Evaluation of Flexible Pavement Profile Using Developed Profilometer

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Abstract: One of the important parameters to determine the maintenance and rehabilitation needs for road networks is surface unevenness of the pavement. Currently, road agencies use equipment which has high initial cost in order to find roughness condition which leads to more survey cost and labor. Apart from that most of the road agencies, especially for local government, frequently examine the pavement condition through visual inspections. This study involves the development of a profilometer to make data collection and real time monitoring of the pavement unevenness more effectively and economically.

The measurements of the unevenness in the modified profilometer can be directly converted to the standard unevenness unit such as the International Roughness Index (IRI). It displays the unevenness information on an onboard computer simultaneously in real time. The paper also shows the profile measurement experiments in order to verify the accuracy of the developed profilometer for unevenness data collection and enlighten its benefits in monitoring of the local roads. Current profilometer measures longitudinal surface profile of the road while developed profilometer will measure longitudinal as well as lateral profile of the road simultaneously.

***Index Terms*- International Roughness Index (IRI), Lateral profile, Longitudinal surface profile, Profilometer, Unevenness.**

I. INTRODUCTION

India has one of the massive road networks across the world, with 5.5 million km of total length. Around 64.5 % of goods traffic and 90 % of passenger traffic are being commuted by road. In India, rural roads constitute around 70.23 % of the total road. Quality of numerous rural roads are poor and it cannot withstand the heavy farm equipment loads. Connectivity of these roads with good quality two lane and four lane highways are also not good which makes the flow of economic resources slow. Hence, Scientific management tools are essential for efficient management of these roads. Right preservative treatment is to be given to the appropriate place at the appropriate time.

Designing of the roads are done for a finite life which can be described as the traffic that road can carry with reference to the cumulative number of equivalent standard axles. Rehabilitation of the road becomes necessary when this design traffic has been conveyed, or due to premature distress triggered by some environmental influence. It is essential to evaluate and fully assess the pavement condition and cause of distress before adapting any rehabilitation design. Detailed investigation of the road generally requires great amount of time as well as financial resources hence, it is essential to collect appropriate information in a systematic and complete manner.

Smoothness, or roughness of road, is very important road functional characteristics because it affects vehicle dynamic load and quality of ride. It also affects vehicle operating costs, such as wear of tyre, fuel consumption and vehicle durability. Hence, it is a common task of highway state agencies to entrench evaluation and measurement methods of road smoothness. There are several approaches available to evaluate smoothness of road, mostly compute the perpendicular variation of the road surface along a longitudinal line of travel in a wheel path, which can be stated as the profile.

In the early 1900s, straight edge devices were used for profile measurement of road. Over the passes of time these devices are advanced to vehicles which can evaluate the profile while running at normal traffic speed. longitudinal profiles are measured using this equipment, that shows vertical elevation as a part of longitudinal distance along a directed path. For roughness measurement, International Roughness Index (IRI) is commonly used in the USA. Since 1990. The American Society of Testing and Materials (ASTM) standard E-1926 states the standard procedure for finding IRI from longitudinal profile measurements.

A levelled surface is always desirable, but it is rarely possible to have such a one. Although we construct the road with high quality paver, there is still a chance of development of unevenness because of pavement failure. Riding comfort, fuel consumption, speed, vehicle operating cost, safety and tires quality are affected by unevenness.

Basically, unevenness (Fig.1) of the pavement is divided into two groups:

i. Longitudinal unevenness (roughness)
ii. Transversal unevenness (rutting)

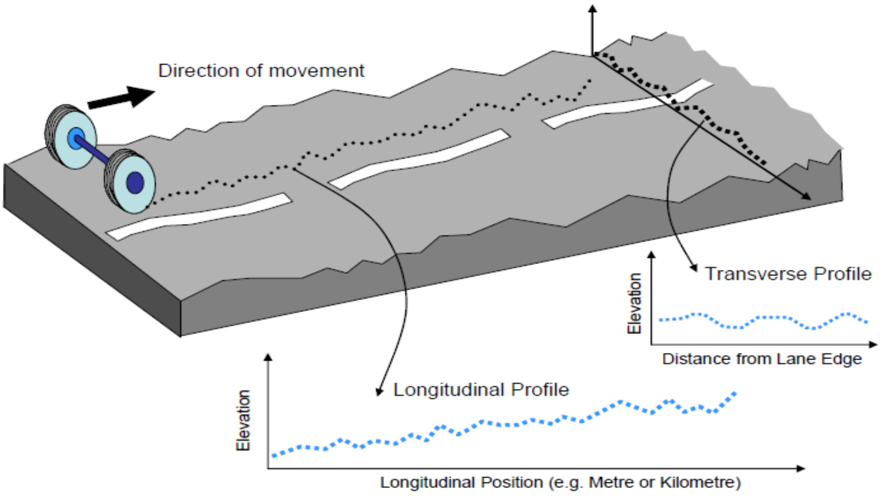

Figure 1: Unevenness of the pavement

1.1 PROFILOMETER

Road pavement Profilometer holds a distance computing laser along with an odometer and an inertial unit that institutes a moving reference plane which amalgamates the laser distances. Profile data is mostly independent of the speed of Profilometer vehicle due to the inertial compensation along with an assumption that vehicle does not make substantial variations in speed and remained above 25 km/h. The Profilometer system fetches data at usual highway speeds, evaluating the surface elevations at 2–15 cm (1–6 in) intervals. System needs a high-speed data gathering system capable of taking measurements in the kilohertz range.

International Roughness Index (IRI) is calculated from the data collected by a Profilometer and shows in units of inches/mile or mm/m. Range of the IRI values are from 0 (matches to running on a glass plate) to several hundred in/mi (a very bumpy road). To supervise road safety and quality issues, IRI value is mainly used for road management.

There are two categories of equipment available for measuring unevenness: -

i. Contact type roughness measuring unit,
ii. Non-contact type roughness measuring unit.

Non-contact type roughness measuring units are less time consuming as well as more accurate than contact type roughness measuring unit. Table 1 shows the different classes of the roughness measuring equipment based on their accuracy.

Table 1: Example of Roughness Measuring Equipment [4]

Class	Equipment
Class I Precision profiles	Laser Profiles: TRL beam, Face Dipstick/ROMDAS Z-250, ARRB Walking Profiler
Class II Other Profilometer Methods	APL Profilometer, Profilographs (e.g. California, Rainhart), Optical Profilers, and Inertial Profilers
Class III IRI Estimates from Correlation Equation	Roadmaster, Roughometer, Bump Integrator, Rolling Straightedge
Class IV Subjective Ratings/ Uncalibrated Measures	Key Code Rating System, Visual Inspection, Ride Over Section

1.2 INTERNATIONAL ROUGHNESS INDEX

An experiment to measure the International Road Roughness was performed in Brazil (1982), which was aimed to formulate an International roughness index (IRI) for data exchange and to bring out guidelines for evaluating roughness on a conventional scale. The earliest globally accepted profile index was IRI in which the analysis method is focused to work with dissimilar kind of profiles. IRI is capable of being reproduced and steady with time. Development of the IRI was intended to test the reaction of passenger cars however, following testing has unveiled that IRI coordinates well with other vehicles such as heavy commercial trucks and light trucks. IRI is greatly connected to three vehicle response variables;

i. Road meter response,
ii. Vertical passenger acceleration
iii. Tyre load.

Based on the Roughness values in terms of IRI, conditions of the road surface are given in IRC: SP:16-2004, “Guidelines for The Surface Unevenness of Highway Pavements”. Table 2 shows the road surface condition based on the roughness values mentioned in IRC: SP16-2004.

Table 2: Maximum Permissible Values of Roughness (mm/km) for Road

Types of Surface	Condition of Road Surface		
	Good	Average	Poor
Surface Dressing	<3500	3500-4500	>4500
Open Graded Premix Carpet	<3000	3000-4000	>4000
Mix Seal Surfacing	<3000	3000-4000	>4000
Semi Dense Bituminous Course	<2500	2500-3500	>3500
Bituminous Concrete	<2000	2000-3000	>3000
Cement Concrete	<2200	2200-3000	>3000

The IRI is a mathematical model applied to a measured profile. This model replicates a quarter car systems (QCS) running at a constant velocity of 80 kmph. The IRI is the ratio of cumulative motion of suspension of QCS to the covered distance and expressed in m/km or inch/mile. Fig.3 shows the QCS model.

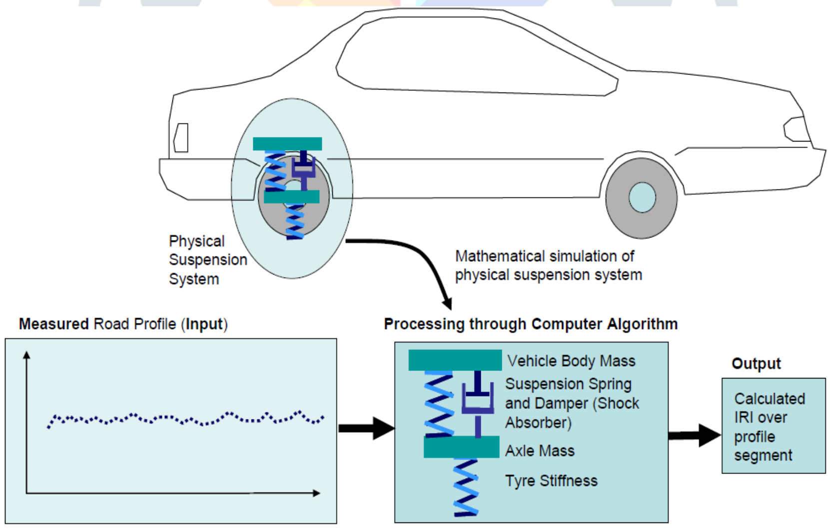

Figure 2: Quarter Car System Model

II. LITERATURE REVIEW

Akira Kawamura et.al. (2016) [6] the study focused on the development of a method which provided the basic information about IRI and pavement roughness on urban roads, which might serve and enhance the application of Pavement Management System (PMS) in municipalities. The aims of the study were: 1. To establish the principle of a novel compact road profiler to evaluate IRI and roughness condition of urban roads in dissimilar cities during non-identical seasons, 2. To launch the use of digital road map of Japan and GIS to conceptualize the survey results between land use and classification of roads, 3. To formulate statistical analysis and methods of evaluation based on a differentiation study using road classes, local cities, wheel paths, road directions, and various conditions of pavement roughness. A unique, time stable and cost effective mobile Profilometer (MPM) was developed by Kitami Institute of Technology. The name of the profilometer was STAMPER which stands for “system with two accelerometers for measuring profile, enabling real-time data collection”. The developed system includes two small accelerometers, one global positioning system (GPS) sensor, a portable computer and an amplifier. The function of the small GPS sensor was to collect travelling speed and spatial position of measurement and placed at either corner of front panel of the vehicle. Both the small accelerometers were fixed on the unsprung and sprung weights on the suspension system of a vehicle. Using transducer, the tension of accelerometers was converted into the electrical signal, and so the values of road roughness was shown on a Portable Computer screen in real-time.

Josef Zak et.al. (2016) [3] The objectives of the research were to develop an improved program which was capable to evaluate IRI and unevenness properties of road profile using point cloud data and also capable of evaluating the quality and effectiveness of the point cloud data to check their use in calculation of surface smoothness parameters. The comparison study was carried out between the methods of pavement unevenness measurement– rod and level, precise levelling and IRI. In this study, the author concluded that the point cloud data which we measured from the field could be used for the calculation of the pavement layers unevenness parameter like roughness and IRI. Another key result of the study was the lower value of standard deviation calculated from point cloud data than the standard deviation measured by precise levelling. To study the roughness and rectified slope, histogram descriptor was adopted in the study. Diaconis and Freedman's law was used to determine class widths. Out of various distributions, the Pearson type IV distribution was capable of providing logical interpretation of roughness and rectified histogram both. These distribution parameters can be referred for the comparison of data.

Nebojša Radović et.al. (2016) [5] In this study various surface quality evaluating methods were examined to predict the roughness of the pavement in the Republic of Serbia over a length of around 13,19,134 km. For measurement of the pavement surface over the road of Serbia, a multifunctional vehicle named ARAN (Automatic Road ANalyzer) on which a portable laser profiler was fitted had been used. Portable laser profiler was a non-contact type scanner used to scan the values of perpendicular acceleration of the measuring axle's un-sprung and sprung mass of the vehicle's body. In this study, replication of the quarter-vehicle was done using the values obtained by laser camera. After the analysis and the measurements, it was found that over 40% of the total road network was in substandard condition and requires an immediate investment in the pavement to stop further propagation of the unevenness and cracks. In this study a Pavement roughness model was developed in HDM-4 softwarel.

Manish Pal et.al. (2014) [4] This case study was performed to evaluate roughness index using 5th wheel Bump Integrator on minor roads in Tripura. Towing vehicle speed was kept at 32 kmph. It is difficult to maintain constant speed throughout the pavement due to heterogeneous traffic composition and in some typical scenarios. To overcome this problem, in this study an interrelation equation was generated between the roughness readings of different speed with standard speed of 32 kmph. Developed equation was focused to convert the roughness values of any speed into the standard speed. In this paper, SPSS (Statistical Package of Social Sciences) software was used to derive a unspecified equation between the roughness index value of random speed and the roughness index value at standard speed of 32 kmph. In this paper, Bump Integrator was moved at different speeds ranging from 20 kmph to 50 kmph with a variation of 5 kmph between two successive velocity and separate equations were developed to convert Bump Integrator value. But it was required to institute a generalized equation to convert Bump Integrator values of the speed other than the speeds taken above. Equation1 was developed Using SPSS software as follows:

$$(BI)32 = 0.956(BI)v + .842V - 25.544 (R2 = .958) \qquad \text{Eq.1}$$

where, (BI) 32 = BI value at standard speed of 32 km/hr. (BI)v = BI value at speed V.

Yuchuan Du et.al. (2014) [9] In this paper an IRI evaluation model was developed based on regression analysis. In this study an integrate system was developed based on various velocity correction model and multiple linear fitting model. The integrate system was capable of recording Z-axis acceleration in real time in various pavement conditions, at discrete times, and with non-identical values for other parameters. It was also found that the fluctuation in acceleration of in-car Z-axis due to roughness of pavement was produced by the vibration of various mechanical parts of car, and thus it was relevant to correlate the vertical acceleration with the IRI. For the field test, eight typical roads were taken in Shanghai with known IRI values. Accelerometer was placed inside the vehicle to get full response of sprung vibration. In this study, the adoption of regression method for modelling between IRI and Z- axis acceleration was due to the observation that size of signal amplitude could be represented with the mean square value of power spectral density. Instead of the one, various local accelerations were taken into account which improved the goodness of fit of the model and considered as an innovative feature.

Yaxiong (Robin) Huang et.al. (2013) [8] In this paper, to measure accurate rut value, a unique rut measurement system was developed by the TxDOT Construction Division, Materials and Pavement Section. The system named as VRUT (in fig. 4) was the modified version of 5-point acoustic or laser sensor–based rut measurement systems of TxDOT. The principal of VRUT system is laser triangulation. Data was collected from different pavement sections at 3m intervals. Major Highways and Major District Roads of the local area was selected for data collection. Width of roads were ranging from 2.4m to 3.7m. The system includes a high-speed 3D digital camera with a height resolution of 0.75 mm and a high-speed infrared laser line projector capable of covering a 14 ft lane width. VRUT system can be operated from 16 to 113 km/hr. (10 to 70 mph) speed range. VRUT notes down 12 readings and the mean value of them is considered which eliminates the noise.

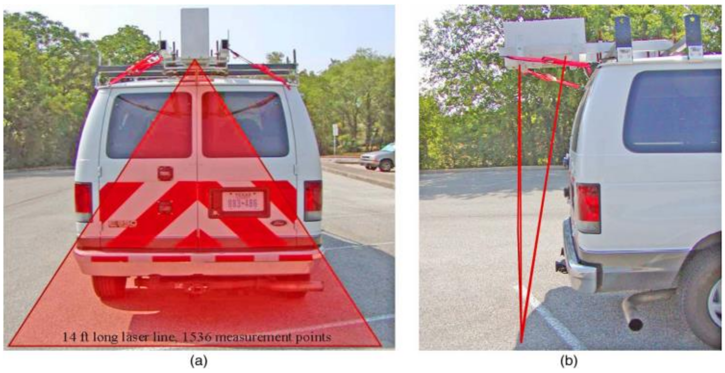

Figure 3: VRUT System

Shahbaz khana et.al. (2013) [7] In this research, an organized study was done on the permanent deformation development implicating a flexible pavement based on the Accelerated Pavement Testing (APTF), a national facility recently set by CSIR (Council of Scientific and Industrial Research)-CRRI (Central Road Research Institute). Indian APTF' capabilities and applications had also been discussed in this paper along with the evaluation study. Test section was separated into 16 parts with each part having a length of 8m and width of 900mm. APTF' Laser Profilometer were used for the evaluation. The profilometer was made of an aluminum frame that covered the whole width of the test section resting on legs. In this profilometer, the laser head contained a measuring head which had capacity to take readings at every 10 mm interval over a 2.56 m of total length. With increased load repetitions, many fit lines were drawn for rut depth advancement and the best fit line was found and expressed in the form of equation with R^2 value of 0.978. Equation2 is as follows:

$$y = -2E{-}05x4 + 0.0024x3 - 0.0841x2 + 1.2918x + 0.8128 \quad \text{Eq.2}$$

Where, y is rut depth in mm and x is number of passes.

Jia-Ruey Chang et.al. (2009) [2] In this paper, a test was conducted using an autonomous robot to check its compatibility to measure IRI. A robot named the Pioneer P3-AT (in fig.5) was made and equipped with odometer, CCD laser, a laptop computer and a SICK laser ranger finder for collection of the roughness profile. For computation of IRI ProVAL (Profile Viewing and AnaLysis) software was used. The test was conducted on a very smooth pavement surface of 50 m length. Eight rear sonar were used in this robot which detect obstacles from 150 mm to 7 mm. maximum speed that can be reached by the robot is 0.8 m/sec. Robot was configured to collect the longitudinal profile at a 15 cm sampling interval. There was no accelerator placed in the robot because the test surface was levelled and smooth however, accelerometer could be required to measure non-level surface profile. According to the author, centimeter level positioning accuracy was achieved using the developed robotic structure and further it need more improvement to give accurate results.

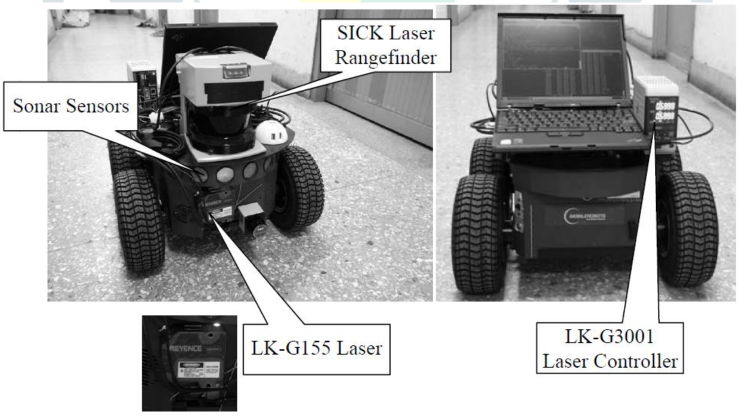

Figure 4: P3-AT robot

III. CONCLUSION

Quarter-car model is a mathematical model used for the computation of International Roughness Index. In the quarter-car model, a quarter car is advanced with a stimulated velocity of 80 kmph along the longitudinal surface profile. Deflection of the suspension of quarter car is measured using standard car structure variable and calculated profile measurement. The ratio of the integrated suspension motion and distance travelled along the profile gives an index called IRI and can be expressed in (m/km or in/mi). Many states are using IRI obtained from profiler measurements to check pavement condition while some states are referring it for quality control management of individual projects.

Unevenness parameters are very essential for maintenance and improvement practices of the road surface. It directly affects various parameter like vehicle operating cost, fuel consumption, lifespan of the vehicle, tire durability. Comfort and safety are the main concerns for any road surface. Through proper and effective inspection of the road surface, extent of the maintenance can be determined accurately which may ensure the maximum comfort and safety on the road. Various software (ProVAL, HDM-4, SPSS etc.) is being used for evaluation and prediction of the pavement surface quality.

Currently available equipment in India are costly and requires significant manpower. Hence, there is a need to develop a low-cost equipment which can measure more than one parameter of the road surface simultaneously with minimum manpower requirement and high precision. Operating cost of the survey should also be minimum so that a long stretch on the road surface can be covered within low budget. A new equipment is being developed keeping all the above concerns in mind to bring revolution in the area of pavement maintenance.

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