High-speed network level road texture evaluation using 1mm resolution transverse 3D profiling sensors using a digital sand patch model.

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Abstract: In order to maximize road maintenance funds and optimize the condition of road networks, pavement management systems need detailed and reliable data on the status of the road network. Over the last 10 years Pavemetrics Systems inc. in collaboration with INO (National Optics Institute of Canada) and the MTQ (Ministère des Transports du Québec) have been developing and testing a new 3D technology called the LCMS (Laser Crack Measurement System). This article presents the results obtained after analyzing the detailed 3D data collected in order to evaluate road surface texture. Results show that macro-texture can be evaluated over the entire road surface at the network level with accurate and repeatable results.

Introduction

The LCMS is composed of two high performance 3D laser profilers that are able to measure complete transverse road profiles with 1mm resolution at highway speeds. The high resolution 2D and 3D data acquired by the LCMS is then processed using algorithms that were developed to automatically extract crack data including crack type (transverse, longitudinal, alligator) and severity, rutting (depth, type) , potholes and raveling. This paper describes results obtained recently regarding road tests and validation of this technology for the evaluation of macro-texture.

The sensors used with the LCMS system are 3D laser profilers that use high power laser line projectors, custom filters and a camera as the detector [1,2]. The light strip is projected onto the pavement and its image is captured by the camera (see figures 1 and 2). The shape of the pavement is acquired as the inspection vehicle travels along the road using a signal from an odometer to synchronize the sensor acquisition. All the images coming from the cameras are sent to the frame grabber to be digitized and then processed by the CPU. Saving the raw images would imply storing nearly 30Gb per kilometer at 100 km/h but using lossless data compression algorithms on the 3D data and fast JPEG compression on the intensity data brings the data rate down to a very manageable 20Mb/s or 720Mb/km. The critical specifications for the LCMS system can be found on table I.

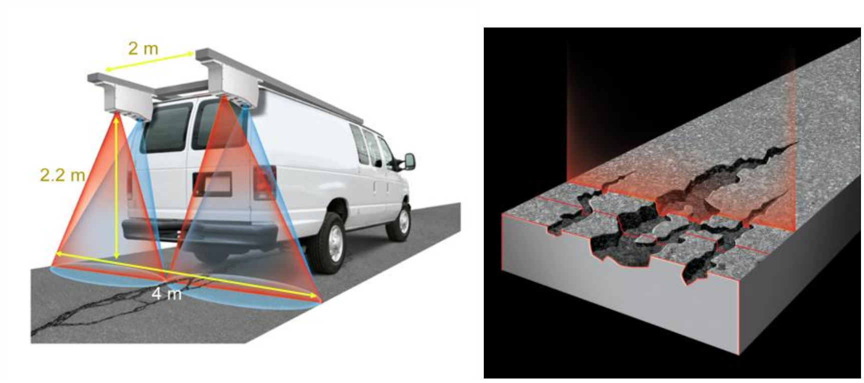

Figure 1. LCMS on an inspection vehicle (left), laser profiling of cracks (right).

Nbr. of laser profilers	2

Sampling rate (max.)	11,200 profiles/s
Vehicle speed	100 km/h (max)
Profile spacing	Adjustable up to 1mm
3D points per profile	4096 points
Transverse field-of-view	4 m
Depth range of operation	250 mm
Z-axis (depth) accuracy	0.5 mm
X-axis (transverse) resolution	1 mm

Table I - *LCMS Specifications.*

Figure 2. Photo of the LCMS system (sensors and controller).

The LCMS sensors simultaneously acquire both range and intensity profiles. The figure 3 illustrates how the various types of data collected by the LCMS system can be exploited to characterize many types of road features. The graph shows that the 3D data and intensity data serve different purposes. The intensity data is required for the detection of lane markings and sealed cracks whereas the 3D data is used for the detection of most of the other features.

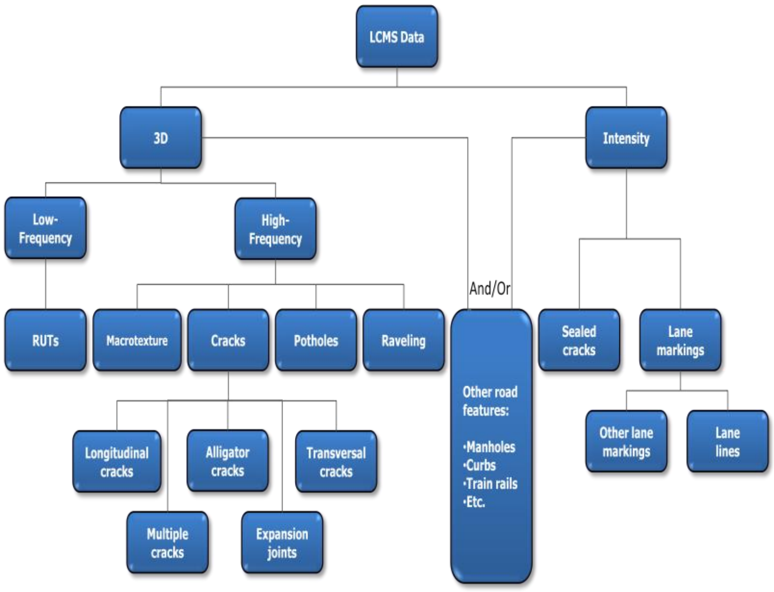

Figure 3. Data analysis library diagram.

Macro-texture

Macro-texture is important for several reasons, for example, it can help estimate the tire/road friction values, water runoff and aquaplaning conditions and tire/road noise levels produced just to name a few. At the project level or for the local evaluation of texture in areas where problems are suspected after accidents the most accepted way of measuring road texture is the sand patch method (ASTM E965) [4]. The sand patch method is a manual technique that requires the user to spread a known volume of sand on the road surface in such a way as to fill all the voids in the surface with the sand. The volume of sand divided by the covered surface area gives a measure of the road texture called MTD. While precise and repeatable this technique is not very practical when confronted with needs for the network level evaluation of texture.

At the network level, macro-texture is commonly measured using a single point high frequency (64khz) 3D laser sensor that acquires one high resolution longitudinal profile of the road. This profile is then processed by applying the ASTM 1845-01 standard [3] which specifies the calculation of the mean profile depth (MPD). To calculate the MPD (see figure 6), the profile is divided into small (10cm) segments and for each segment a linear regression is performed on the data. The MPD is then computed as the difference between the highest point on the profile and the average fitted line for the considered portion.

The relationship between MPD and MTD is not always perfect, Fisco [5] showed that MPD does not always correlate very well with MTD especially depending on the surface type.

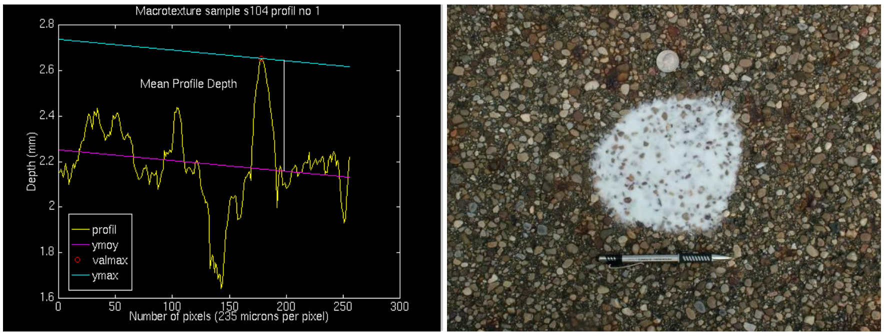

Figure 4. MPD vs sand patch.

The LCMS however acquires sufficiently dense 3D data over the entire road surface width to not only measure standard MPD but also to evaluate texture using a digital model of the sand patch method. This allows the possibility to measure texture as a sand patch test would (MTD) over a full lane at the network level. Figure 5 compares the coverage resulting from using MPD, sand patch and the LCMS systems to measure texture.

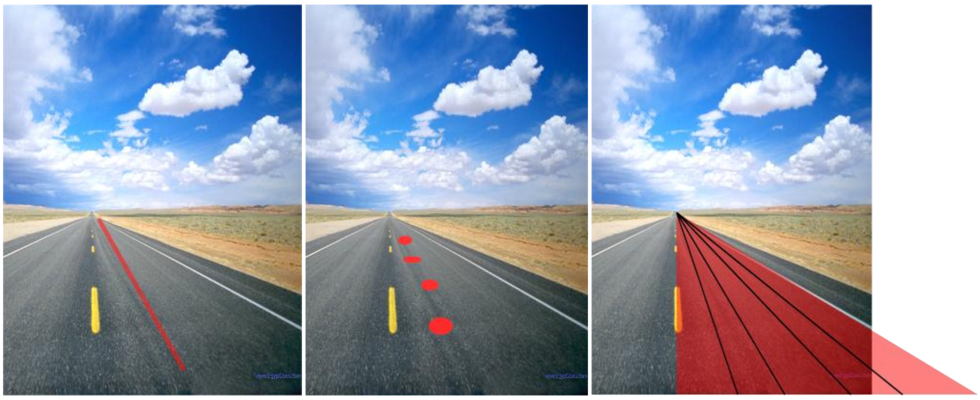
Figure 5. MPD (left), sand patch - MTD (center), LCMS - RPI (right)

The LCMS calculates macro-texture values via a digital sand patch model using the following proposed Road Porosity Index (RPI). We define the RPI index as the volume of the voids in the road surface that would be occupied by the sand (from the sand patch method) divided by a user defined surface area. Since the standard sand patch method specifies that texture should not be measured at locations where cracking or other surface defects are present we subtract the volume of 'holes' present because of cracking, ravelling or other defects from the RPI calculation. Figure 6 illustrates and defines the RPI or digital sand patch model. The digital sand patch method implemented with the LCMS thus allows texture to be evaluated continuously over the complete road surface instead of measuring only a single point inside a wheel path (MPD). The RPI can be calculated over any user definable surface area but LCMS reports by default the macro-texture values within the 5 standard AASHTO bands (center, right and left wheel paths and outside bands) as illustrated on figure 5.

$$RPI = \frac{(Vol_{air\ void} - Vol_{ravelling} - Vol_{cracks})}{Surface\ Area}$$

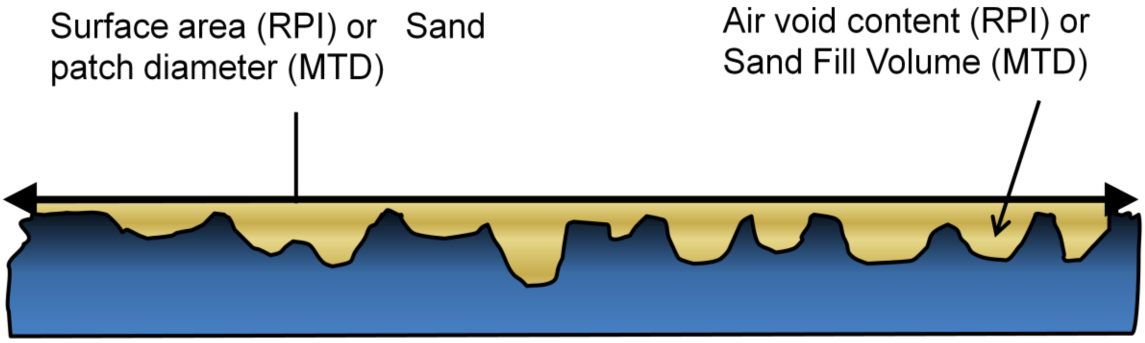

Figure 6. Digital Sand Patch model – Road Porosity Index (RPI)

3D Range Data

The 3D data acquired by the LCMS system measures the distance from the sensor to the surface for every sampled point on the road. In a range image the height can vary along the cross section of the road. The areas in the wheel path can be deeper than the sides and would correspond to the presence of ruts. Height variations can also be observed in the longitudinal direction due to variations in longitudinal profiles of the road causing movements in the suspension of the vehicle holding the sensors. These large-scale height variations correspond to the low-spatial frequency content of the range information in the longitudinal direction. Most features that need to be detected are located in the high-spatial frequency portion of the range data. The figure 7 shows a 2m (half lane) transverse profile where the general depression of the profile corresponds to the presence of a rut, the sharp drop in the center of the profile corresponds to a crack point and the height variations (in blue) around the red line correspond to the macro-texture of the road surface.

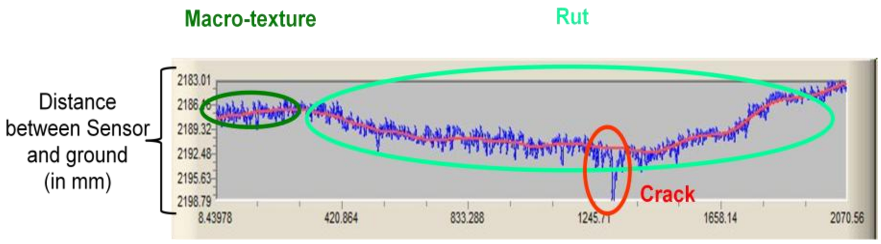

Figure 7. LCMS (half lane) 2 m transverse profile showing ruts, cracks and texture.

Figure 8 show a 2 by 2 meter road section acquired at a location where two very different types of asphalt join together. It is easily apparent from the data that the LCMS system has the necessary resolution to distinguish between these types of textures.

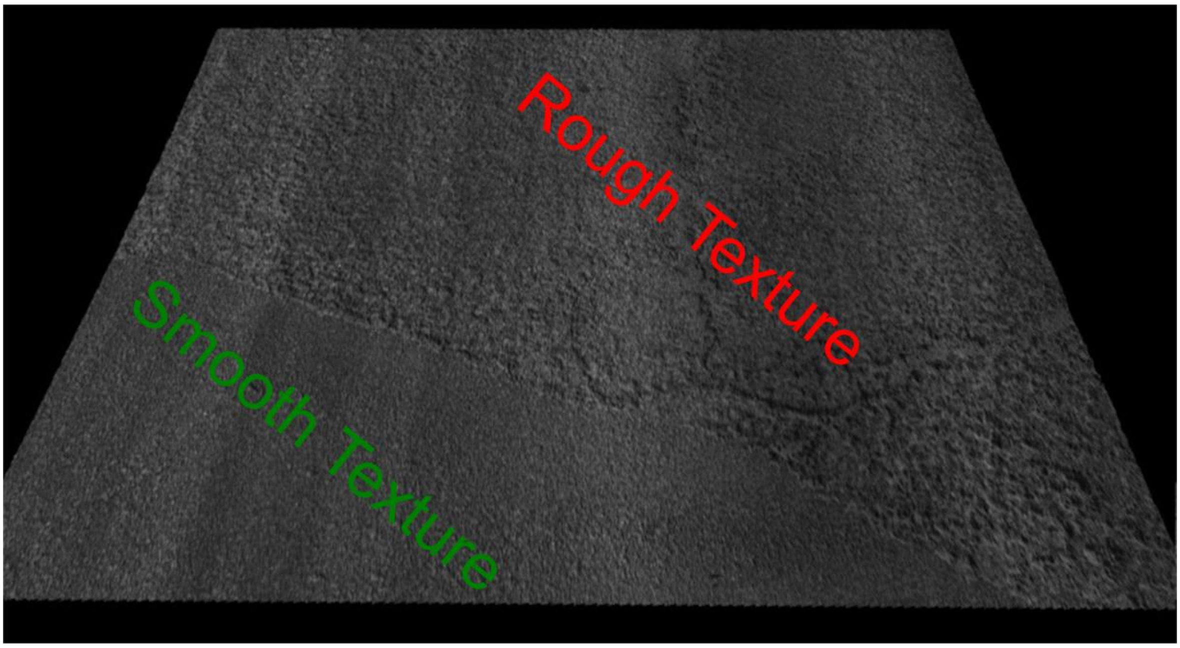

Figure 8. LCMS 2 m x 2m section showing both rough and smooth road texture.

Macro-texture results

In order to measure the capacity of the system and model to reliably evaluate macro-texture several tests were done on test sections in both Quebec (MTQ) and in Alabama (AL DOT). Figure 9 shows the results of repeated texture measurements on three Alabama test sites. These tests and others confirm the very high repeatability (95%+) of the texture measurements using the RPI model and the LCMS.

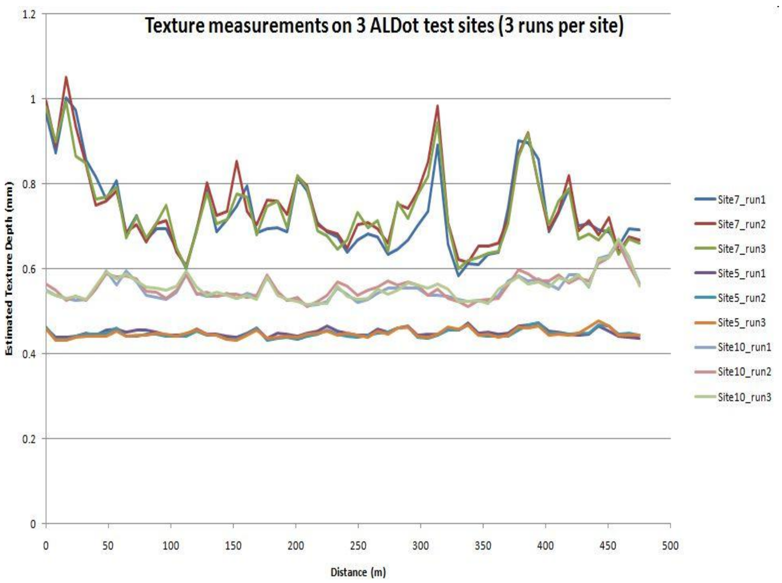

Figure 9. Texture measurements (3 runs, 3 sites) using RPI model and LCMS.

In order to compare the accuracy of the RPI model several tests were done on test sections in Quebec (MTQ) on several pavements and comparing the results with MPD measurements collected by a standard 64kHz texture laser. Figure 10 shows a high degree of correlation (88%) between the RPI – LCMS method as compared to the MPD measurements for this range of asphalt textures.

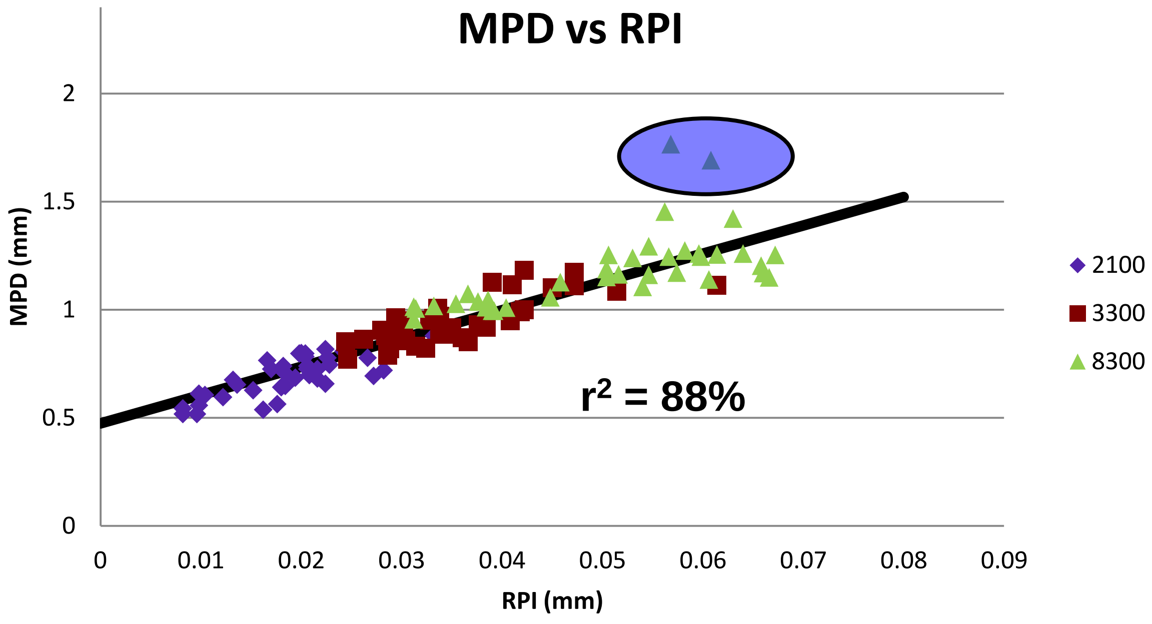

Figure 10. Digital sand patch (RPI) *model vs MPD*

Figure 10 also shows the presence of two outlier points highlighted in a blue oval. When these outlier road sections are analysed in greater detail it quickly comes apparent why these discrepancies exist. Since the RPI model removes voids due to cracks and MPD calculations do not, significant discrepancies will occur due to the presence of cracks especially when they are located in the wheel path area where the MPD texture lasers are positioned. Figure 11 below shows an example of one of these outlier road sections.

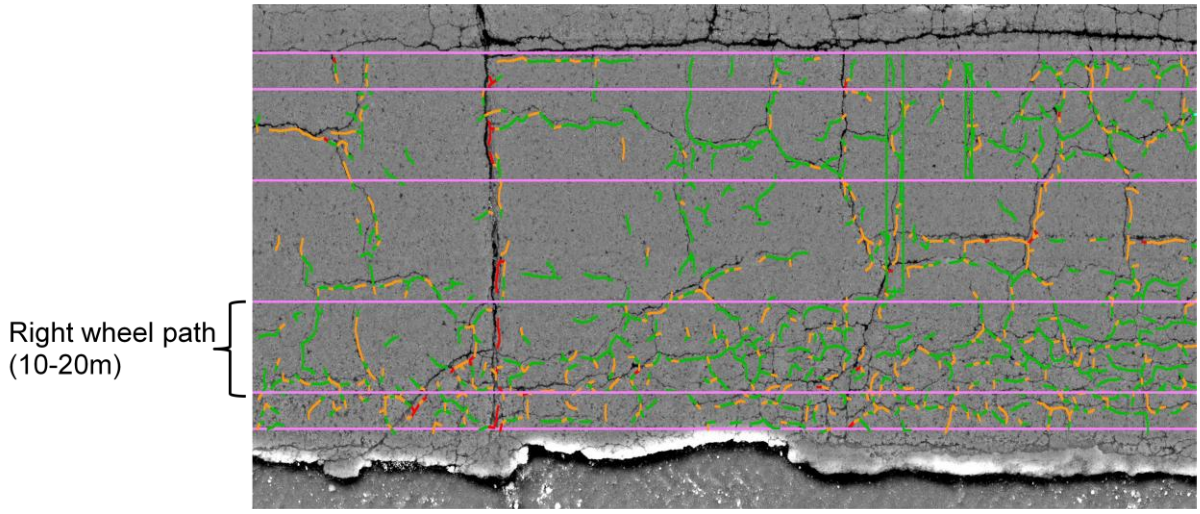

Figure 11. Example of an MPD outlier texture measurement caused by the presence of cracks.

Conclusions

We have presented a road surveying system that is based on two high performance transverse 3D laser profilers that are placed at the rear of an inspection vehicle looking down in such a way as to scan the entire 4m width of the road surface with 1mm resolution. This configuration allows the direct measurement of many different types of surface defects by simultaneously acquiring high resolution 3D and intensity data.

A Road Porosity Index (RPI) was proposed as a model to measure the equivalent of a digital sand patch. The digital sand patch (RPI) method implemented allows texture to be evaluated continuously over the complete road surface and within each of the five AASHTO bands.

The RPI model proposed showed a high degree of precision (95%+) over repeated runs and a good degree of correlation (88%) versus MPD measurements on the tested road sections.

The RPI model was also shown less sensitive to errors caused by the presence of road surface defects such as cracks than is the MPD method.

References

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