ORTHOGRAPHIC PHOTOGRAMMETRY METHOD FOR PAVEMENT TEXTURE CHARACTERIZATION

Ivana Ban, Aleksandra Deluka-Tibljaš, Marijana Cuculić
University of Rijeka, Faculty of Civil Engineering, Croatia

Abstract

Image analysis methods are recently in use for asphalt pavement surface texture characterization and analysis in terms of pavement friction performance assesment. These methods enable more detailed description of texture properties at both micro and macro texture levels which are important for friction realization as they result in a digital representation of pavement surface. In comparison to the traditional methods for texture characterization which result in one characteristic texture parameter, methods that are based on digital image analysis can yield more texture parameters describing both profile and spatial characteristics of inspected surface texture. Previous application of image analysis methods for pavement texture characterization showed that pavement texture and friction relationship could be described more thoroughly by including texture parameters other than standard mean texture depth and mean profile depth derived from traditional measuring procedures. The possibility of texture data acquisition by means of digital images that can be further processed and exploited for creation of a 3D digital pavement surface model is presented in this paper. A research was performed on selected pavements in use where orthographic photogrammetry method was applied for texture data acquisition. Images were used for creation of a 3D pavement surface model defined as a dense point cloud data with XYZ coordinates. From the created 3D digital texture model, selected texture parameters were calculated and compared to the frictional performance of the pavements determined for inspected surfaces by using standard pendulum device.

Keywords: pavement, texture, friction, image analysis, photogrammetry

1 Introduction

Investigation of pavement surface characteristics responsible for skid resistance realization represents an important aspect of pavement functional performance assessment in terms of traffic safety. The main role in the development of frictional response of the pavement surface-vehicle tire system plays the pavement surface texture. Two significant texture levels are responsible for the friction force realization - pavement micro-texture and macro-texture [1]. Each of the levels governs the frictional response of the system differently, being responsible for the development of either adhesion or hysteresis component of the friction force [2]. Micro-texture is mostly responsible for the friction realization at low-speed and macro-texture governs frictional mechanisms at high-speed and it is especially significant when water is present at the pavement surface. Table 1. shows the main characteristics of texture levels important for the friction realization.
The determination of texture characteristics is well known and defined by international standards and regulations describing the procedures for texture measurements and inter-

pretation of the results [3]. Micro-texture is indirectly characterized by low-speed skid resistance measurements and macro-texture is directly determined by either volumetric or profilometric measurements. Research interest is mostly focused on determination of macro- level of pavement texture and its effect on friction realization which stems from the traditional measuring principles that resulted in a single macro-texture indicator that is correlated to the frictional response of the surface. Numerous studies have been performed in order to establish the connection between pavement texture features and the measured friction coefficient determined by traditional measurements. The results are limited due to the equipment used and the local conditions of the performed measurement, so the established relations between texture and friction are not always straightforward [4].

Table 1 Pavement texture levels responsible for friction realization

Texture level	Wavelength range	Amplitude range	Influencing factors	Friction-related property	Determination procedure
Micro-texture	0 – 0.5 mm	up to 0.2 mm	Aggregate properties: petrological and physical properties and geometry (shape and size)	Adhesion	Indirect via low-speed friction measurements
Macro-texture	0.5 – 50 mm	0.2 – 10 mm	Asphalt mix properties: aggregate type, mix gradation and distribution, maximum aggregate size, binder type, air voids content, placement methods	Hysteresis	Profilometric and/or volumetric contact and non-contact measurements

To overcome the limitations of traditional measuring methods, new methodologies for pavement texture assessment are recently developing. They are based on digital image analysis technologies that enable a more detailed description of pavement texture features. Texture data acquisition is done by either a digital camera via photogrammetry techniques or by a laser scanner capable of capturing the surface at a sufficient resolution for further analysis of friction-related texture features. The “digitalization” of inspected pavement surface gives a new perspective for the description of pavement surface properties. From the acquired digital images or from a surface scan a 3D digital pavement texture model can be reconstructed and further analysed by means of both 2D and 3D texture features that can be related to the friction realization [4-9]. There are several advantages of pavement texture analysis from the digital texture models. Primarily it is the possibility to extract more surface features than from the standard texture measurements. This enables better description of texture properties which results in better understanding of their effect on the friction realization. In comparison to the measurement outputs from the traditional texture measurement methods, image analysis methods enable the determination of 2D and 3D texture parameters of both texture levels and further analysis of their influence on friction realization. A detailed overview of image analysis methods applied for pavement texture characterization in terms of friction is given in [10].

The goal of this study is to investigate the possibility of relating selected pavement texture parameters calculated from the 3D digital surface model to the measured friction values. The established methodology for pavement surface texture characterization in laboratory conditions was tested for in-situ surface measurements [10]. For this purpose, three different asphalt pavement surfaces were inspected in terms of skid resistance under dry conditions and afterwards “digitalized” by using orthographic photogrammetry method for the creation of a 3D pavement surface model. From the digital pavement models, selected texture parameters were calculated and correlated to the measured skid resistance in order to determine if they could indicate the frictional performance of the pavement surface.

2 Experimental procedure for pavement surface characterization

2.1 Selection and preparation of asphalt pavement surfaces

Three different asphalt pavement surfaces were investigated in terms of frictional performance and texture characterization. The inspected surfaces were located on a light-trafficked low-speed road. Authors do not have details on the asphalt mixture composition, age or traffic load. From the visual inspection, Section 1 was categorized as the most homogenous regarding the aggregate size and type, with uniform distribution of aggregate particles. It was recognized as the smoothest one and without large asperities coming out from the surface. Section 2 was quite different, with higher amount of significantly larger aggregate particles in comparison to Section 1. The surface however, seemed quite polished and worn out. Section 3 was specific for aggregate type, which is different than the previous two. Larger particles are darker in colour so they could be of eruptive rock origin. The size of the aggregate particles is similar to those from Section 1. This section seemed less polished than the previous two.

The dimensions of inspected pavement sections were 35 cm by 45 cm. Prior to the measurements, the selected surfaces were brushed to remove dust, sand particles and other debris that could affect the measurement results. The measurements were taken under dry conditions to exclude the effect of water film on the results. At each section, two centrally positioned smaller areas were selected where both skid resistance measurements and texture data acquisition by orthographic photogrammetry method were performed. The size of these smaller areas was approximately 20 cm x 20 cm.

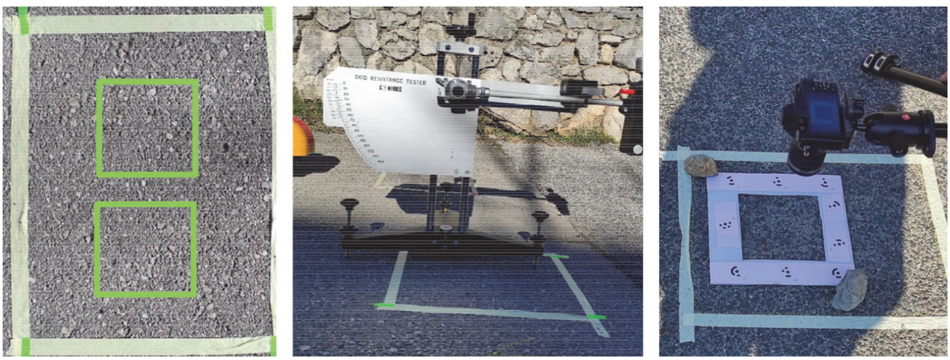

Figure 1 An example of analysed pavement section measured with SRT and photographed by orthographic photogrammetry method

2.2 Skid resistance measurements

In order to analyse the frictional performance of the selected asphalt pavement surfaces, skid resistance measurements were performed by Skid Resistance Tester with respect to the relevant standard [11]. The SRT device is designed for the skidding simulation between the vehicle tire and road surface for driving speed of approximately 50 km/h, where the measured skid resistance test (SRT) value indicates the skid resistance of the inspected surface. In general, higher SRT values represent better frictional performance. As this device is designed as a low-speed and stationary measuring equipment, it is considered to be an indirect measurement of the surface micro-texture. An example of the position of the pendulum device on a measured surface section is presented in Figure 1. For each inspected surface, two consecutive measurements were performed on two central areas of the inspected surface, marked in Figure 1. The sliding length was approximately 125 mm and the width of the pendulum slider was 75 mm. The measurements were performed in the direction of the travel. For each selected area, five consecutive SRT measurements were obtained.

2.3 Pavement texture characterization via orthographic photogrammetry

Pavement texture characterization was performed by using an advanced texture analysis methodology that was previously established and tested for laboratory-produced asphalt slabs and skid resistance measurements [10]. The image acquisition was performed by orthographic photogrammetry method, where digital images of pavement are taken orthogonally to the surface at approximately 20 cm height (Figure 2, left). Images were acquired with Olympus OM-D E-M5 digital camera, with 12-50mm f/3.5-6.3 EZ lens. Each surface was photographed in two sections corresponding to the areas measured with the pendulum tester. A reference frame dimensions 20 cm x 20 cm with nine targets was assembled in order to acquire better accuracy of the model. A set of 25 overlapping images was taken for each inspected surface. To exclude the effect of the reflectance caused by the sun, the inspected surfaces were shadowed. The images are imported in Agisoft Metashape software, where 3D models of inspected surfaces were generated (Figure 2, left).

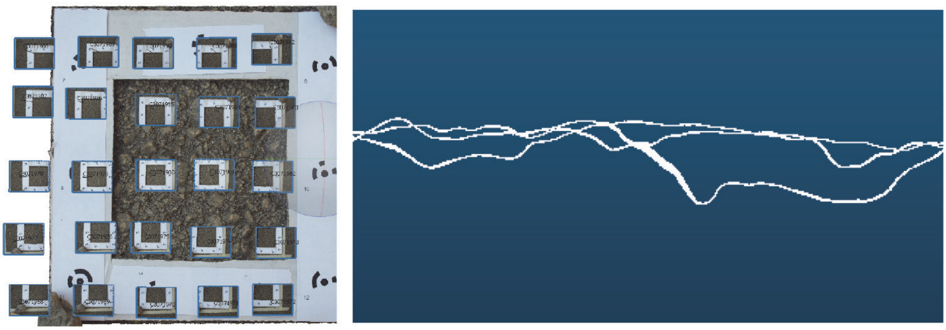

Figure 2 3D pavement surface model with camera overlapping views (left) and an example of resulting surface profiles (right)

The inner frame with dimensions 15 cm x 15 cm was exported as a dense point cloud (DPC) and further processed in CloudCompare software, where levelling and scaling of imported data was performed to correspond to the real size of the inspected surfaces. For each section, three surface profiles were extracted as a set of XZ coordinates further exploited for the calculation of selected parameters (Figure 2). The length of each profile was 125 mm, corresponding to the sliding length of SRT device, and profiles were extracted at a distance that covers nearly whole sliding width. In this way, entire surface tested by SRT device was observed in the texture analysis. Standard texture indicators mean profile depth MPD and estimated texture depth ETD were calculated from the extracted profiles of digital texture models with respect to the standard [3]. Furthermore, other texture indicators commonly used for the texture profile description were also determined [12, 13]. These indicators are average roughness Ra, peak to valley height Rm, root mean square roughness Rms, profile asymmetry-skewness Rsk and profile flattening-kurtosis Rku.

3 Results and discussion

The measured values of skid resistance and calculated texture parameters for the profiles extracted are averaged and given as a single value for each analysed section, as given in Table 2 and Figure 3.

Table 2 Average values of SRT measured at each section

Section no.	1_1	1_2	2_1	2_2	3_1	3_2
SRT [/]	87	83	89	85	85	90

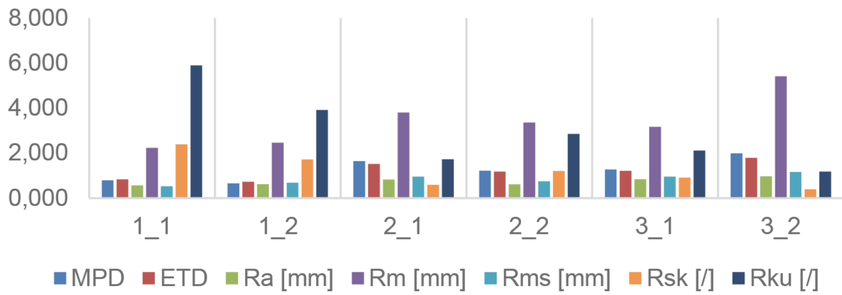

Figure 3 Texture parameters values calculated for sections

The highest SRT values are recorded for sections 2_1 and 3_2, which also have highest MPD values. Correlation analysis resulted in a significant relationship between SRT and MPD values, but also indicated that other texture parameters, especially average roughness Ra and peak to valley height Rt parameters, could describe the frictional performance of pavement surface (Table 3).

Table 3 Correlation analysis – Pearson correlation coefficients

	MPD	Ra [mm]	Rm [mm]	Rms [mm]	Rsk [/]	Rku [/]
SRT	0,86	0,67	0,78	0,63	-0,58	-0,49

Linear regression analysis however, showed no significant results for texture parameters Ra, Rt and Rms but only for MPD (Figure 4). This might be due to the small number of observations, but it also indicates that frictional performance of a pavement surface and corresponding texture parameters have to be investigated more thoroughly. Therefore, multiple regression analysis was performed resulting in generally higher R-square values for all inspected variable combinations in comparison to linear regression analysis results. The best results were obtained for the model including MPD, Ra and Rms texture parameters and SRT value with very high R-square values, that showed to be statistically significant (Table 4)

Table 4 Multiple regression analysis results

Analysed parameters	MPD, Ra vs SRT	MPD, Rm vs SRT	MPD, Rms vs SRT	MPD, Rm, Rms vs SRT	MPD, Ra, Rm vs SRT	MPD, Ra, Rms vs SRT
R-square	0,88	0,75	0,88	0,88	0,78	0,98
Adjusted R-square	0,62	0,58	0,81	0,71	0,45	0,96
P-values	0,13; 0,54	0,28; 0,70	0,04; 0,14	0,18; 0,97; 0,27	0,34; 0,65; 0,79	0,02; 0,08; 0,04
F-statistics	0,11	0,13	0,04	0,17	0,31	0,03

Figure 4. R-squared values for linear regression analysis of texture parameters vs. SRT values
The results obtained from the in-situ measurements of friction and texture on pavements in use follow similar trend as the results obtained in laboratory conditions [10]. The statistical significance for the in-situ dataset is even higher, which indicates the suitability of the developed methodology.

4 Conclusions

This study explored the possibility of in-situ application of established orthographic photogrammetry method for pavement texture data acquisition and analysis in terms of surface frictional performance. The texture parameters calculated from the 3D texture model obtained by the developed methodology correlate fairly with the measured friction expressed as SRT values. Statistical analysis showed that better relationship is obtained when more than one texture parameter is observed. What is interesting, the best results are achieved when Rms parameter is considered in multiple regression, which showed the weakest correlation coefficient and R-square value in linear regression analysis. In general, the best model was obtained for MPD, Ra and Rms texture parameters. Other models achieved reasonably high R-square values, but have no statistical significance. The results of the performed analysis showed that pavement texture-friction relationship should be analysed by observing not only one measured texture parameter, and that advanced methods for pavement texture characterization can yield a better insight into pavement friction phenomenon. On the basis of the developed texture data acquisition methodology further research will include larger dataset and determination of other texture parameters, including the spatial texture indicators.

Acknowledgments

The research was supported by the project “Transport infrastructure in the function of sustainable urban mobility” (uniri-tehnic-18-143-1289) supported by the University of Rijeka, Croatia. A special thanks goes to the technician Duje Kalajžić for the data acquisition process.

References

[1] Kogbara, R.B., Masad, E.A., Kassem, E., Scarpas, A.T., Anupam, K.: A state-of-the-art review of parameters influencing measurement and modeling of skid resistance of asphalt pavements, Construction and Building Materials, 114 (2016), pp. 602-617, DOI: 10.1016/j.conbuildmat.2016.04.002

[2] Yu, M., You, Z., Wu, G., Kong, L., Liu, C., Gao, J.: Measurement and modelling of skid resistance of asphalt pavement: A review, Construction and Building Materials, 260 (2020), 119878, DOI: 10.1016/j.conbuildmat.2020.119878

[3] EN ISO 13473-1:2004 E, Characterization of Pavement Texture by Use of Surface Profiles—Part 1: Determination of Mean Profile Depth, Croatian Standards Institute HZN: Zagreb, Croatia, 2004.

[4] Kogbara, R.B., Masad, E.A., Woodward, D., Millar, P.: Relating surface texture parameters from close range photogrammetry to Grip-Tester pavement friction measurements, Construction and Building Materials, 166 (2018), pp. 227–240, DOI: 10.1016/j.conbuildmat.2018.01.102

[5] Edmondson, V., Woodward, J., Lim, M., Kane, M., Martin, J., Shyha, I.: Improved non-contact 3D field and processing techniques to achieve macrotexture characterisation of pavements, Construction and Building Materials, 227 (2019), 116693, DOI: 10.1016/j.conbuildmat.2019.116693

[6] Alamdarlo, M.N., Hesami, S.: Optimization of the photometric stereo method for measuring pavement texture properties, Measurement, 127 (2018), pp. 406–413, DOI: 10.1016/j.measurement.2018.05.109

[7] Li, Q., Yang, G., Wang, K.C.P., Zhan, Y., Wang, C.: Novel Macro- and Microtexture Indicators for Pavement Friction by Using High-Resolution Three-Dimensional Surface Data, Transportation Research Record: Journal of the Transportation Research Bord, 2641 (2017), pp. 164–176, DOI: 10.3141/2641-19

[8] Chen, D.: Evaluating asphalt pavement surface texture using 3D digital imaging. International Journal of Pavement Engineering, 21 (2020), pp. 416–427, DOI: 10.1080/10298436.2018.1483503

[9] Madeiros, M.S., Babadopulos, L.F.A., Maia, R.S., Castelo Branco, V.T.F.: 3D Pavement Macrotexture Parameters from Close Range Photogrammetry, International Journal of Pavement Engineering, 2021, ahead-of-print, pp. 1-15, DOI: 10.1080/10298436.2021.2020784

[10] Pranjić, I., Deluka-Tibljaš, A.: Pavement Texture–Friction Relationship Establishment via Image Analysis Methods, Materials, 15 (2022), DOI: 10.3390/ma15030846

[11] EN 13036-4:2011 (E); Road and Airfield Surface Charactersitics—Test Methods—Part 4: Method for Measurement of Slip/Skid Resistance of a Surface: The Pendulum Test, Croatian Standards Institute HZN: Zagreb, Croatia, 2012

[12] Zuniga-Garcia, N., Prozzi, J.A.: High-Definition Field Texture Measurements for Predicting Pavement Friction, Transportation Research Record, 2019, pp. 246-260, DOI: 10.1177/0361198118821598

[13] Bitelli, G., Simone, A., Girardi, F., Lantieri, C.: Laser Scanning on Road Pavements: A New Approach for Characterizing Surface Texture. Sensors, 12 (2012), pp. 9110-9128, DOI: https://doi.org/10.3390/s120709110