

THE AUSTRALIAN 3D ROUGHNESS EXPERIENCE

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ABSTRACT

Most road agencies are willing to take advantage of new developments in automated data capture if it helps them to better manage their road networks. However, the acceptance process for new technologies can be a long and arduous task for service providers and equipment vendors with ultimate success often depending on how well the equipment can reproduce historical data or whether they meet existing test methods or standards.

Road agencies in Australia are only just beginning to utilise 3D¹ systems for monitoring their road network surveys and up until now they have been predominantly used for crack measurement. However, these systems are also capable of measuring a variety of other pavement condition indicators, one of which is road roughness. This paper investigates whether the roughness measurements made by a 3D system can meet the current requirements specified in the Australian test methods for measuring pavement roughness.

INTRODUCTION

Advances in pavement data collection technology are occurring at a rapid pace. It does not seem that long ago that equipment vendors were striving to mount as many single point lasers as possible across the front (or rear) bumper bar of their survey vehicles in an effort to improve transverse profile measurement. (Before that, it was cheaper and less accurate ultrasonic sensors).

Then point lasers were replaced with 2D line lasers, which were mounted to the rear of a vehicle, at an increased height above the pavement. These were capable of generating hundreds of measurement points over the full width of a lane. As the speed of the sensors increased, the longitudinal sampling interval decreased and suddenly systems were capable of making 3D measurements of the pavement surface. The extra information collected by these sensors also allowed them to measure much more than just the transverse profiles.

This technology is now being used to measure cracking and after various trials it has been embraced by several Australian road agencies. Much of the attraction to this technology is that the 3D system is small enough to be fitted to a regular size survey vehicle and allows this data to be collected in conjunction with other pavement condition parameters.

Whilst 3D systems have not as yet replaced point lasers for measuring established pavement condition parameters such as roughness and texture, they can theoretically measure these parameters.

To investigate whether they can do so to a sufficient level of accuracy for use by road network managers, an exercise was undertaken to determine whether the outputs of a 3D system can meet the requirements of the current Austroads pavement condition monitoring guidelines for measuring roughness and texture. This paper documents the results of the investigation into the measurement of roughness.

ROUGHNESS MEASUREMENT USING A 3D SYSTEM

A 3D system uses two sensors, each consisting of a line laser and camera, to measure the transverse profile of the pavement surface often doing so at a 1 mm spacing (*l*). Depending on the sampling speed of the system, the transverse profile measurements are made every

¹ Please note when using the term '3D system' the authors are not referring to LiDAR systems but 3D line laser based systems that only measure the pavement surface.

5 mm or less of longitudinal travel. Because of the small sample interval the system is capable of measuring the short wavelength (high frequency) content of the pavement at any point across the pavement.

However, to be able to measure longitudinal profile of the pavement and calculate roughness statistics such as the International Roughness Index (IRI) the system must also be able to measure the long wavelength (low frequency) content of the pavement.

To overcome this shortcoming each sensor was fitted with an accelerometer, as shown in FIGURE 1.



FIGURE 1 3D system with additional accelerometers (circled).

Combining the output of the accelerometer which determines the inertial frame of reference of the 3D system, with the height of the ground relative to the accelerometer (measured using the sensor spot directly under the accelerometer), and sampling both together at a constant interval, allows the longitudinal profile of the pavement to be measured (2). In this way the 3D system operates in exactly the same way as a typical inertial laser profiler.

AUSTROADS TEST METHODS FOR VALIDATING ROUGHNESS MEASUREMENT

In 2003, Austroads, the association of Australasian road transport and traffic agencies, initiated a project which brought together the major service providers in the region along with representatives from the road agencies to develop a series of test methods and standards for collecting pavement condition data including roughness. The main purpose of the project was to harmonise data collection and reporting, and to validate the measurements made by automated pavement data collection systems (3). The test methods are now specified in most data collection contracts for road agencies.

Rather than dictating the precision and accuracy of any particular component of the data collection equipment, the test methods focus on making direct comparisons of the measured pavement condition parameter with those obtained from a reference device.

At present there are two methods for validating the roughness outputs from an inertial laser profiler in Australia. The following is a brief description of each method:

1. Reference device method (AGAM-T002-11) – the outputs of the laser profiler are compared against ground truth measurements which are collected using a manual reference device such as a Walking Profiler, rod and level etc. The data is collected over 5 test sections of pavement, each 500 m long. The sites must cover a specific range of roughness levels which are typically experienced across a road agency's network. The testing is undertaken at 3 speeds and a minimum of 5 runs are made at each speed. The average IRI for each 100 m result is then calculated by averaging the left and right wheel path IRI values and calculating a linear regression between the average of the 5 profiler runs and the reference device. This is done at each speed and for the combined speeds. Limits for the coefficient of determination (r^2), slope and intercept from the resultant straight line of best fit must then be met (4).

2. Loop method (AGAM-T003-07) – the IRI outputs of the laser profiler are compared against the roughness results obtained from a reference profiler collected over a loop (which may consist of more than one section). The minimum allowable loop length is 10 km. The laser profiler is required to make 5 runs of the loop and the average IRI for each 100 m result is calculated by averaging the left and right wheel path IRI. The average of the five repeat 100 m results are then calculated and statistically compared with those from the reference profiler (the results from which are also based on the average of 5 repeat runs) using a least squares regression. The coefficient of determination (r^2) must then meet a specified limit as does the average percentage difference between the two data sets (5).

The loop method is currently the preferred option of the majority of road agencies in Australia and is used by agencies in the Australian Capital Territory, New South Wales, South Australia and Tasmania. An adaptation of the method is also used in Victoria.

EXPERIMENTAL METHOD

A 3D system with tri-axial accelerometers fitted to each sensor was mounted onto a network survey vehicle (NSV). The NSV was also fitted with a 13 laser digital laser profiler (DLP) mounted on the front of the vehicle which was capable of measuring both longitudinal profile and a 3 m wide transverse profile (as shown in FIGURE 1). Both the 3D system and DLP were integrated into a single data collection platform thus allowing them to operate via a single acquisition system.

The DLP's roughness lasers were positioned in the NSV's wheel paths, 750 mm either side of the centre line of the vehicle. Each roughness laser had a single axis accelerometer mounted above the laser aperture in the laser housing. To allow a direct comparison of the roughness results from the DLP and the 3D system, the 3D system was configured so that the longitudinal measurements were made in exactly the same position as the DLP.

Having both systems on the same vehicle collecting the data at the same time had two distinct benefits. Firstly, it removed the possibility of introducing any errors due to variations in driver tracking and secondly there were no changes in the condition of the pavement due to

maintenance works or environmental effects that could have influenced the measurements if the data were collected at different times.

Two test sites covering a range of roughness values were selected for the validation exercise. The sites, which are in close proximity to each other, were as follows:

1. Nar Nar Goon loop – a separated two-way, dual lane section of the old Princes Highway still open to local traffic and used for the validation of pavement data collection equipment. It was surveyed in both directions and has a combined length of approximately 8.2 km. It is classified as a low to medium roughness site with IRI values ranging from 1 to 3 (m/km). It also contained 5 test sections, each 500 metres long, which were used to undertake the reference device validation.

2. Pakenham – Koo Wee Rup Road – a two way, single lane road. The test site consisted of a 5.3 km long section south of Pakenham which was surveyed in both directions. It was chosen for its higher roughness which ranged from an IRI of 2 to 5 (m/km).

Black tape was placed on the pavement to accurately identify the start and end of each of the test sections. This is shown in FIGURE 2. This was essential as the processing software for the 3D system required the manual entry of the start location and the length of the survey. In contrast, the DLP was fitted with an auto trigger which detected reflective tape on bollards set up alongside the road (in line with the black tape) thereby identifying the start and end points. This removed the need for the operator to manually input the start and end points and possible introduce a misalignment in the data. The two test sites were surveyed in June 2014.

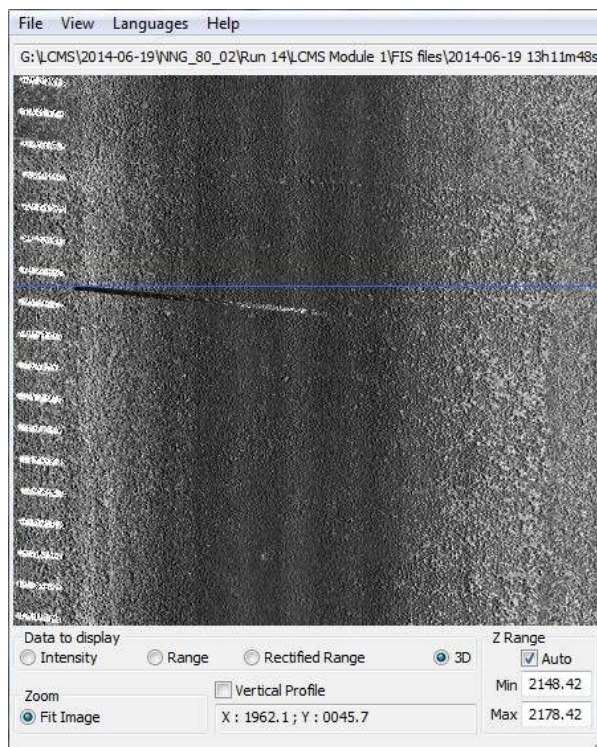


FIGURE 2 Identification of start and end points of reference sites using tape

The 3D processing software produced two files, one containing the longitudinal profile for the left wheel path and the other the right wheel path. ProVAL, an engineering software application for viewing and analysing longitudinal pavement profiles, was then used

to process these profiles and calculate the IRI at 100 m intervals (6). The DLP data was processed using its own proprietary software.

RESULTS

The following is a summary of the validation results for the 3D system using each of the two methods.

Loop method

The roughness results from the Nar Nar Goon test loop and the Pakenham-Koo Wee Rup Road were combined to form a loop 18.8 km long. The NSV made five runs over the loop at a nominal survey speed of 80 km/h.

In this instance, the average IRI results from the DLP were chosen as the reference data set as the system had been validated in accord with the Austroads reference device method at the Nar Nar Goon test loop in March 2013.

The resulting correlation between the 3D system and the reference data set from the DLP is shown in FIGURE 3.

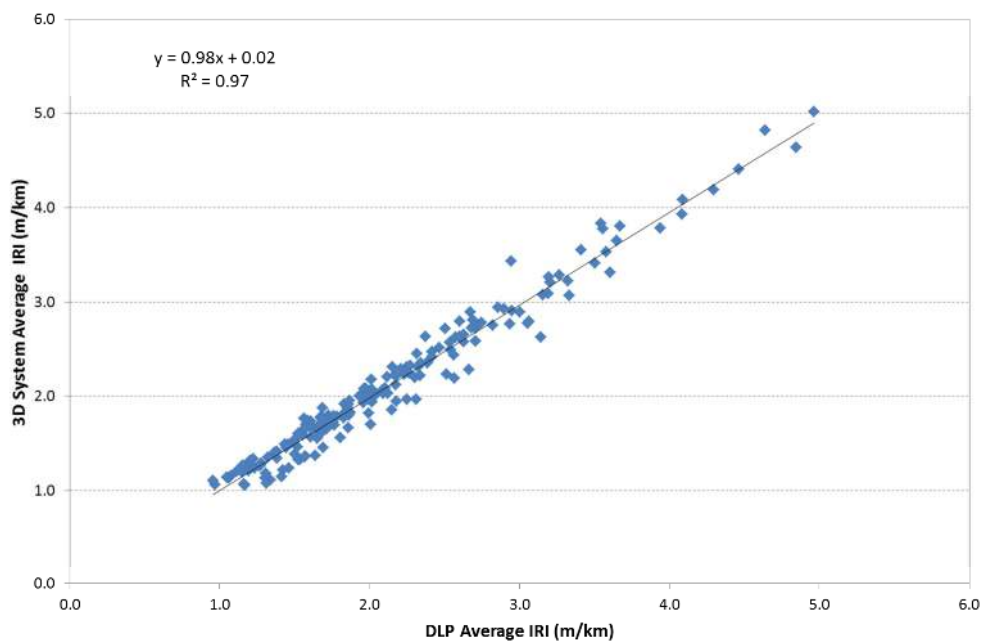


FIGURE 3 Correlation between DLP and 3D system roughness measurements

The test method states that the 3D system must meet two criteria if it is to pass the validation check:

1. The calculated coefficient of determination, r^2 , between the two data sets must be at least 0.95.
2. The overall average of the percentage differences for each 100 m section between the average of the five runs of the 3D system and the corresponding reference must be less than or equal to 5%.

The results of the validation exercise are shown in TABLE 1. According to the limits specified in the test method the 3D system passed the validation.

TABLE 1 Loop Method Validation Results

Parameter	Result	Limit	Pass/Fail
Coefficient of determination (r^2)	0.97	≥ 0.95	Pass
Percentage difference (%)	0.40	$\leq \pm 5$	Pass

Reference Device Method

After an initial inspection of the Nar Nar Goon loop, five test sections, each 500 m in length were selected based on their roughness characteristics which is a requirement of the test method.²

Two Walking Profilers were used to collect the ground truth IRI measurements as shown in FIGURE 4. The data was collected in each wheel path at each of the five sites. Two runs were made in each wheel path and the results averaged. This data was collected in March 2013.

**FIGURE 4 Ground truth data collection with reference device**

In accordance with the test method, the NSV made five runs over each of the 5 sites at 3 speeds – 60, 80 and 100 km/h. The individual 100 m IRI results from the 3D system were then compared against the ground truth data from the Walking Profilers using a least squares regression to determine the line of best fit between the two data sets. This was done for each speed and for all results combined.

TABLE 2 shows the results of the validation and whether the 3D system passed or failed each of the specified limits.

² The 5 sites did not meet all the roughness characteristics requirements specified in the test method. They were deficient in the area of high roughness.

TABLE 2 Reference Device Method Validation Results

Speed (km/h)	Parameter	Limit	Result	Pass/Fail
60 (low)	Coefficient of determination (r^2)	≥ 0.950	0.933	Fail
	Slope	$0.95 \leq A \leq 1.05$	0.97	Pass
	Intercept (m/km)	$-0.25 \leq B \leq 0.25$	-0.09	Pass
80 (medium)	Coefficient of determination (r^2)	≥ 0.950	0.943	Fail
	Slope	$0.95 \leq A \leq 1.05$	0.99	Pass
	Intercept (m/km)	$-0.25 \leq B \leq 0.25$	-0.11	Pass
100 (high)	Coefficient of determination (r^2)	≥ 0.950	0.944	Fail
	Slope	$0.95 \leq A \leq 1.05$	0.94	Fail
	Intercept (m/km)	$-0.25 \leq B \leq 0.25$	-0.13	Pass
Combined	Coefficient of determination (r^2)	≥ 0.975	0.934	Fail
	Slope	$0.97 \leq A \leq 1.03$	0.970	Pass
	Intercept (m/km)	$-0.25 \leq B \leq 0.25$	-0.11	Pass

The same analysis was undertaken for the DLP which achieved similar results.

DISCUSSION

The results showed that the 3D system fully met the requirements of the loop validation method. However, it did not meet all of the limits for the reference device method.

There are several reasons as to why this may have happened. Firstly, a significant period of time, 15 months, had passed from the time the ground truth measurements were made and the 3D system was tested. Even though there was no obvious evidence of maintenance works having been undertaken on the test sections, it is possible that the roughness had changed in that time due to trafficking and environmental factors. It is interesting to note that the DLP also failed to meet all of the limits for the reference device validation method whereas it passed them when it was tested over the same sites in 2013. Collecting the reference and test data within a shorter time frame may help address this issue.

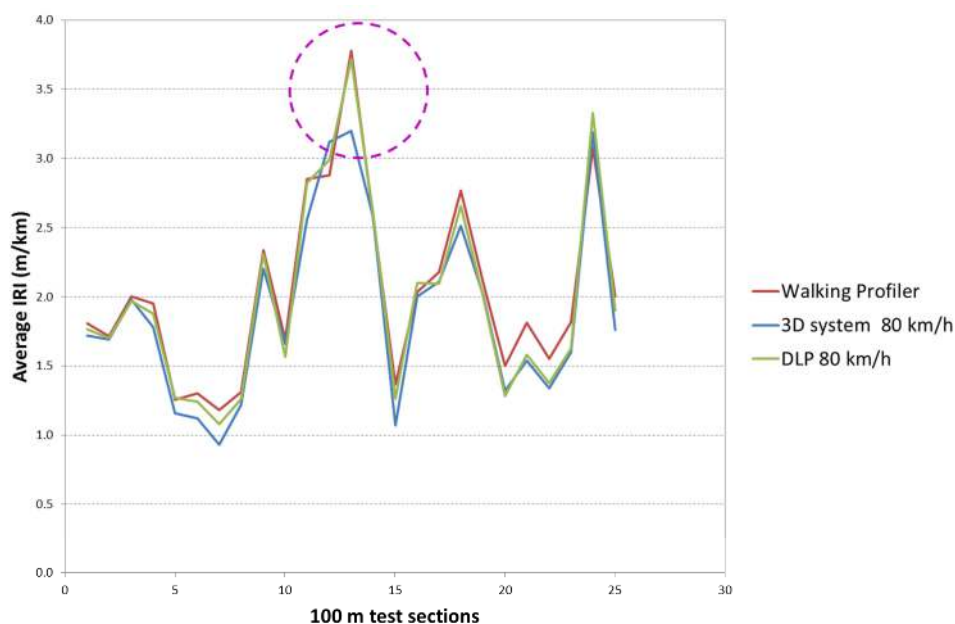


FIGURE 5 Average IRI results from test sections - Walking Profiler, 3D system and DLP

As shown in FIGURE 5 the average IRI values reported by both the 3D system and the DLP were often lower than the Walking Profiler. It is possible that the difference is due to a variation in tracking between the two systems and the reference device.³

As circled in FIGURE 5 there is also one 100 m section where there is a significant difference in the IRI values recorded by the Walking Profiler and the 3D system. However, the same difference was not present in the DLP data which agreed with the reference device. A detailed investigation of this 100 m section is yet to be undertaken but there is a thought that the location of the longitudinal profile measurements made by the 3D system may have been slightly offset (narrower or wider) than those of the DLP meaning it did not pick up the pavement defect(s) or profile variation that the DLP and Walking Profiler both did.

The results also showed the measurements from the 3D system appear to exhibit a slight speed dependency, which is more evident at high survey speeds, and a brief comparison of the statistics, such as the coefficient of variation (COV) for each set of 5 repeat runs at the 100 m level, showed the average COV to be 0.5% higher than the DLP.

FURTHER INVESTIGATIONS

This investigation was based solely on the IRI outputs of the 3D system. Whilst the results either matched, or were similar, to those of both the DLP and Walking Profiler, it would be prudent to examine the frequency response of the system with the aim of determining whether it is amplifying or attenuating any wavelengths that affect the measurement of IRI and other ride quality parameters.

Additionally, the reasons for the apparent speed dependency of the 3D system and why the variation of the repeat IRI measurements is slightly larger than those of the DLP require further investigation.

The testing for this project was undertaken on relatively straight sections of road with only the odd minor bend and curve. As such, it is intended to investigate how the 3D system handles roughness measurements on windy roads given that the distance between the accelerometer and the laser measurement point on the pavement surface is > 2.2 m.

It is also intended to use the same data sets to assess the ability of the 3D system to measure texture for which there are also Australian test methods.

CONCLUSION

The two Australian test methods for validating a laser profiler for roughness measurement can be applied to a 3D system.

It has been shown that with the addition of an accelerometer, a 3D system can meet the requirements of the loop validation method and therefore be used for roughness surveys by agencies who adopt this validation method. However, prior to doing so, it is recommended that further research be undertaken to investigate the frequency response of the 3D system and the effect of speed and different operating conditions on the roughness measurements.

³ As with the results from the test loop, the average IRI measurements made by the 3D system and the DLP over the Nar Nar Goon test sections had a very high correlation.

The 3D system did not pass the reference profiler validation method. However, there are valid reasons for why this may have happened. This testing should be repeated with a shorter duration between the collection of the reference and test data.

ACKNOWLEDGEMENTS

The 3D system referred to in this paper is the Laser Crack Measurement System (LCMS) marketed by Pavemetrics in Canada which forms the basis of the current ARRB Automated Crack Detection (ACD) system. The authors wish to acknowledge the help received from Pavemetrics in providing the hardware and software to allow the IRI comparisons to be made.

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