Use of close range terrestrial photogrammetry to assess accelerated wear of asphalt concrete surface course mixes

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ABSTRACT: This paper reports the initial findings of a study to assess the use of close range terrestrial photogrammetry to model the wear of asphalt surface course mixes. Slabs of 10mm asphalt concrete were subjected to accelerated wear under laboratory conditions using the University of Ulster Road Test Machine. Macro-texture profiles were generated from photo stereo pairs. The output data was compared to texture depth change determined using the conventional volumetric sand patch test. The initial findings suggest that this methodology based on digital imagery can be used to model highway surface change and provide improved understanding of the processes at the tyre road surface interface.

1 INTRODUCTION

Photogrammetry was first used by French military officer Aime Lausedat in 1851. In less than ten years Meydenbauer had developed photogrammetric techniques to document building surveys predating aerial applications for which the method is now best known (Quinn, 2006). Development of terrestrial photogrammetry from plane table techniques through analog to contemporary digital processing has greatly enhanced its usefulness and potential across many aspects of civil engineering and aligned disciplines.

The method was used by Georgopoulos et al (1995) to develop an algorithm designed to approximate the expert's judgement in evaluating roadway surface defects from digital images. With subsequent development of camera technology and proprietary post processing software Chandler et al (2005) found that consumer grade digital cameras could produce images from which sub-millimetre digital elevation models could be produced at close range.

This paper reports the initial findings of a study to use photogrammetric techniques, first demonstrated by Gendy and Shalaby (2007) to quantify texture depth change for highway surface course mixes under accelerated laboratory trafficking conditions.

The photogrammetric method was chosen as it offers a number of benefits to alternative techniques. The examples reported in this paper are derived from analysis of stereo photo pairs captured under natural light. Although it may be argued that enhanced lighting is required to illuminate the full texture depth of the pavement surface, it may also be argued that the tyre does not penetrate to the full depth of the macrotexture. Therefore it is reasonable to conclude that the most significant change in profile at micro and macro-scales occur towards the top of the trafficked interface surface.

Another advantage is simplicity of the method. Specialist photographic analytical skills are not required as post processing and stereo matching are carried out using proprietary software. Close range sub-pixel accuracy is achievable with modest camera technology which has significant implications for rapid capture surface monitoring. This made it ideally suited for exploratory investigation under the accelerated laboratory conditions.

The key aim of the initial investigation was to assess the potential usefulness of close range i.e. approximately 1m camera to object distance photogrammetry. According to Luhman et al

(2006) these much shorter imaging ranges and alternative recording techniques differentiate close range photgrammetry from its aerial and satellite equivalents.
The initial investigation had several objectives related to real world scenarios i.e. to quantify aggregate wear and to explore additional uses of the data e.g. the application of triangular irregular network (TIN) meshes to model changes in the characteristics of surfaces subject to increasing trafficking under simulated conditions.

2 METHODOLOGY

The data reported in this paper was determined using slabs of proprietary 10mm nominal size asphalt concrete surface course 305 x 305 x 50mm in size prepared using roller compaction. The slabs were subjected to simulated laboratory trafficking using the Road Test Machine (RTM) at the University of Ulster.

Up to 10 slabs can be placed on a table rotating at 10rpm and 2 full-size car tyres used to simulate trafficking conditions. The RTM is located in a temperature controlled room. The work reported in this paper was carried out a 10^0C. This specific accelerated testing protocol is used in the UK to assess the wear characteristics of high friction surfacing materials and is detailed in Appendix H of TRL Report 176 (Nicholls 1997).

Prior to testing two sets of stereo image pairs were taken of each slab using a calibrated 10 megapixel Canon SLR camera with a 28mm to 55mm zoom lens. The slabs were placed on the RTM table and subjected to increasing number of wheel passes. Testing was stopped after 500, 1000, 2000, 4000, 16000 and 100,000 wheel passes and further digital image pairs recorded.

The camera was recalibrated for a nominal 55mm focal length immediately prior to each set of photographs. Calibration was based on correlation of five images obtained of a hybrid proprietary calibration pattern generated by the post processing software. Only one stereo pair was selected for post processing in each case. The baseline to height ratio was maintained at 0.1 to 0.3 and captured normal to the plane of the asphalt slab.

The stereo image pairs of each sample were post processed using proprietary digital photogrammetric software. The processed images were transformed within a prescribed reference framework and projected onto a two dimensional plane.

A stainless steel mesh overlay was used to provide control for post processing and to indicate possible differential distortion of the slab due to trafficking. At least six common points were cross matched with the aid of a corner detect algorithm within the post processing software. Following transformation slab surfaces were modelled using TIN meshes to generate 3D images.

These were used to assess a range of parameters and variables. For example, it is possible to determine how the negative texture of the asphalt concrete mixes develop with time. The software can show how the perimeter of either an individual aggregate particle or a given area of the slab changes with increasing number of wheel passes. It is possible to quantify texture in relation to a reference plane that can be specified at 0.5mm intervals vertically down through the TIN mesh. The images may also be projected as contour and photo realistic texture maps.

3 RESULTS

Figure 1 shows an area of the trafficked asphalt slab as a simple ortho-rectified digital image. The lighter areas are the trafficked slab/tyre interface whilst the darker areas are the negative texture of the asphalt concrete. Figure 2 shows the same image with a superimposed 0.1mm vertical contour interval.

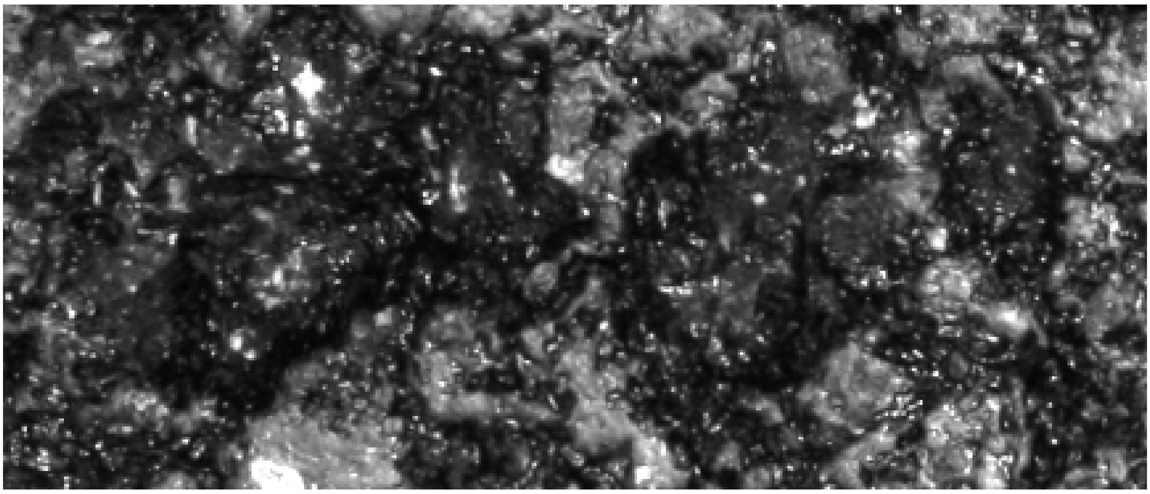

Figure 1. Simple orthorectified digital image of trafficked asphalt concrete slab surface.

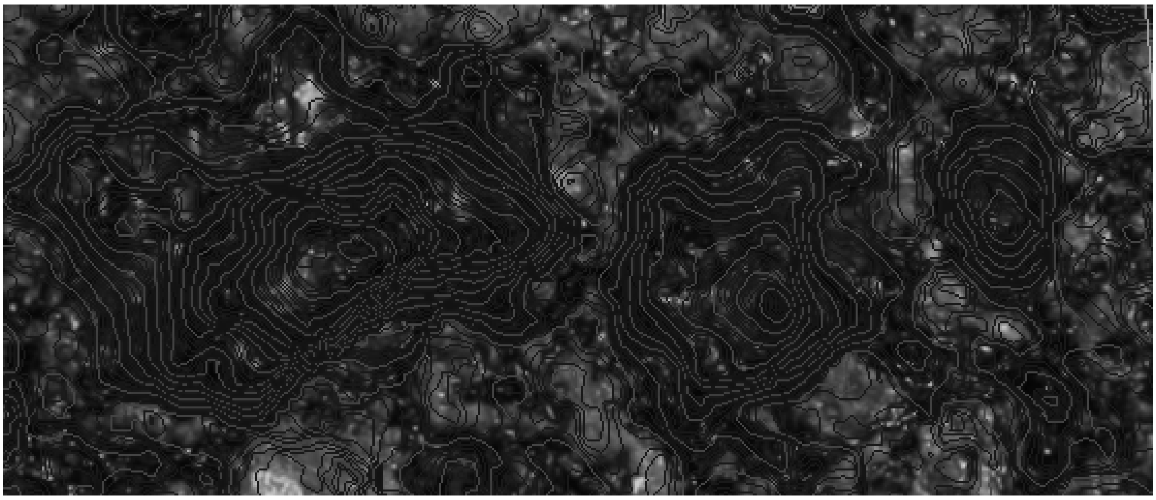

Figure 2. Superimposed contours plotted at a 0.1mm vertical interval.

Figure 3 shows 0.5mm vertical contours without the original digital image. The highlighted polyline defines the perimeter of three distinct areas of negative texture depth. The volume of each negative textured area enclosed by the polylines may be determined from the TIN mesh. Figure 4 shows a cross-section through the 2 largest areas of negative texture depth. Although no special lighting conditions were applied the texture profile clearly highlights the relative depths of each depression or area of negative texture.

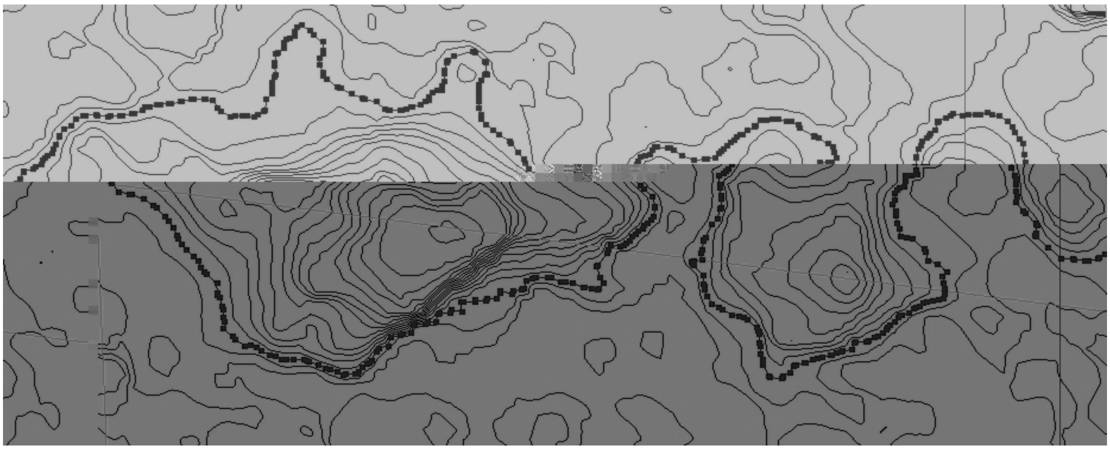

Figure 3. Contoured surface showing 3 areas of negative texture at 0.5mm vertical contour interval.

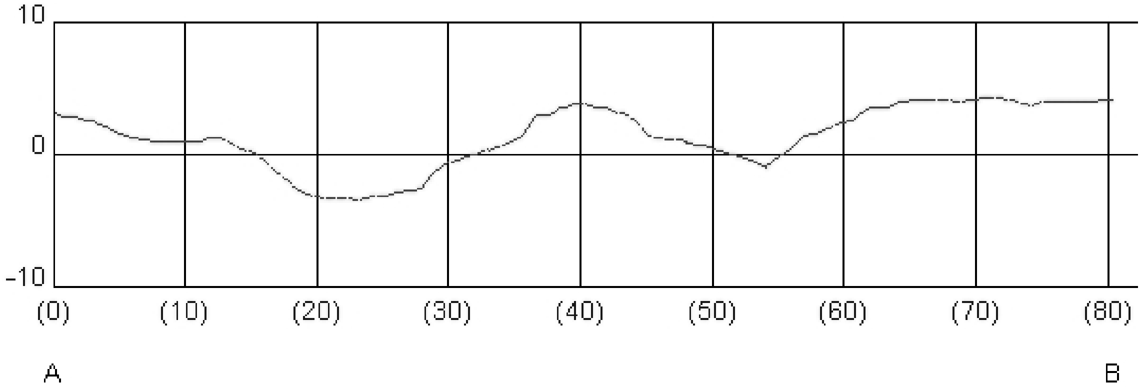

Figure 4. Cross-section of negative textured slab surface.

Figure 5 plots the change in area of the selected negative texture areas, or depressions, throughout the experimental cycle from 500 to 100,000 wheel passes. The contour perimeter at 500 passes was adopted as a reference plane. The overall trend shows a reduction in area with increasing number of wheel passes indicating surface wear.

The plot also shows specific early life phenomena during the first few thousand wheel passes. There is an initial rapid reduction in area, followed by an increase in area. Thereafter the values decrease towards equilibrium conditions.

This early life phenomena in terms of area can be explained by what is happening to the coarse aggregate binder films and mastic rich components of the mix. During very early simulated trafficking, these change the contact area of the tyre / asphalt interface. With continued trafficking this bitumen / mastic component is removed revealing the coarse aggregate structure and increasing the levels of texture depth.

Continued trafficking then continues to wear the asphalt surface causing a gradual reduction of texture depth. It should be pointed out that in this example the slab had not suffered surface ravelling. If the slab had been suffering surface ravelling the plot would show a further increase in area as the aggregate particles became dislodged from the surface of the slab.

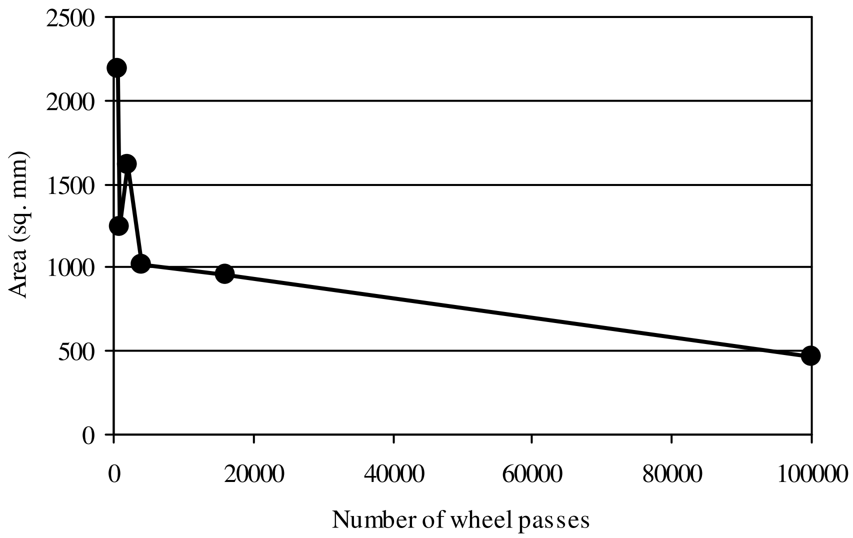

Figure 5. Change in depression area with increasing number of wheel passes.

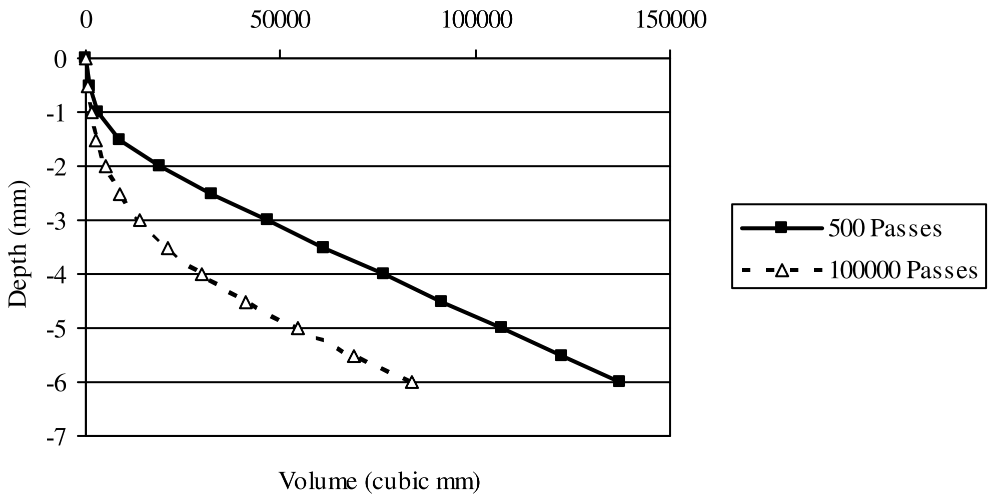

Figure 6. Change in material volume with depth at 500 and 100000 wheel passes.

Figure 6 shows an example of how the data can be used to better understand texture depth changes. In Figure 6 a reference plane at 0mm texture depth corresponds to the asphalt surface after 500 passes. The plot compares the volume change at 500 and 100000 wheel passes with increasing depth into the slab. As expected it shows that the most extensive abrasion and wear occurs at the higher number of wheel passes of 100,000.

Compared with the plot of 500 passes there is a continuous loss of texture material to approximately 4mm into the surface texture of the asphalt slab. For example, at a depth of 4mm into the slab the volume of surfacing material remaining at 100000 passes is 30045mm^3 over the area of the test specimen as compared with 76328mm^3 for the same depth at 500 passes. This represents a change of approximately 60% during the 100000 wheel pass test.

The volume of material loss after 100000 wheel passes compared to that after 500 wheel passes is plotted in Figure 7. This shows minimal loss from 0 to 1.5mm depth into the slab surface texture. Thereafter the rate of material volume loss is uniform from 1.5 to 4mm into the surface. A sharp reduction in the rate of material loss below 4mm suggests that the tyre could not penetrate significantly below this level. Below this level the difference in volume of material remaining after 500 and 100,000 passes should be reasonably constant.

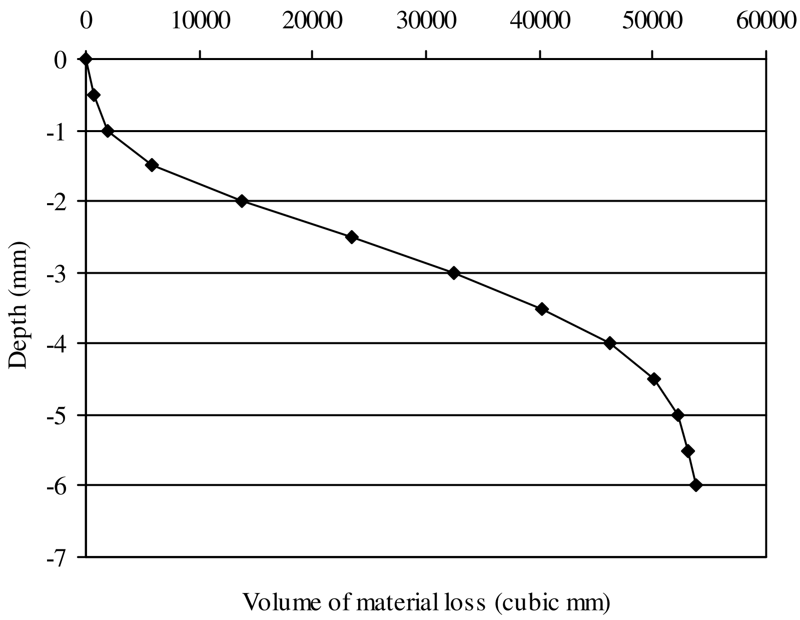

Figure 7. Plot of material loss with depth.

Figure 8 plots the conventional volumetric sand patch method of quantifying texture depth. The plot shows an initial early life loss in texture. Thereafter the texture depth values remained relatively constant over the 100000 wheel pass test. Although broadly agreeing with the digital imagery data Figure 8 offers considerably less insight into the ongoing processes as the slab is subjected to trafficking.

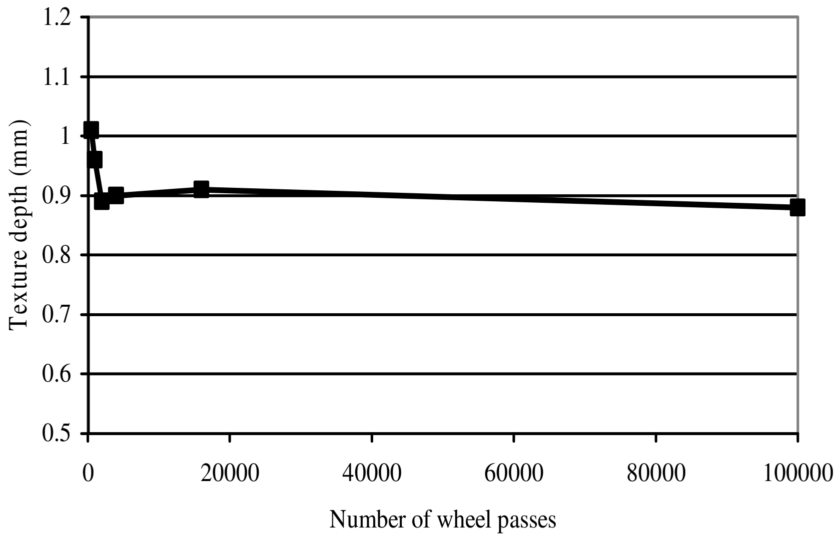

Figure 8. Change in texture depth measured using the sand patch test.

4 CONCLUSION

This paper has shown the use of close range photogrammetry to model and monitor surface macro-texture change of asphalt concrete test slabs subjected to laboratory accelerated trafficking. Stereo image pairs were taken during testing and processed using proprietary photogrammetric software to show change in macro-texture profiles, depression perimeters and volumes.

A simple example plotting perimeter area against number of wheel passes shows an early rapid reduction followed by an increase and subsequent gradual decline. This simple example provides evidence suggesting early re-deposition of material in voids and infilling of surface texture during early life trafficking due to smearing of the bitumen coating off the trafficked asphalt concrete surface. In contrast the conventional sand patch method offered much less insight of the processes taking place during the trafficking period.

It is concluded that stereo photo analysis offers a potentially viable method of correlating mechanical processes at the tyre/surface interface with surface characteristics.

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