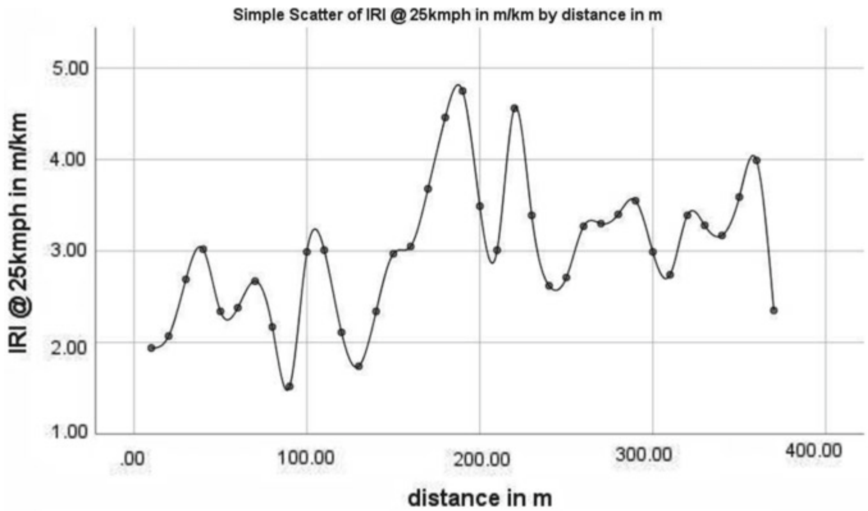
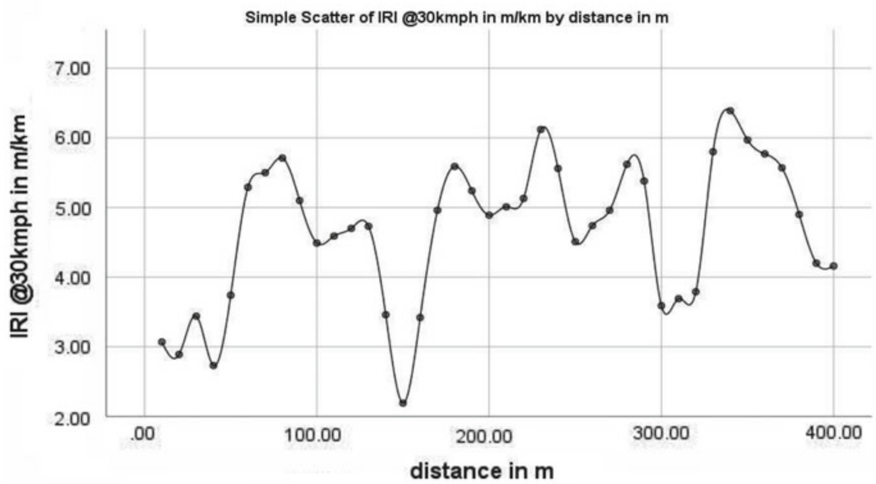


Fig. 8 **a** Correlation in IRI values in Honda LIVO. **b** Correlation in Honda CB Shine

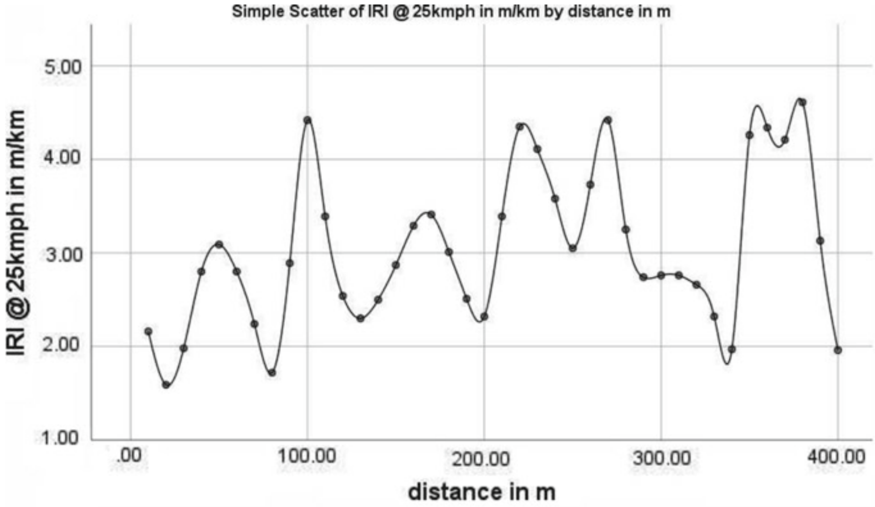


(a)

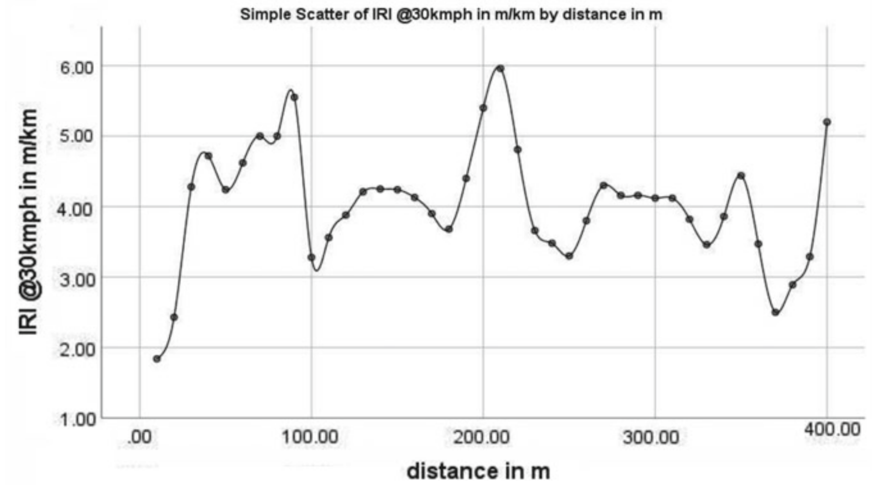


(b)

Fig. 9 **a** IRI versus distance @25 kmph speed in Honda LIVO. **b** IRI versus distance @30 kmph speed in Honda LIVO. **c** IRI versus distance @25 kmph speed in Honda CB Shine. **d** IRI versus distance @30 kmph in Honda CB Shine



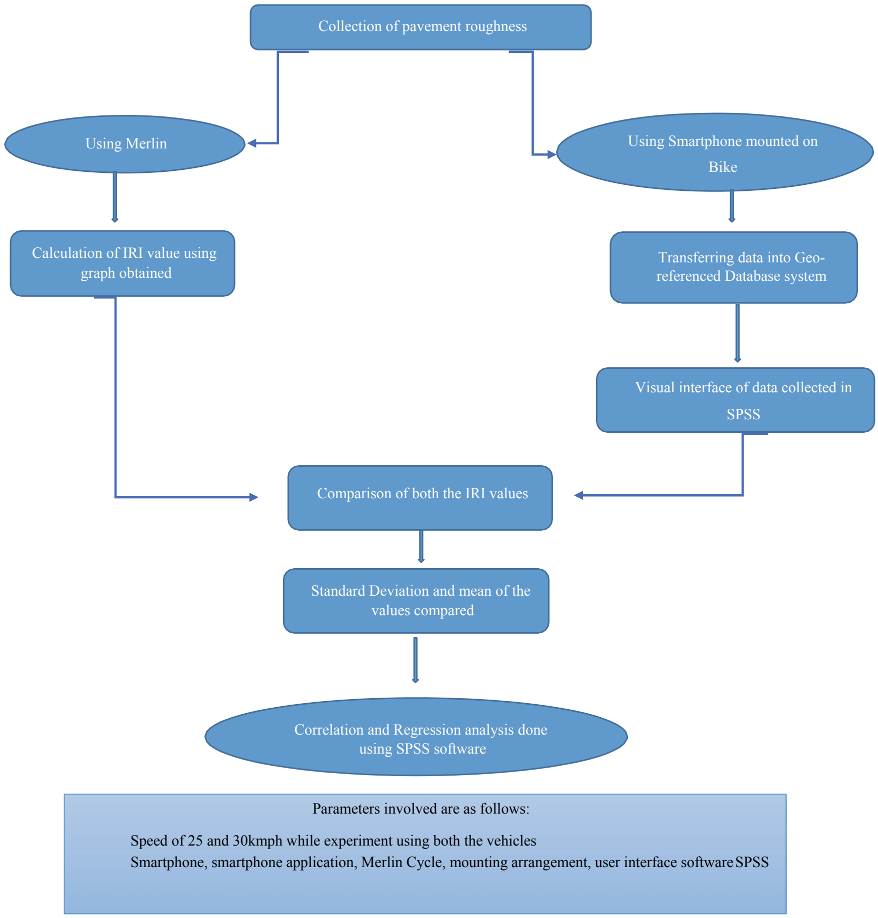
(c)



(d)

Fig. 9 (continued)

5 Flow Chart



6 Results and Discussion

6.1 Merlin

The standard value of IRI obtained from Merlin equipment was 2.7125 m/km.

Table 2 Variation in IRI value by varying speed and vehicle type

S. no.	Device type	Vehicle type	Speed in km/h	Average IRI in m/km	Number of observations in 400 m length	% Difference from Profiler
(1)	Moto G^5	Honda LIVO	25	2.9330	40	8.129
(2)	Moto G^5	Honda LIVO	30	4.6647	40	71.970
(3)	Moto G^5	Honda CB Shine	25	3.0032	40	10.717
(4)	Moto G^5	Honda CB Shine	30	4.0352	40	48.763

6.2 Smartphone and Software

The test results demonstrate that there is a significant variation in average IRI value obtained when the speed is increased. Following are the results corresponding to both the bikes:

Honda LIVO: In this bike, the value of IRI obtained @25 kmph speed was 2.9330 m/km, which was close to the standard value, that is, within 10% of the standard value. However, the values @30 kmph speed was 4.6647 m/km, which was highly deviated from the standard IRI, that is, differ by 71.97% from standard IRI.

Honda CB Shine: In this bike, the value of IRI obtained @25 kmph speed was 3.0032 m/km, which was again close to the standard value, that is, within 10% of the standard value. However, the values @30 kmph speed was 4.0352 m/km, which was once again highly deviated from the standard IRI, that is, differ by 48.763% from standard IRI.

This can be seen that the variation in vehicle type does not significantly impact because the suspension type and chassis type are almost similar in both the cases. Only variation is in engine of the vehicle, which is not causing large variation in values (Table 2).

6.3 Correlation and Regression Analysis

Using SPSS software, there was a correlation and regression analysis established between IRI values obtained @25 kmph values with that of 30 kmph values, such that 25 kmph values were the independent variable x and 30 kmph values were dependent variable y. Positive value of correlation represented in Table 3 of Honda LIVO bike represents an increase in difference of IRI value with increase in speed.

Standard deviation is 0.986. The required relation is

Table 3 Correlation in IRI values @25 and 30 kmph speed obtained from Honda LIVO

		Correlations	
		IRI @30 kmph in m/km	IRI @25 kmph in m/km
Pearson correlation	IRI @30 kmph in m/km	1.000	0.322
	IRI @25 kmph in m/km	0.322	1.000
Sig. (1-tailed)	IRI @30 kmph in m/km	–	0.026
	IRI @25 kmph in m/km	0.26	–
N	IRI @30 kmph in m/km	37	37
	IRI @25 kmph in m/km	37	37

$$y = 3.32 + 0.46x \tag{3}$$

However, a negative correlation shown in Table 4 was found in Honda CB Shine values, which represents that on increasing value of speed in this bike, the difference in IRI value decreases. Standard deviation is 0.987. The required relation is

$$y = 4.55 - 0.17x \tag{4}$$

Figure 8 shows the correlation in both the vehicles. Figure 10 shows the histogram. Figure 11 shows the normal *P*–*P* plot of regression standardized residual.

Table 4 Correlation in IRI values @25 and 30 kmph speed obtained from Honda CB Shine

		Correlations	
		IRI @30 kmph in m/km	IRI @25 kmph in m/km
Pearson correlation	IRI @30 kmph in m/km	1.000	−0.167
	IRI @25 kmph in m/km	−0.167	1.000
Sig. (1-tailed)	IRI @30 kmph in m/km	–	0.151
	IRI @25 kmph in m/km	0.151	–
N	IRI @30 kmph in m/km	40	40
	IRI @25 kmph in m/km	40	40

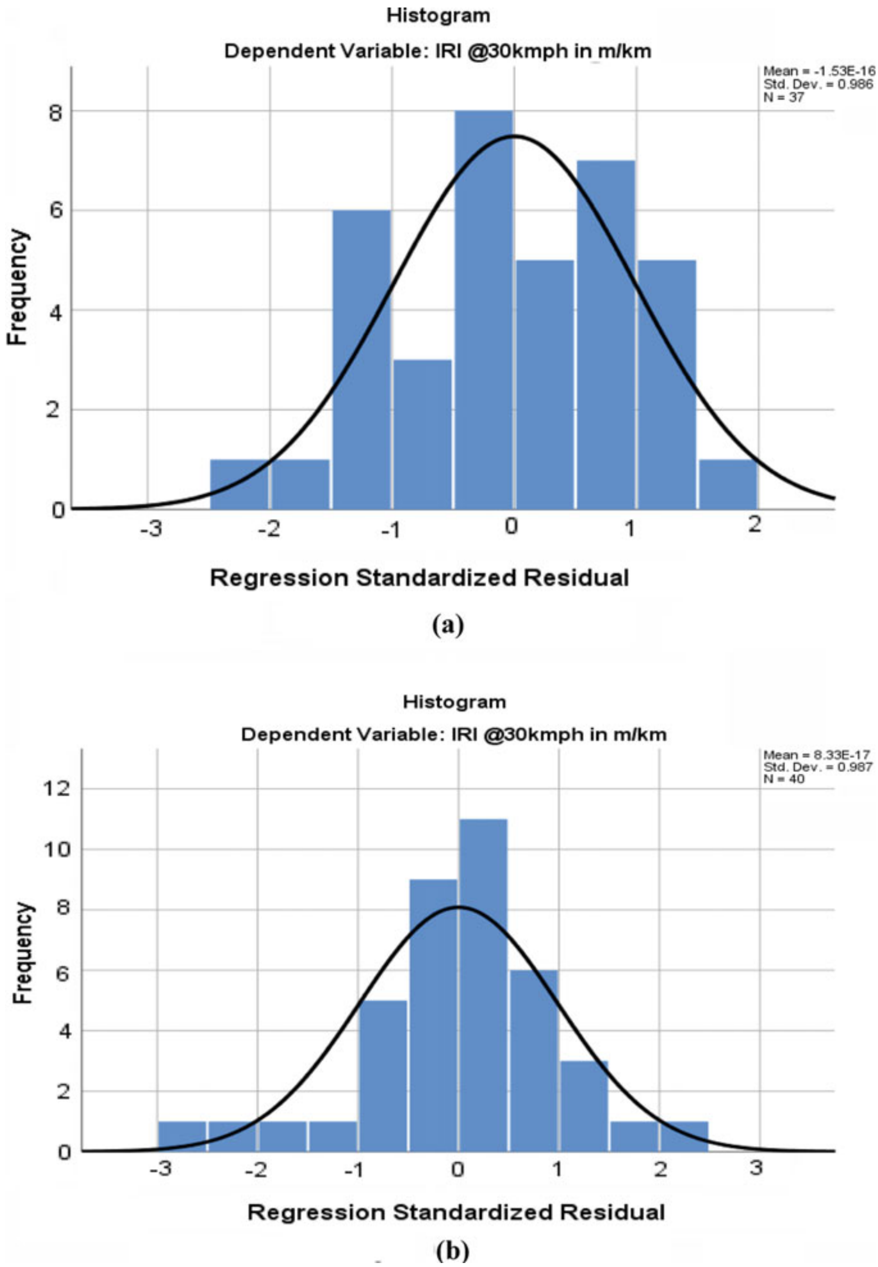
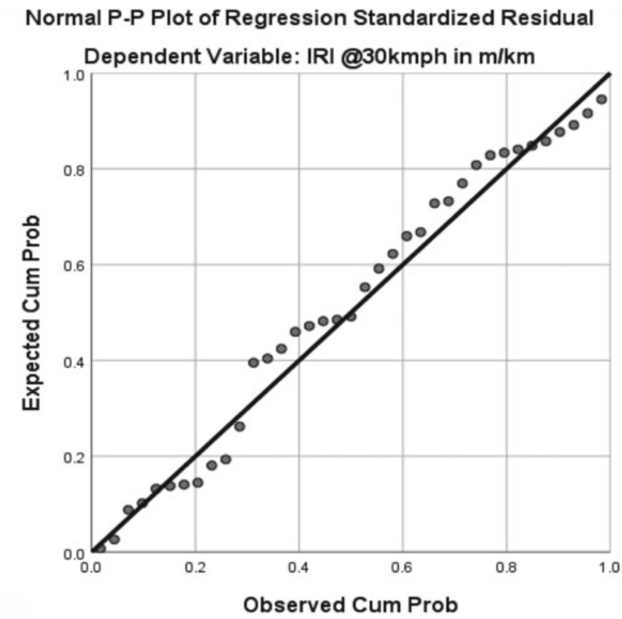
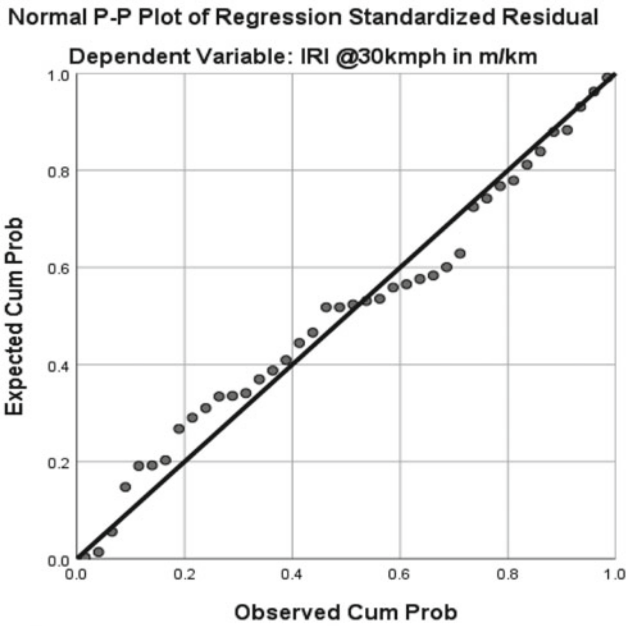


Fig. 10 **a** Histogram in Honda LIVO. **b** Histogram in Honda CB Shine



(a)



(b)

Fig. 11 **a** Normal *P–P* plot of regression standardized residual in Honda LIVO. **b** Normal *P–P* plot of regression standardized residual in Honda LIVO

7 Conclusion

This paper demonstrated the capability of a smartphone to measure pavement profile with the help of its in-built feature accelerometer. Use of a smartphone app, that is ROADROID, visual interface system, that is MS Excel, correlation and regression analysis software, that is SPSS, has enabled accelerometer feature of a smartphone to give a comparable pavement surface unevenness measurement. In this paper, two motor bikes, Honda CB Shine and Honda LIVO, were used with a suitable mount fixed in it to give a platform to smartphone, that is, Moto G^5 for measuring values of IRI in a 400 m stretch of road. The values were recorded at a varying speed of 25 and 30 kmph in both the motor bikes. For the validation of obtained results, a standard profiler, that is Merlin Equipment, was used to record the pavement unevenness value in terms of IRI. IRI value obtained through Merlin equipment was 2.7125 m/km. IRI value obtained through smartphone was within 10% of this value when measurement was made @25 kmph, whereas measurement made @30 kmph gave a significant difference in IRI value, that is about 48 and 72%, respectively, in both the vehicles. A comparison of these values yielded the following conclusion:

- It has been assured that the pavement profile is easily obtainable with the help of smartphone equipped accelerometer technique.
- Higher value of speed gives higher value of IRI, because of higher vertical vibration
- Varying motor vehicle of same kind does not significantly cause the variation in IRI, if the suspension system is not varying
- In Honda LIVO bike, with increase in speed, difference in IRI value also increases.
- However, in Honda CB Shine with increase in speed, difference in IRI value decreases.
- More accurate profile of pavement is obtained @25 kmph speed
- IRI value obtained @ 30 kmph speed in Honda LIVO can be approximated to IRI value of 25 kmph by using relation $y = 3.32 + 0.46x$
- IRI value obtained @ 30 kmph speed in Honda CB Shine can be approximated to IRI value of 25 kmph by using relation $y = 4.55 - 0.17x$
- IRI value obtained from smartphone app is generally higher than the standard equipment because of the engine vibration of vehicle.

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Future Scope Further investigations can be made to get the effect of varying suspension type of the vehicles, mounting arrangement, pavement surface type, and so on, on the IRI values.

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