Implementation and validation of a new 3D automated pavement cracking measurement equipment

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ABSTRACT: In order to maximise road maintenance funds and optimise the condition of road networks thus saving energy and valuable ressources, pavement management systems need detailed and reliable data on the status of the road network. To date, reliable crack data has proven difficult and expensive to obtain. To solve this problem, over the last 7 years INO (National Optics Institute of Canada) in collaboration with the MTQ (Ministère des Transports du Québec) have been developing and testing a new technology called the LCMS (Laser Crack Measurement System). The LCMS is composed of two high performance 3D laser profilers that are able to measure complete transverse road profiles and to process this data using algorithms that automatically extract crack data including crack type (transverse, longitudinal, alligator) and severity. This system was completed in three main phases. The first (2002) aimed at evaluating the 3D laser profilers and was validated by surveying a road section containing artificial cracks created by saw cuts. The second phase validated the algorithms for the detection and classification of road cracks on 400m road segments in 2005. The third phase aimed to perfect the system and software so as to make them robust enough to complete network level surveys. This paper describes results obtained using the LCMS system during the campaign of 2007 when the system was used to survey 10,000 km of the MTQ's road network. An analysis of these results is presented which demonstrates that such equipment can be very useful to feed and maintain a pavement management system (PMS) database. This paper will also explain the 3D laser technology and algorithms and show examples of data acquisitions and processing results.

KEY WORDS: Pavement, cracks, detection, inspection, PMS

INTRODUCTION

The LCMS system is based on two high performance transverse 3D laser profilers that are placed at the rear of the inspection vehicle looking down in such a way as to scan the entire 4m width of the road surface (Laurent et al. 2008, Laurent and Hébert 2002). Figure 1 illustrates the system installed on the MTQ vehicle. The use of 3D laser profilers allows the system to directly measure surface defects such as cracks, ruts, potholes, macro-texture, joints and patches while the intensity data that is also collected allows for the detection of lane markings and sealed cracks. Table 1 summarizes the specifications of the LCMS system and figure 2 shows a close-up picture of the sensors.

Figure 1: Photo of the LCMS on the MTQ Inspection Vehicle

Table 1: LCMS Specifications

Nbr. of laser profilers	2
Sampling rate (max.)	5600 profiles/s
Vehicle speed	100 km/h (max)
Profile spacing	Adjustable (down to 5mm)
3D points per profile	4160 points
Transverse field-of-view	4 m
Depth range of operation	250 mm
Z-axis (depth) resolution	0.5 mm
X-axis (transverse) resolution	1 mm

Figure 2: Photo of the LCMS System (Sensors and Controller)

The recommended system configuration that was used and tested by the MTQ is the following: two LCMS sensors were placed 2m apart and 2m above the road surface looking down. Instead of placing the sensors at a 90 degree angle perpendicular to the road surface a slight (15 degree) slant was put on the sensors in order to improve the detection of transverse cracks (see figure 3).

With such a configuration it is possible, with the 15 degree tilt angle, to reliably detect both longitudinal and transverse cracks as can be seen with the following illustrations of the sampling intervals for each case. At 100 km/h in the case of transverse cracks, the 15 degree tilt angle results in the fact that each transverse crack will effectively be measured at over 200 different points. For longitudinal cracks, the effective sampling rate is one point every 5 mm.

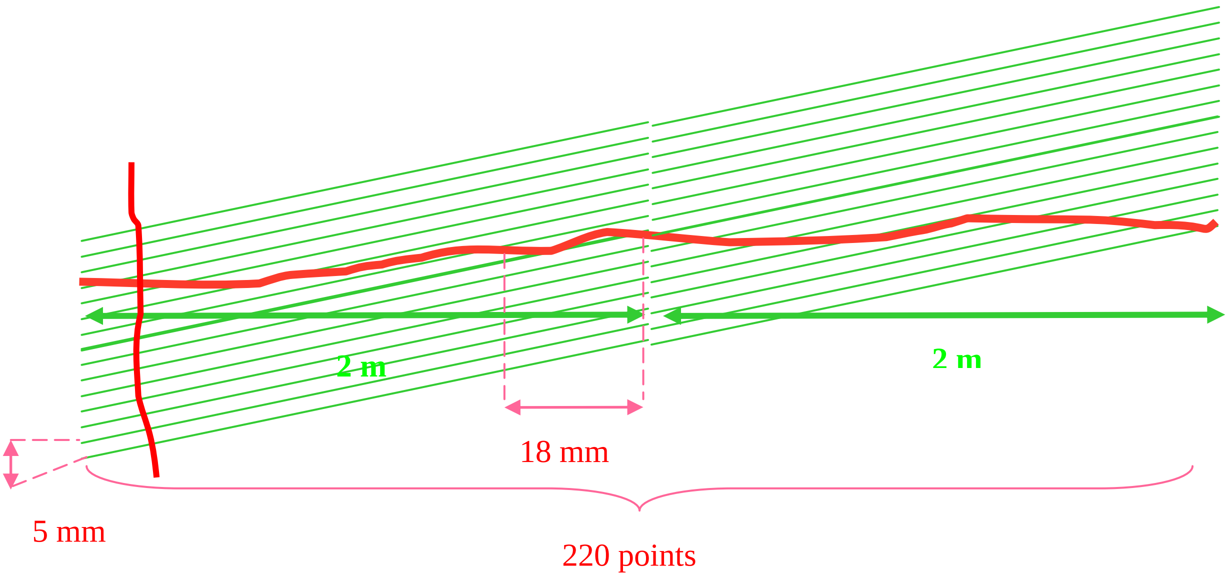

Figure 3: Diagram of the Crack Sampling Interval

1 HARDWARE CONFIGURATION AND DATA

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. The light stripe is projected onto the pavement and its image is captured by the camera. The shape of the pavement is acquired as the inspection vehicle travels along the road using a DMI 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 30 Gb 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 20 Mb/s or 720 Mb per kilometer. The LCMS sensors simultaneously acquire both range and intensity profiles. On one hand, the range profiles give the 3D shape for a transversal portion of the road. On the other hand the intensity profiles are more or less a greyscale one dimensional image of the road. Figure 4 illustrates how the various types of data collected by the LCMS system can be exploited to characterize many types of road features. Figure 5 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 most of the other features.

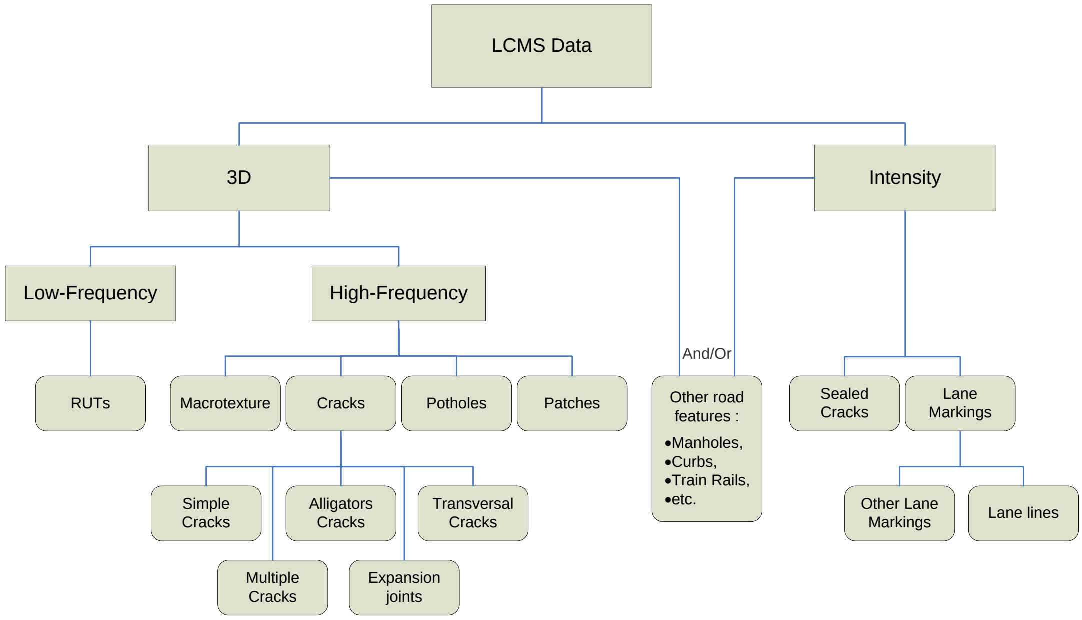

Figure 4: Data analysis library diagram

1.1 Detecting Lane Markings

Intensity profiles provided by the LCMS are actually a continuous picture of the road. The first role of the intensity information is for the detection of road limits. This algorithm relies on the detection of the painted lines used as lane markings to determine the width and position of the road lane (see figure 5). The lane position data is then used by the other detection algorithms to circumscribe the analysis within this region of interest in order to avoid surveying defects outside the lane. Highly reflective painted landmarks are much easier to detect in 2D since they generally appear highly contrasted in the intensity images. With the proper pattern recognition algorithms, various markings can be identified and surveyed. To date, only the detection of lane lines has been implemented and tested. In future work we will also be exploring the possibility of evaluating the 'quality' of the lane marking by computing deterioration as the ratio of the surface of the marking having lost its reflectivity. The following figure shows two intensity images with painted lane marks.

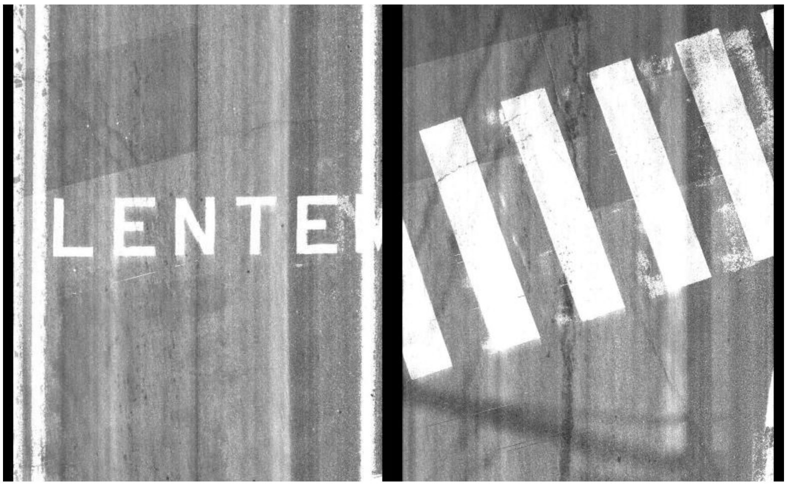

Figure 5: LCMS images of painted lane marks

1.2 Range Data

The 3D data acquired by the LCMS system gives the surface height for every sampled point on the road. The figure (6a) below is an example of the raw range data acquired by the sensors. In this image, elevation has been converted to a gray level. The brighter the point, the lower is the surface. As can be seen, the height varies along the cross section of the road. The areas in the wheel path are usually deeper than the sides and thus appear brighter this would correspond to the presence of ruts. Height variations can also be observed in the longitudinal direction. This is due to the suspension of the vehicle holding the sensors. In this case, the variation comes from the changes in the sensor height rather than the road surface itself. This phenomenon does not affect rut measurements since these are made on a profile-by-profile basis whereas the suspension motion causes relative height changes from one profile to the next. 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. For instance, cracks correspond to very sudden, sharp transitions in height i.e. high frequencies.

The first step in range analysis is to separate the high frequency content from the low one. This is performed using a specially designed filter. Figure 6b shows the result of this process. The low frequency part is what can be referred to as the mean surface. The high-frequency part clearly shows the presence of surface defects (cracks). Once separated, both frequency parts are then used as an input to the various feature detection algorithms.

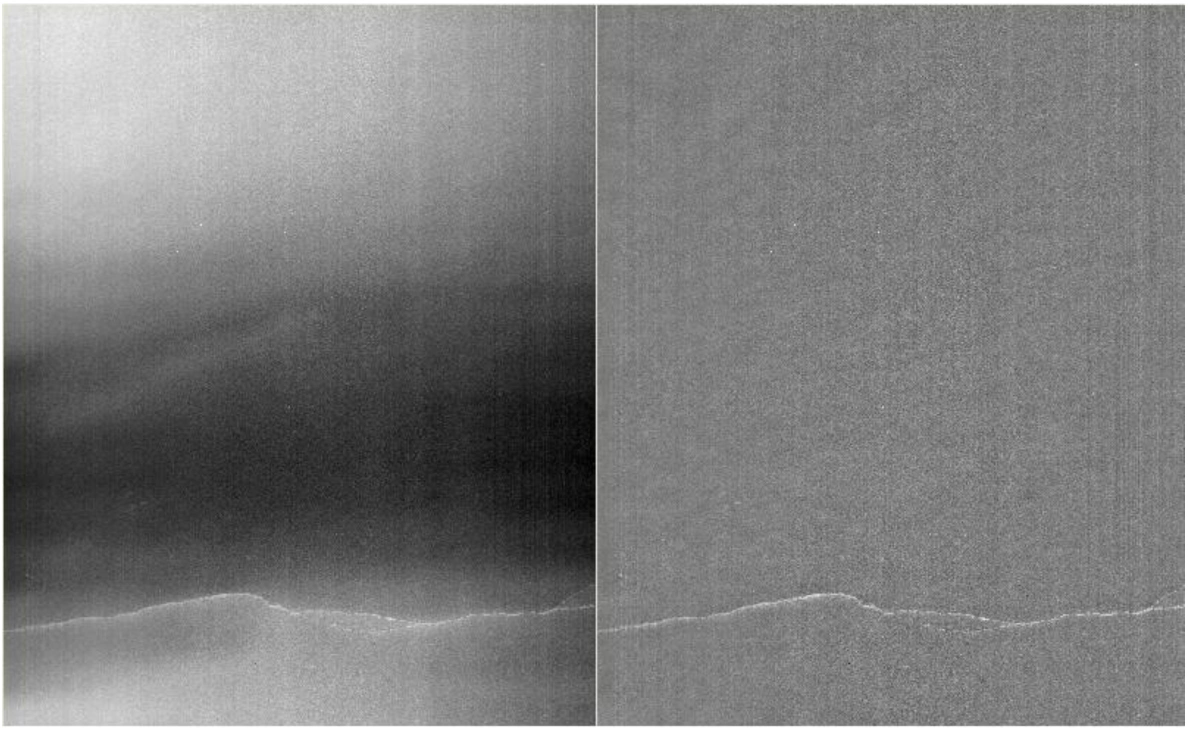

Figure 6: (a) Range (raw) and (b) Range (corrected) images

1.3 Macrotexture

Macrotexture is important for several reasons, for example it can help estimate the tire/road friction level, water runoff and aquaplaning conditions and tire/road noise levels produced just to name these. Macrotexture can be evaluated by applying the ISO 13473 norm. This standard requires the calculation of the mean profile depth (MPD). To calculate the MPD, the profile is divided into small 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. See figure 7 below.

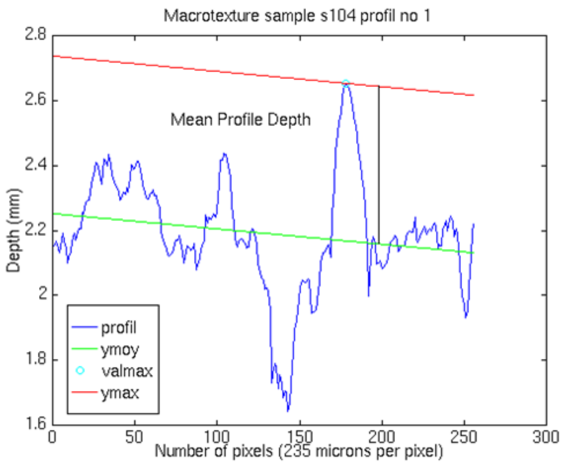

Figure 7 : Macrotexture Analysis Example

1.4 Cracking

Detecting cracks reliably is far more complex than applying a threshold on a range image. As mentioned previously, 3D profile data needs to be detrended due to the effects of rutting and vehicle movements. Macrotexture is also a problem; road surfaces have very variable macrotexture from one section to the next and even from one side of the lane to the other. For example, on roads with low macrotexture we can hope to detect very small cracks which will be harder to detect on more highly textured surfaces. It is thus necessary to evaluate and to adapt the thresholding operations based on the macrotexture of the road. Once the thresholding operation is performed, a binary image is obtained where the remaining active pixels are potential cracks. This binary image is then filtered to remove many of the false detections which are caused by asperities in the road surface which are not cracks on the pavement. At this point in the processing, most of the remaining pixels can correctly be identified to existing cracks, however many of these crack segments need to be joined together to avoid multiple detections of the same crack.

2 MTQ PROTOCOL

After the detection process, the next step consists in the characterization of the cracks. This was done using the MTQ protocol. With this protocol, severity level of a crack is determined by evaluating its width (opening). For a single continuous crack, the severity is evaluated every 5 cm. In order to facilitate the interpretation of the detection results, the cracks are classified into three categories as shown in the table below:

Table 2 : Cracks Categories

Severity level	**Width**
Weak	Less than 5 mm
Medium	Between 5 mm and 20 mm
Severe	More than 20 mm

The cracks were also grouped into two main categories: longitudinal and transverse cracks. A transverse crack is defined as a crack which has a skew angle of less than 20 degrees. Furthermore, transverse cracks are further divided into complete and incomplete types. A complete transverse crack covers more than 75% of the pavement width. An incomplete transverse crack covers between 25% and 75% of the road lane. Any crack which is less than 25% of the road width is not considered as a transverse crack. Finally, the transverse cracks are graded as weak, medium or severe depending on its maximum severity (width) which composes at least 25% of the transverse crack. The definition of a longitudinal crack is simply a crack that has not been classified as a transverse crack. However, longitudinal cracks are further refined into three subcategories: simple, multiple and alligator.

3 RESULTS

During the summer campaign of 2007 the LCMS system was used by the MTQ to survey 10,000 km of its road network. In order to validate the system, an independent 3rd party under the supervision of the MTQ was mandated to manually qualify the crack detection results of LCMS system over the entire survey. To do this each 10m section was visually analyzed and the results were categorized in 3 classes (good, average and bad). A forth class (NA) was used when, for what ever reason, it was not possible to correctly evaluate a section. Figure 8 shows three examples of good, average and bad crack detection results on a 10m pavement section. Transverse cracks are identified with a bounding box. Regions with a red cross indicate the presence of alligator cracking. Regions with a yellow cross indicate regions with multiple cracks. Green, yellow and red cracks represent weak, medium and severe crack severities respectively. Table 3 shows the results of the compilation of the manual evaluation. The final results are deemed excellent as the overall 'Good' rating reaches 96.5%.

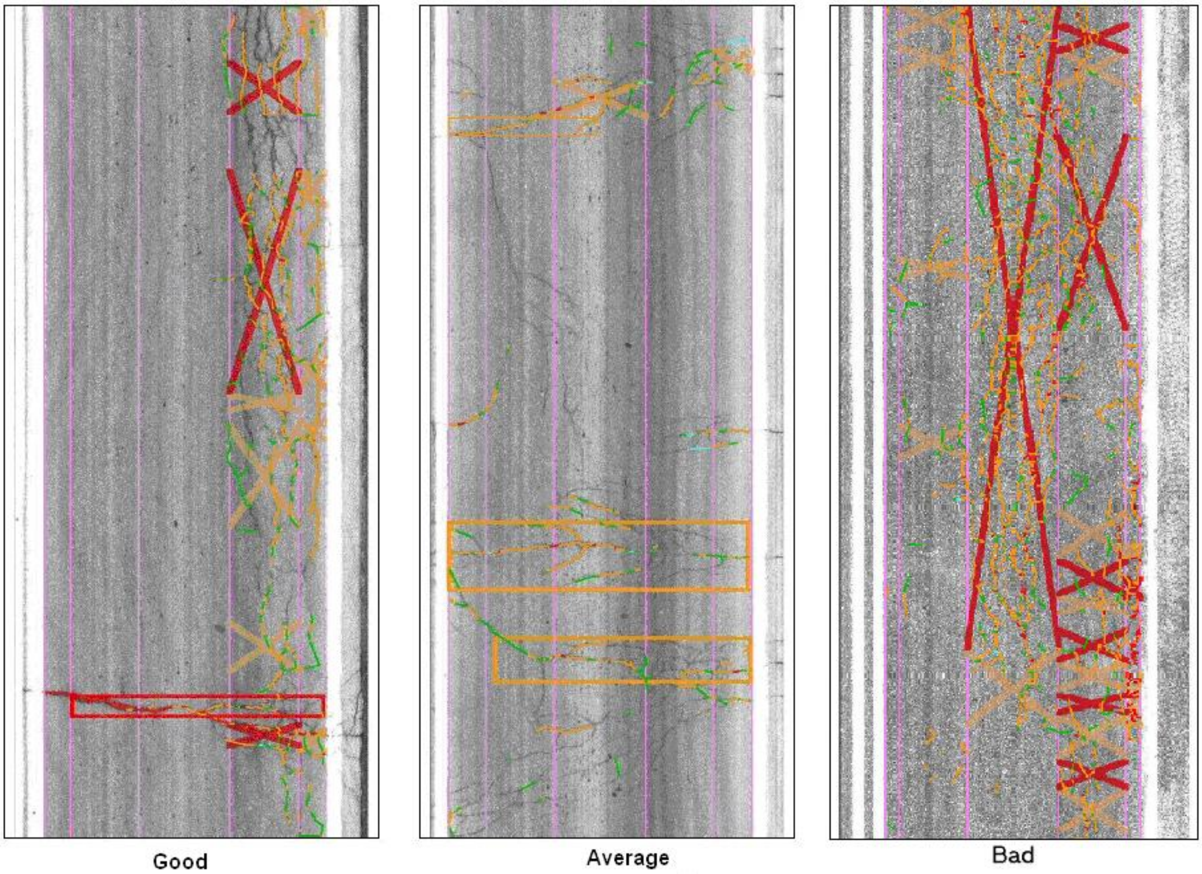

Figure 8: Three crack detection results (Examples of good, average and bad results)

Table 3: 10,000 km survey results

District #	Total (10 m sections)	Results (manual classification)							
		Number of images (10m sections)				Proportion (%)			
		Good	Average	Bad	NA	Good	Average	Bad	NA
84	35288	34144	310	144	690	96,8	0,9	0,4	2,0
85	4243	4101	53	51	38	96,7	1,2	1,2	0,9
86	147903	144040	516	1520	1827	97,4	0,3	1,0	1,2
87	149926	138453	1170	5728	4575	92,3	0,8	3,8	3,1
88	189097	183010	1064	2002	3021	96,8	0,6	1,1	1,6
89	125003	121835	442	2015	711	97,5	0,4	1,6	0,6
90	123653	116930	2980	2434	1309	94,6	2,4	2,0	1,1
91 & 92	215513	213142	197	956	1218	98,9	0,1	0,4	0,6
Total	**990626**	**955655**	**6732**	**14850**	**13389**	**96,5**	**0,7**	**1,5**	**1,4**

A second evaluation test was performed on 770 km of the MTQ road network using 77 000 images of 10m sections acquired by the LCMS system that were compared to images of the same sections measured by a video camera. This time, a more detailed analysis was done to evaluate the capacity of the LCMS to detect and correctly classify the following road surface characteristics: longitudinal cracks, transverse cracks, incomplete transverse cracks, patches and potholes). Again, each 10m section was visual analyzed and the detection results were classified as follows: much less (missing 2 or more cracks), less (missing 1 crack), good, more (1 or more false detections). Table 4 summarizes these results. Overall, the results are very good except for what might be expected for the detection of the transverse cracks. The table indicates that a large number of transverse cracks were missed (33.4%). However, most of these missing cracks were complete transverse cracks that were detected as incomplete transverse cracks (80%). Also, since these tests were done, the acquisition rate of the LCMS sensors has been multiplied by 4, the performance of the new sensors is expected to greatly increase the detection rate of the transverse cracks.

Table 4: 770 km detailed survey results

Defect type	Results (manual classification of 77,000 images) Proportion (%)			
	Much Less	Less	Good	More
Longitudinal cracks	1.1	1.9	95.5	1.6
Transverse cracks	6.5	26.9	63.2	3.4
Patches	6.5	18.2	74.0	1.5
Potholes	0.5	7.5	89.6	2.5

4 CONCLUSION

We have presented a 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. This configuration allows the system to directly measure many different types of surface defects by simultaneously acquiring high resolution 3D and intensity data. Examples of different algorithms and results were shown using the 3D data to detect cracks while the intensity data is used for the detection of lane markings.

The LCMS system was tested at the network level (10000km) to evaluate the system's performance at the task of automatic detection and classification of cracks. The system was evaluated to be over 95% correct in the general classification of cracks when the 3D crack data was visually present in the images.

The LCMS system was also compared to 770 km of detailed manual video analysis techniques and the system performance was measured to be: 95% accurate for the detection of longitudinal cracks, and 63% accurate for the detection of transverse cracks with a majority (80%) of the missing transverse cracks being partially detected as incomplete transverse cracks.

5 REFERENCES

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