UPGRADATION OF LOW COST ROUGHNESS MEASURING EQUIPMENT AND DEVELOPMENT OF PERFORMANCE MODEL

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Abstract

Today road and transport authorities around the world collectively spend large sums of money each year enhancing and maintaining their road networks. Road users in the majority of countries around the world continue to desire better and smoother roads, despite pressure on road authorities to further reduce expenditure. This pressure is brought about, because funding for road infrastructure is only one of the many priorities competing for Government funds. Pavements cannot be managed to the degree desired by decision makers, unless detailed accurate information and analysis supports the system. Road roughness data is considered one of the most important aspects of road condition information used in practice in pavement management systems.

At present in the market, we have various roughness measuring equipments starting from costliest equipment such as ARAN laser (which uses laser beam to measure the roughness) to moderately costly Bump integrator (which uses the bump counts made by the probe wheel), to cheaper equipment such as MERLIN (which uses the slope value of the wheel to calculate the roughness). In the present research work, an attempt is made to develop low cost roughness measuring equipment and to check its reliability and repeatability to minimize the calibration error. It is calibrated using Bump integrator.

Keywords: *roughness, low cost equipment, calibration error*

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1. INTRODUCTION

Road roughness is the deviation of a road surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and pavement drainage. Roughness is primarily related to serviceability, structural deficiencies and road deterioration. It is one of the key indicators to evaluate road performance and condition. Roughness affects safety, comfort, travel speed, vehicle maintenance and vehicle operating costs. Roughness is the factor that most influence user's evaluation when rating ride quality.

A more detailed definition is provided by Paterson (1987), where roughness is described as a composite distress comprising components of deformation due to traffic loading and rut depth variation, surface defects from spalled cracking, potholes, and patching, and a combination of aging and environmental effects.

The roughness data collected over a period of time will help in building up the data bank. This data bank is the basic essence of any pavement management system A pavement management system allows fund managers to defend budget requests and to evaluate quickly and accurately they implications of alternative funding profiles on the resulting condition of the highway (Kennedy and Butler 1996).

The need to measure roughness has brought a wide of instruments on the market, covering range from rather simple devices to quite complicated systems. In the past decades, roughness measurement instruments had become the everyday tools for measuring road roughness. The majority of States now own pavement roughness measurement systems. There are many proven methods for analyzing and interpreting data similar to the measurement results obtained from these systems.

There are several causes of pavement roughness: traffic loading, environmental effects, construction materials and built-in construction irregularities. All pavements have irregularities built into the surface during construction, so even a new pavement that has not been opened to traffic can exhibit roughness. The roughness of a pavement normally increases with exposure to traffic loading and the environment. Short-wavelength roughness is normally caused by localized pavement distress, that is, depression and cracking, at the same time the long-wavelength roughness is normally caused by environmental processes in combination with pavement layer properties.

1.1 IRI

At present, the most commonly used road roughness measuring index is the International Roughness Index (IRI) introduced by the World Bank. The IRI is a mathematically defined as summary statistic of the longitudinal profile in the wheel paths of a traveled road surface. Although roughness measurements are matured technologies, there are still works to be done in improving their accuracies.

The IRI has been reported to be relevant as an indicator of pavement serviceability, independent of the particular equipment used to measure it, it is internationally and geographically transferable and time stable. IRI is often used as an accepted standard against which roughness measuring systems are calibrated.

1.2 Need and Objective of Present Study

It has been clear at the outset that skid resistance is influenced by many variable factors and therefore its value is sensitive to changes in all these factors. Moreover, this implies that it is very difficult to achieve a direct marked relationship between skid resistance and any one particular factor. In this study more significance has been attributed to the primary and secondary factors association with the pavement surface, so as to derive correlation tendencies between the pavement-surface mixture composition and skid resistance.

2. PRESENT INVESTIGATIONS

The MWUI (Multiple Wheel Unevenness Indicator) is low cost equipment developed at Bangalore University. This equipment was developed by Dr. Krishnamurthy as a part of thesis work. It consists of 8 bogie wheels, connected through hinges to a datum frame. The main objective of providing the bogie wheels is to achieve fixed datum throughout the study. The probe wheel (cycle wheel) is centrally placed, which acts as a medium to measure the response to the road roughness. Each pair of bogie wheel are first individually mounted to ball bearing and then hinged to the datum frame.

- The length of the wheel base is 320 cm.
- Width of the wheel- 50 cm
- Diameter of the probe wheel- 38 cm

Fig-1: Multiple Wheel Unevenness Indicator

2.1 WORKING PRINCIPLE (Old Method)

The recording and integrating of humps and depression was done separately with a pair of mechanical integrator units attached on either side of the central probe wheel. The mechanical integrator unit consists of 2 bits of cycle chain and 2 free wheels of a common pedal cycle, a pair of 5-digits mechanical counter.

2.2 Upgradation

The following components are upgraded in MWUI

- A metal sensor to evaluate the distance travelled.
- A sensor to measure the movement of probe wheel.
- LCD display to display the bumps and odometer readings
- Software to record the bumps and the distance travelled.

A metal sensor is used to measure the number of revolutions made by the probe wheel. The tail end of the sensor is attached to the circuit board.

To record the number of bumps, ten slots are made and a metallic strip is attached to the probe wheel. These slots are coded to record the movement of the probe wheel.

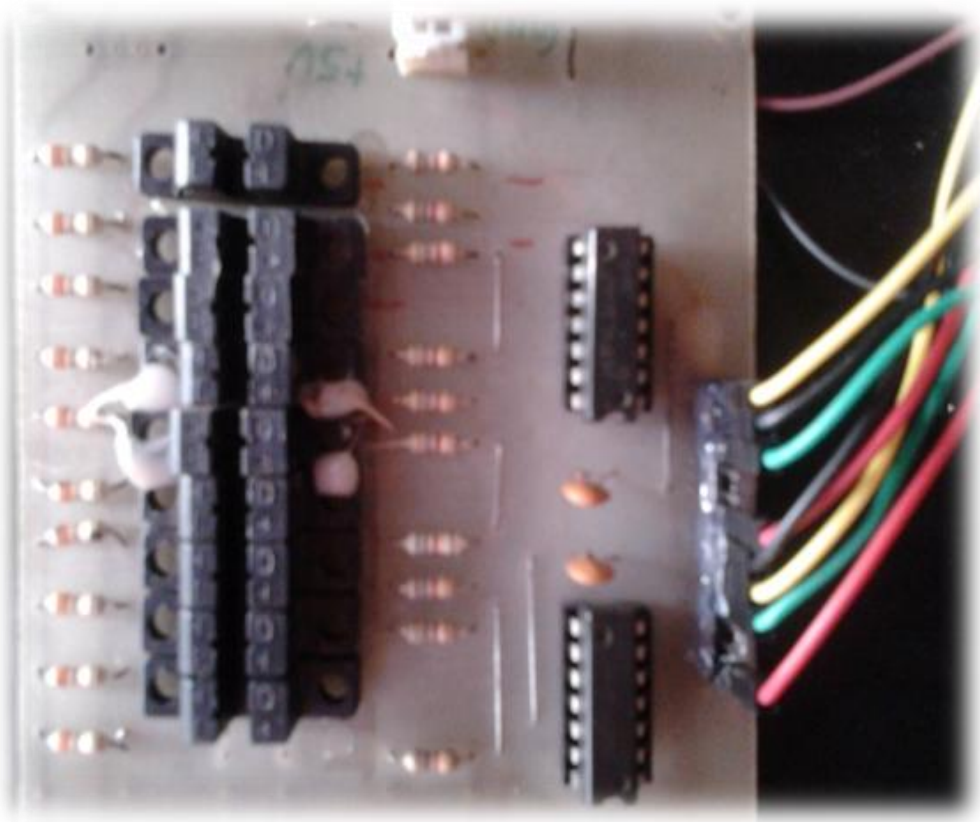

Fig-2: Slots for the movement of metallic strip

LCD Modules can present textual information to user. It's like a cheap "monitor" that you can hook in all of your gadgets. A LCD display is connected to the circuit board. This helps in viewing the number of bumps made by the probe wheel on the road surface and the odometer reading i.e. the number of revolutions made by the probe wheel during the run.

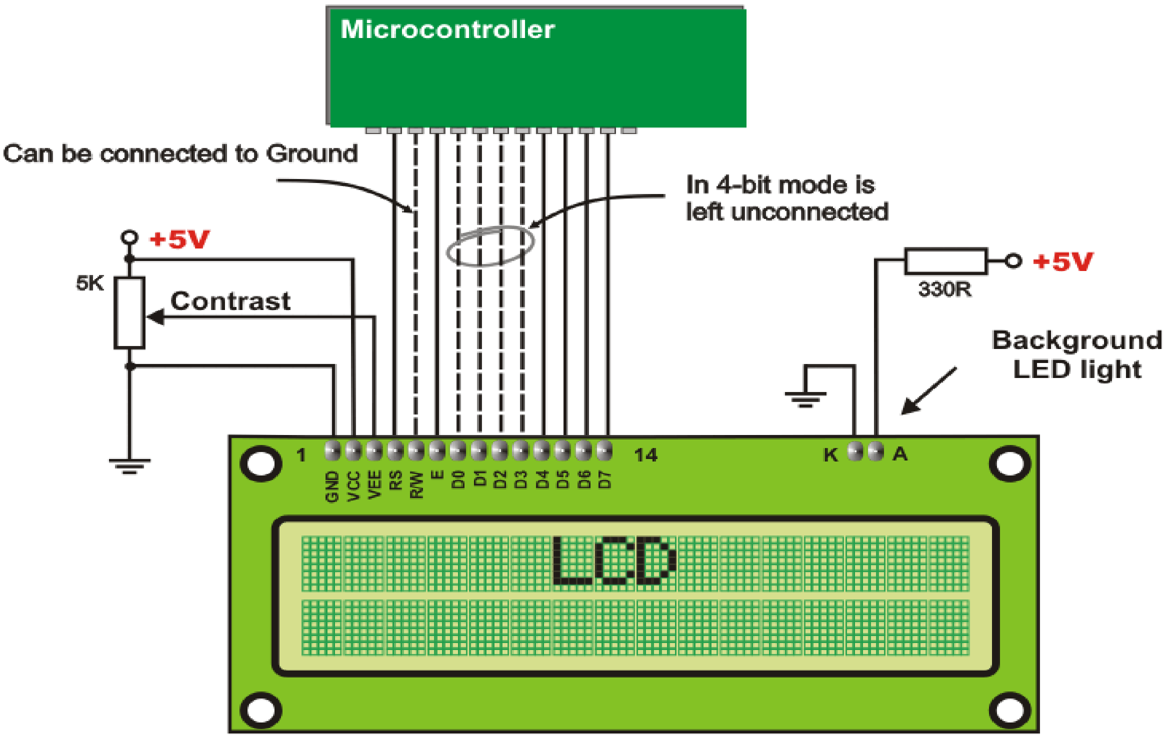

Fig-3: Animated view of LCD

ROMDAS- software for Roughness Evaluating and Bump Integrating is adopted to evaluate the number of bumps made the equipment on the road surface during the run.

Interfacing software used is

- Flash Magic
- Keil

Flash Magic: Flash Magic can control the entry into ISP mode by using COM Port handshaking signals to control the devices. Typically the handshaking signals are used to control the pins such as RESET, VCC and PSEN. The exact pins used may depend on the used device. This is mainly used in measuring the movement or the revolution made by the probe wheel which is detected by the metal sensor.

Keil : The Keil ULINK USB-JTAG family of adapter connect the USB port of a PC to the target hardware also to the LCD display. They enable you to download, test, and debug your embedded application on real hardware. This interface is used to connect the PC and LCD for the display of the collected data.

2.3 Working Principle

The equipment is pulled along the wheel path at a walking speed of 4-5 kmph. The number of revolutions is detected by the metallic sensor attached to the probe wheel. Similarly the unevenness/ roughness of the road is evaluated by the movement of the metallic strip attached to the probe wheel.

With the help of the ROMDAS software, the total number of bump counts made, the distance covered and the speed of travel is evaluated. The data obtained can be saved for further verifications and calculations.

3 CALIBRATION PROCEDURES

The data obtained from 15 stretches were used for the analysis. Out of which, 6 stretch data were used for arriving at the calibration equation for Multiple Wheel Unevenness Indicator, 8 stretch data for developing Pavement Performance Model

08 stretches are located and the wheel paths (left wheel path and right wheel path) are marked to ensure that the two equipments (MERLIN AND MULTIPLE WHEEL UNEVENESS INTEGRATOR) traverse the same wheel path during the testing.

Fig-4: wheel path marking

Firstly, MERLIN is made to run along the wheel path. For every test section 4 runs were made (2 on left wheel path and two on the right wheel path) to achieve the accuracy.

Fig-5: Study using MERLIN

Using the MERLIN 'D' values, International Roughness Index (IRI) and Unevenness Index (UI) is calculated using the formula

$$IRI= 0.593+0.0471\ D$$

$$UI= 630(IRI)^{1.2}$$

The Multiple Wheel Unevenness Indicator is pulled along the same wheel path that was traversed by MERLIN to measure the roughness of the road surface in the form of bumps.

MERLIN 'D' values and MWUI's bump counts are used to develop the calibrating equations for MWUI.

3.1 Field Work

The calibration exercise in this study was done at two stages. A preliminary calibration was done with a MERLIN. *8* test sections were identified for paved roads. The beginning and end of the test sections were marked so that they could clearly be seen. For paved roads, the outside wheel path was marked using a white paint at about 0.6m from edge of the pavement for single lane and about 0.9 m for two-lane roads to mark the wheel path. The MERLIN was run twice on each wheel path giving a total of four MERLIN runs per lane which is considered a minimum. It is also a good practice to take an even number of passes on each wheel path, the starting point of each slightly offset from the previous, and an equal number of passes running opposite directions to improve the averaging. Then the Multiple Wheel Unevenness Indicator was run five times on each test section, again equal numbers in both directions. Tables 1and 2 present the Bump counts and the IRI values obtained from MERLIN respectively for paved road calibration.

[TRRL 91] provides only one equation (for all road surfaces) for converting the MERLIN *D* values into the International Roughness Index (m/km). The equation is given by,

IRI = 0.593 + 0.0471 D.......................... (1)

where,
IRI = roughness in the International Roughness Index (m/km), and,
D is as defined earlier.

Fig-6: Study using MWUI

3.2 Development of Model

In order to determine the model parameters, data on the road under study were collected for 3 cycles to obtain a broad picture of pavement conditions under various climatic and traffic situation. The information such as crack area, rut depth, raveled area, patched area and traffic volume obtained trough field survey were used to develop the Pavement Performance Model.

4. RESULTS

Table-1: MERLIN Results from Test Sections

Stretch	Run1	Run2	Run3	Run4	Avg, m/Km
Stretch A	8.49	7.82	8.44	7.93	8.17
Stretch B	6.48	6.95	6.72	6.68	6.71
Stretch C	5.61	5.58	5.49	5.6	5.57
Stretch D	7.658	7.762	7.746	7.684	7.71
Stretch E	8.96	8.317	8.78	8.45	8.63
Stretch F	4.12	4.18	4.08	4.12	4.13
Stretch G	5.83	5.53	5.31	5.28	5.49

Table 2: Bump Counts from Test Sections

Stretch	Run1	Run2	Run3	Run4	Run5	Avg
Stretch A	394	379	388	401	398	392
Stretch B	312	327	306	334	298	315.4
Stretch C	245	231	237	221	242	235.2
Stretch D	365	348	357	355	373	359.6
Stretch E	520	512	514	545	519	522
Stretch F	118	135	112	142	123	126
Stretch G	213	221	203	228	208	214.6

Regression analysis was then performed on the results with the bump counts (measured by the MWUI) as the independent variable from which roughness in terms of a standard index is to be estimated.

Table 3 Regression Analysis

Stretch	Bump Counts	IRI
Stretch A	392	8.17
Stretch B	315.4	6.71
Stretch C	235.2	5.57
Stretch D	359.6	7.71
Stretch E	522	8.63
Stretch F	126	4.13
Stretch G	214.6	5.49

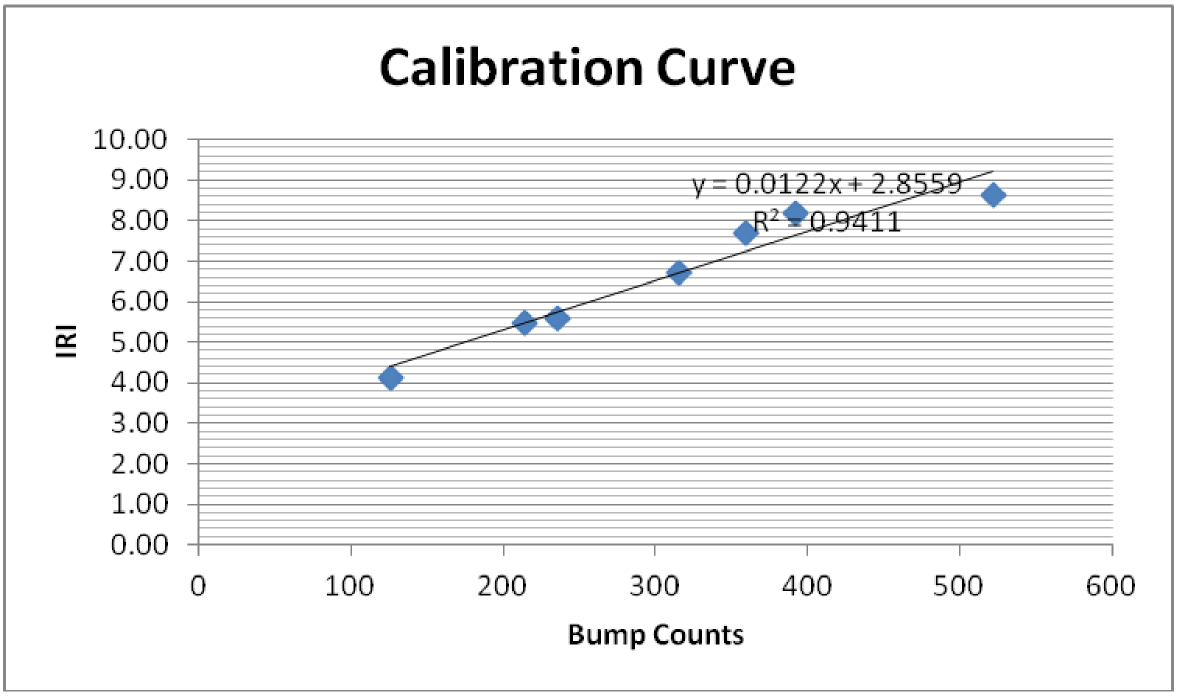

Chart -1: Calibration curve

IRI = 2.8559 + 0.0122 * BI Counts

Where,
IRI = the roughness index in m/km
UI = the unevenness index, mm/km
BI counts = the bump counts per km

Table 4 : Stretch data

Stretch	UI Mm/Km	Cracking, Sqm	Patch Sqm	Rut depth,mm	PCI
1	2547	123.1	153.0	13.5	90
2	2235	54.04	61.0	10	84
3	2083	32.96	20.0	8.3	82
4	2568	189.1	202.0	16.2	94
5	2258	82.11	67.0	13.1	88
6	1778	24.64	13.0	6.2	73
7	1749	7.18	11.7	5.8	71
8	1979	26.4	19.6	6.4	77

Table 5 : Stretch data

Stretch	Ravelling Sqm	Traffic vol (CVPD)
1	492.1	4719
2	412.3	2529
3	376.9	2442
4	653.3	3624
5	428.2	3402
6	131.1	1266
7	101.9	912
8	253.2	2289

The UI model was developed using the field measurements such as Cracked Area, Patched Area, Rut depth, Raveled Area, Traffic volume and UI values. The UI equation was developed using the Toolpak and Regression analysis. The UI equation was developed for each individual distress and finally multiple linear regression analysis was carried out to develop model. The models developed are given below.

UI= 283.94 ln (Crk) + 1070.9…………………………1

UI model with cracked area as a distress expressed in Sqm.

UI=274.84ln(Patch)+1127.1…………………………..2

UI model with Patched Area as distress expressed in Sqm.

UI=752.52ln(RD)+473.77………………………………3

UI model with rut depth as distress expressed in mm.

UI=446.01ln(Ravel)+399.59...………………………….4

UI model with Raveled Area as distress expressed in Sqm.

UI=532.23ln(Traffic)+ 1398.1………………………….5

UI model with Traffic volume as distress expressed in CVPD.

4.1 Multiple Linear Regression Analysis

Model: Y_i **(UI)=** $\beta_0 + \beta_1$**(Crk) +** β_2**(Patch) +** β_3**(RD) +** β_4 **(Ravel) +** β_5 **(Traffic)……………………………………..6**

Assumptions:
The response variable Y is linearly related to regressor variables Crack area, patch area, rut depth, ravel area and traffic volume.

4.1.1 Model for UI

Model for linear variation:

UI= 1519 + 3.73(Crk) + 3.27(Patch) + 11.34(RD) + 0.92(Ravel) + 0.24(Traffic) ……4.7

Table 6 Model summary for linear variation

Regression Statistics	
Multiple R	0.99757
R Square	0.99515
Adjusted R Square	0.98304
Standard Error	0.41157
Observations	8

ANOVA					
	Df	SS	MS	F	Significance F
Regression	5	660857	132171	82.1312	0.012073
Residual	2	3218.54	1609.27		
Total	7	664075			

	Coefficients	Standard Error	t Stat	P-value
Intercept	1519.125	49.241	17.9146	0.0031
Cracking	3.729	1.3544	2.535248123	0.05009
Patching	3.271	0.9065	2.897354593	0.03389
Rutdepth	11.343	11.007	2.635624165	0.04621
Raveling	0.9155	0.1605	2.845343522	0.03602
Traffic vol	0.2442	0.0530	2.794761038	0.03823

4.1.2 Significance Test of an Individual Coefficient in the Regression Model

In order to test the significance of each parameter in the predicted regression model, Student's T- Test and Anova are carried out using the Toolpak.

Table 7: Anova (Linear variation)

Parameter	F significance	(1-F) value
Intercept	0.0045	0.99
Cracking		
Patching		
Rutdepth		
Ravelling		
Traffic vol		

It can be observed that the value (1-F) = 0.99, it shows that the one of the parameters considered is significant. But it does not indicate the significance of each parameter. The significance of individual parameter can be analyzed by conducting F-distribution Test.

Table 8: T- statistics (Linear variation)

Parameter	P value	(1- P) value	Desired Value
Intercept	0.0031	0.999	> 0.95
Cracking	0.0500	0.97	
Patching	0.0333	0.97	
Rutdepth	0.0462	0.96	
Ravelling	0.0360	0.97	
Traffic vol	0.0382	0.97	

Since the values obtained are less than the desired value it can be concluded that the parameters considered are significant

5. CONCLUSION

- The upgraded MWUI was tested for calibration errors and it satisfactorily proved that it serves for both repeatability and reproducible.
- The calibration equation was developed and the variation is assumed as linear i.e, linear regression analysis is conducted between the IRI values obtained by MERLIN and Bump counts obtained by MWUI.

The calibration equation for MWUI obtained is as follows

IRI = 0.0122 (Bump counts) + 2.8592

With $R^2 = 0.93$.

- The distress parameters, age, traffic volume and rainfall data were considered for the development of performance prediction models.

The model developed for roughness is as follows

UI = 1519 + 3.73 (Crk) + 3.27 (Patch) + 11.34 (RD) + 0.92 (Ravel) + 0.24 (Traffic)

By the regression analysis it was observed that the parameters viz. age of the pavement and rainfall were statistically insignificant in prediction of roughness. It was also observed that the distress parameters and traffic were significant at 95% confidence level. Also, as distress increases, the roughness value increases.

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BIOGRAPHY

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