AUTOMATED DETECTION OF SEALED CRACKS USING 2D AND 3D ROAD SURFACE DATA

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Abstract: Reliable cracking data has proven difficult and expensive to obtain using cameras and video systems because of the lack of good automated 2D image processing crack detection algorithms. To solve this problem, 3D technology such as the LCMS (Laser Crack Measurement System) has been used to obtain automated reliable and repeatable cracking data.

The LCMS system has been widely used for automated crack detection on a variety of road surfaces (DGA, porous, chipseal, concrete) in over 35 different countries. While 3D techniques [1] [2] [3] [4] [5] have proven reliable at detecting open cracks these systems have not been used for detecting sealed cracks. These sensors however also often produce intensity (2D) images that are used to detect lane markings. Using this intensity (2D) data for the automated detection of sealed cracks has also proven unreliable because sealed cracks can sometimes be darker or brighter than the surrounding pavement in the images and tire marks and other features can also cause false detections.

This article will demonstrate that the accuracy of sealed crack detection can be improved by using both 2D intensity data and 3D texture information evaluated from the 3D data. To do this 3D texture evaluation algorithms are described and implemented in order to generate a complete texture map of the road surface. The intensity images are also processed in order to extract dark and light areas of the appropriate geometry (size and shape of sealed cracks). The combination of the results from both sets of processed data is then used to detect and validate the presence of sealed cracks.

Introduction

In order to optimize road maintenance funds and improve the condition of road networks, asset managers need detailed and reliable data on the status of the road network. 3D technology such as the LCMS (Laser Crack Measurement System) has been used to obtain automated reliable and repeatable cracking data on a variety of road surfaces (DGA, porous, chipseal, concrete). 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 maps and severity. Also detected automatically are ruts (depth, type), macro-texture (digital sand patch) and raveling (loss of aggregates). This paper describes results obtained recently regarding road tests and validation of this technology for the detection of both sealed and unsealed cracks.

Hardware Configuration

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 strip 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 signal from an odometer to synchronize the sensor acquisition (see figure 1). 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. It is important to note that in addition to the 3D profiles the LCMS acquires the intensity of the reflection of the laser at each 3D point thus creating an intensity 2D image of the pavement while simultaneously measuring the shape. Figure 2 shows range (distance) image and intensity (2D) data acquired from the LCMS. A 3D image can be generated from the range and intensity data as shown.

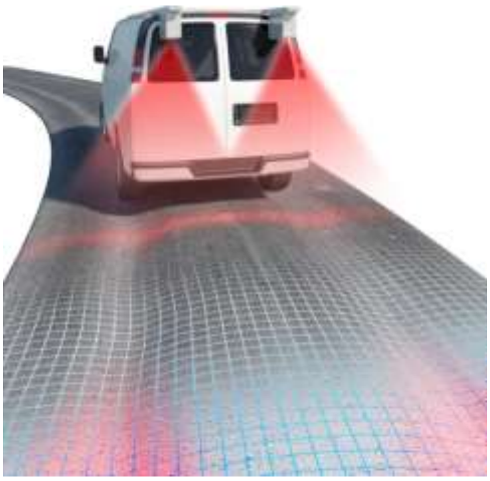


Figure 1. LCMS on an inspection vehicle.

Nbr. of laser profilers	2
Sampling rate (max.)	11,200 profiles/s
Vehicle speed	100 km/h (max)
Profile spacing	Adjustable
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.*

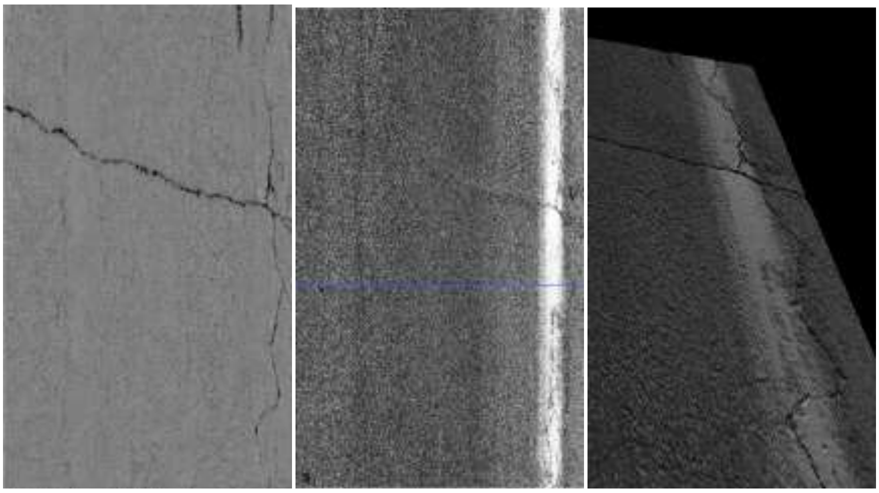


Figure 2. LCMS data type – Range (left) – Intensity (center) – 3D merged (right).

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. The previous image (above left) shows a range data image acquired by the sensors. In this image, elevation has been converted to a gray level. The darker the point, the lower is the surface. 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 thus appear darker this 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. 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 3b 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) and texture. Once separated, both frequency parts are then used as an input to the various feature detection algorithms the high frequency component is called the rectified range image as shown below.

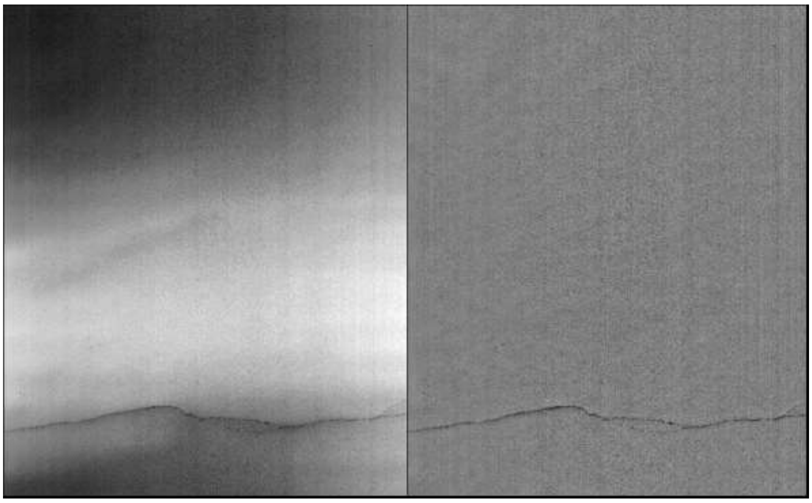


Figure 3: (a) Range (raw) and (b) Range (rectified) images

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 a few. Macrotexture can be evaluated by applying the ASTM 1845-01 norm [6]. This standard requires the calculation of the mean profile depth (MPD). To calculate the MPD, 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. MPD is the only way possible to evaluate texture using standard single point (64 kHz) laser sensors. The LCMS however acquires sufficiently dense 3D data to not only measure standard MPD but also to evaluate MTD texture (mean texture depth) using a digital model of the sand patch method (ASTM E965) [7] as shown on figure 4.

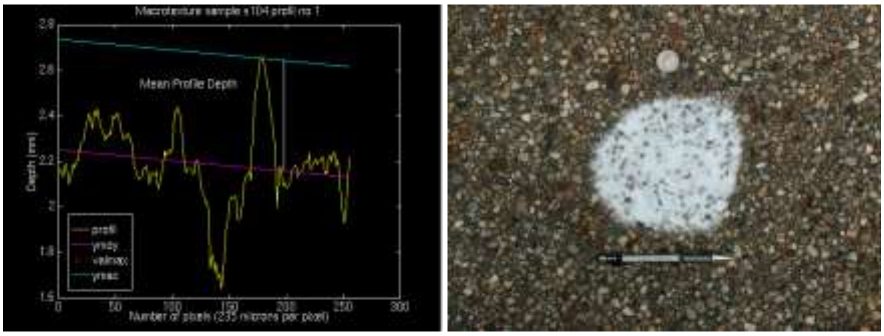


Figure 4. MPD vs sand patch.

The digital sand patch model MTD calculates the volume of the voids in the road surface that would be occupied by the sand (from the sand patch method) divided by a surface area. The digital sand patch method implemented allows texture to be evaluated continuously over the complete road surface instead of measuring only a single point inside a wheel path. The MTD results can be mapped into road surface texture image where the color corresponds to texture levels. In this example bleeding or flushing on the road surface corresponds to areas of very low MTD (0.2mm) shown in blue (figure 5).

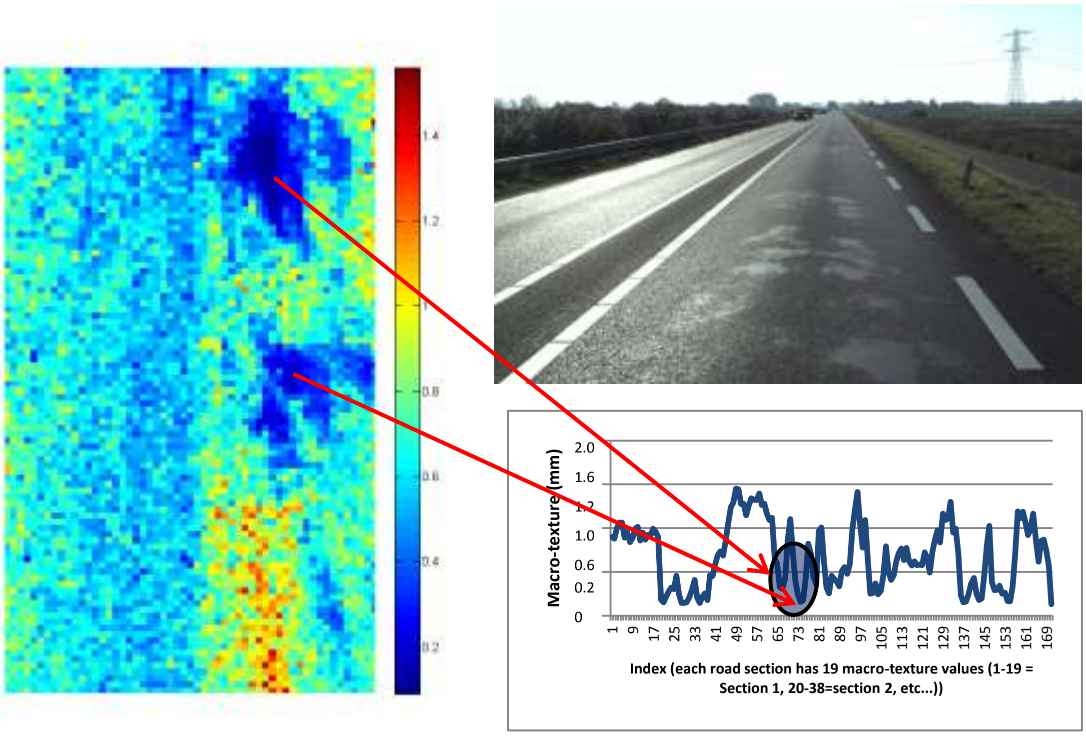


Figure 5. Texture (MTD) map of a road section (blue is low texture)

Cracking

Although the basis of 3D crack detection is finding the crack points that are below the road surface, detecting cracks reliably is far more complex than applying a threshold on a range image. As mentioned previously the 3D data needs to be rectified to remove 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. In general to detect a crack using 3D techniques the majority of the crack points must be below the average depth of the macro-texture of the road surface. For example, on roads with weak 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 processing operations based on the texture and type of road surface. Once the detection 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 and other features 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. After the detection process, the next step consists in the characterization of the cracks. The severity level of a crack is determined by evaluating its average width (opening) typically cracks will be separated in low, medium and high severity levels.

The LCMS system has been used to survey millions of lane kilometers over the past 6 years and has demonstrated its ability to automatically detect cracks [3]. Independent 3rd party users and DOTs have also evaluated the system [8] [9]. Typical results include repeatability tests that usually attain 95%+ in many different conditions.

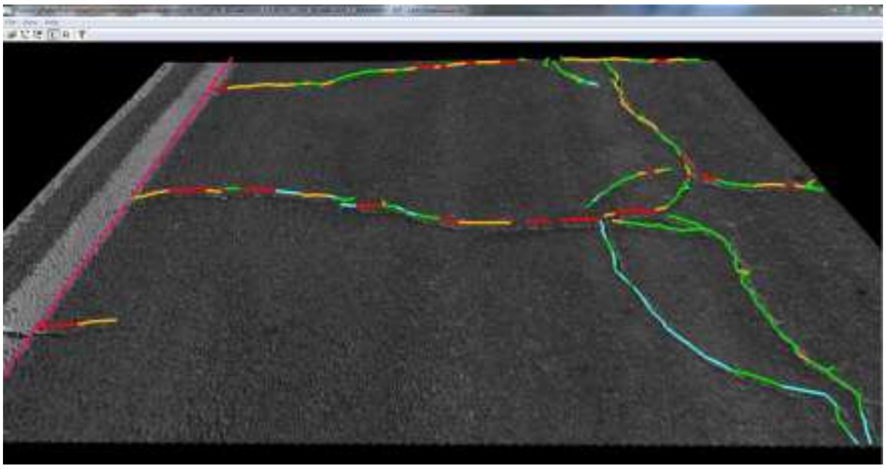


Figure 6. Example crack detection results (severity = color code).

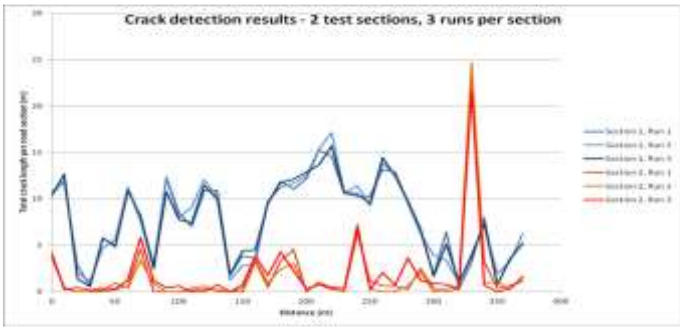


Figure 7. Repeatability results (3 passes) on two MTQ road sections.

Sealed cracks

The images (Figure 8) below demonstrate what the majority of sealed cracks look like, i.e. the sealed cracks are very dark in the images due to the black color of the sealant. This makes these cracks very visible in the intensity images (high contrast) and the fact that they are sealed makes them virtually ‘invisible’ in the range images compared to the unsealed cracks that appear as dark lines in the rectified range images.

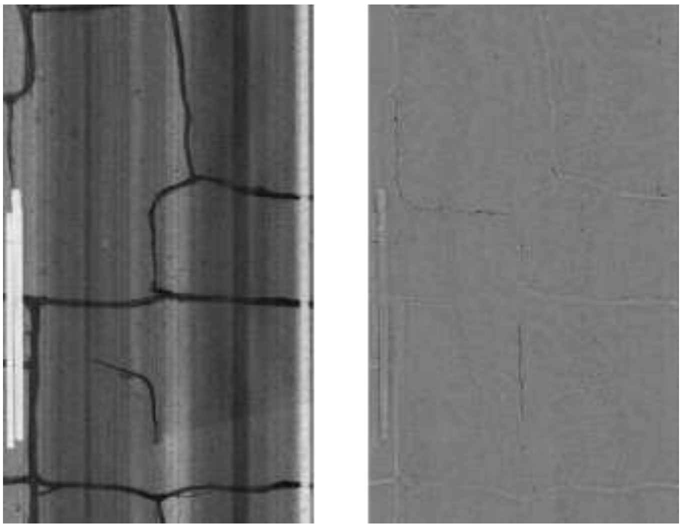


Figure 8. Example sealed cracks: Intensity image (left) Rectified range (right)

However, the next images (Figure 9a) shown below demonstrates that in some cases the sealed cracks do not appear dark, in fact their color can vary greatly ranging from black to shiny white. Thus intensity alone cannot be used as a reliable indicator of their presence.

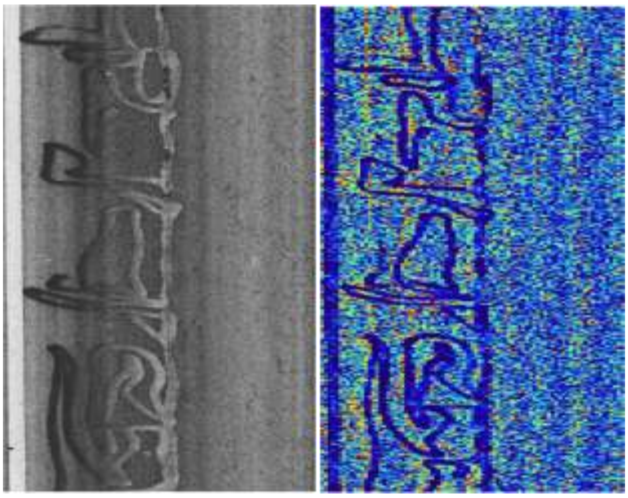


Figure 9. Example sealed cracks: a) Intensity image b)Texture map

Not being able to rely on color and since sealed cracks do not have a 3D depth associated with them as do unsealed open cracks we attempted to detect them using texture measurements as the surface of a sealed crack is very smooth (low MPD values) as the sealant used not only fills the crack but also the air voids of the asphalt texture. Figure 9b shows the texture color map of the roadsection with sealed cracks it is clear that these areas show very low texture MTD values (blue).

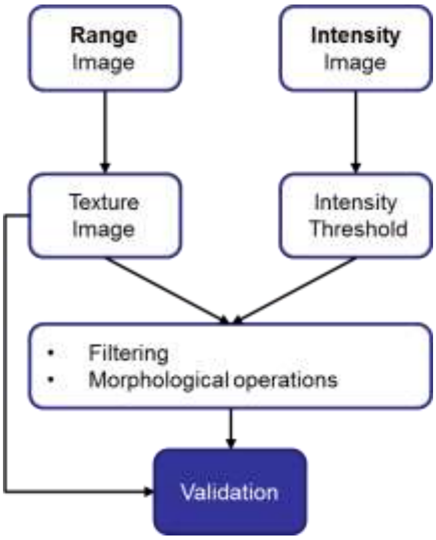
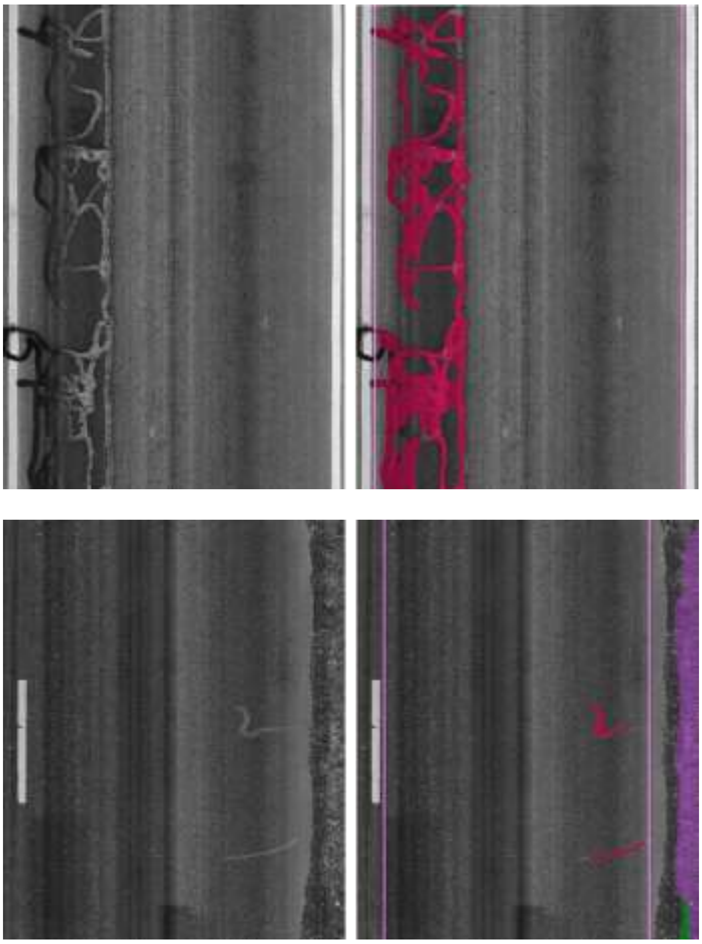


Figure 2. Main steps in the detection of sealed cracks

Figure 10 describes the main steps in the algorithm implemented. This algorithm uses in fact both intensity and range (texture) data to detect sealed cracks. The intensity image analysis algorithm looks for dark or light areas that are of different color then the surrounding background (road surface) and flags these areas as possible sealed cracks. As mentioned above the range data 3D texture is evaluated (MTD) and areas of low texture are detected as possible sealed cracks. All candidate areas are then evaluated as to their shape conformity to make sure they are crack shaped i.e. much longer than wide and with a width ranging up to a few centimeters. A final validation is done to make sure all remaining sealed crack candidate areas have both appropriate texture and color characteristics before being accepted.

Results



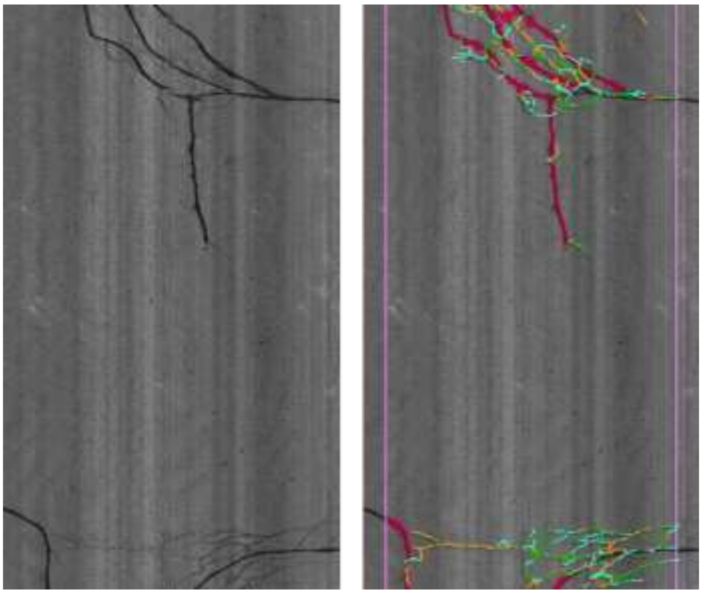


Figure 3. Three examples of sealed cracks detection on road surfaces (results in red)

Conclusions

Initial road tests on sealed crack detection were conducted with algorithms identifying only black sealed cracks based on intensity images only. These tests allowed us to acquire a set of 100+ road sections where the use of an intensity based algorithm alone for the detection of sealed cracks did not work. These examples were taken from different surveys covering several hundreds of kilometers of roads. With the algorithm described above using both 3D texture and intensity combined, over 90% of the sealed cracks missed by the initial algorithm were correctly detected with less than 5% false positives (visually it is never 100% certain in the images if a sealed crack is or isn't present, no on-site validation type ground truth was attempted).

Currently network level testing has been going on over the last six months with two different vehicles in operation in both New Zealand and the USA. No obvious or systematic cases of false or missing detections of sealed cracks have been noted. However, it has been noted that as the sealed crack ages and the sealant wears away and chipping starts. The chipping of the sealant and the texture of the road thus begin to appear increasing MTD (texture) values that can over time cause the sealed crack to be missed by this algorithm.

References

[1] Laurent, J., Lefebvre, D., Samson E. (2008). *Development of a New 3D Transverse Profiling System for the Automatic Measurement of Road Cracks.* Proceedings of the 6th Symposium on Pavement Surface Caracteristics, Portoroz, Slovenia.

[2] Laurent, J., Hébert JF. (2002). *High Performance 3D Sensors for the Characterization of Road Surface Defects.* Proceedings of the IAPR Workshop on Machine Vision Applications, Nara, Japan.

[3] Laurent, J., D. Lefebvre, and E. Samson. Development of a New 3D Transverse Laser Profiling System for the Automatic Measurement of Road Cracks. *Proc., 6th International Symposium on Pavement Surface* ,2008. Bursanescu, L., M. Bursanescu, M. Hamdi, A. Lardigue, and D. Paiement. Three-Dimensional Infrared Laser Vision System for Road Surface Features Analysis. *Proceedings of SPIE,* Vol. 4430, 2001, pp. 801–808.

[4] Wang, K. C. P. *Automated Survey of Pavement Distress Based on 2D and 3D Laser Images.* Mack–Blackwell Transportation Center, University of Arkansas, Fayetteville, 2011.

[5] Li, Q., Y. Ming, Y. Xun, and B. Xu. A Real-Time 3D Scanning System for Pavement Distortion Inspection. *Measurement Science and Technology,* Vol. 21, No. 1, 2010, p. 015702.

[6] ASTM E1845 - 09 *Standard Practice for Calculating Pavement Macrotexture Mean Profile* Depth, Active Standard ASTM E1845 Developed by Subcommittee: E17.23.

[7] ASTM E965 - 96 *(2006) Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique,* Active Standard ASTM E965 Developed by Subcommittee : E17.23

[8] Wix, R & Leschinski, R 2012, '*Cracking a tale of four systems'*, *ARRB conference, 25th, 2012, Perth, Western Australia,* ARRB Group, Vermont South, Vic, 20 pp.

[9] Wix, R & Leschinski, August 2013, '*3D TECHNOLOGY FOR MANAGING PAVEMENTS',* Institute of Public Works Engineering Australia conference , Darwin, Australia