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Three-dimensional survey method of pavement texture using photographic equipment

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A R T I C L E I N F O

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A B S T R A C T

In this paper, an image-based technique for the assessment of a 3D model of pavement texture is presented. Five common cameras were used to collect pictures of the pavement surface. An innovative procedure was developed, based on volumetric calculation, to calculate the *digital* Mean Texture Depth (MTD) starting from the Digital Surface Model (DSM) generated by the photos.

To validate the procedure, 20 different pavement surfaces were acquired for a total of 100 DSMs. For each model the *digital* MTD was calculated and compared with the *measured* MTD performed with the sand patch method, in the same pavement. The coefficients of determination were found for each camera. The results highlighted the high accuracy level of the analysis, with a coefficient of determination from 0.99 to 0.94 in relation to the features of each camera used for the acquisition.

In addition, others texture parameters extracted by profiles were calculated and analyzed. At last, a volumetric study was conducted to investigate the pavement behavior in case of rainfall.

1. Introduction

Pavement texture is defined as the deviation of a pavement surface from a true planar surface, within wavelengths varying between 0 and 500 mm [1]. This characteristic is considered critical to fulfil appropriate operational and serviceability levels in a pavement structure, especially in terms of safety and system efficiency (e.g. comfort, fuel consumption, tires wear, emissions and pollution impact) [2–4].

Depending on the magnitude of the wavelength, the components of texture can be classified in four different ranges [1]:

1. Microtexture, with a wavelength up to 0.4 mm,
2. Macrotexture, from 0.5 mm to 50 mm,
3. Megatexture, from 50 mm to 500 mm,
4. Evenness, which includes all the wavelengths longer than the upper limit of megatexture.

Each one of these components has a different influence in the diverse operational characteristics of a pavement. In 1987, the Committee on Surface Characteristics of the World Road association (PIARC) defined the relationships between these four texture components and various tire-pavement interactions [5]. A scheme of this connection is presented in Fig. 1.

There exist several methods that have been proposed worldwide to estimate surface texture. These methods are commonly categorized as direct or indirect techniques, depending on the methods used to conduct the assessment of the surface texture: direct methods, actual measurements on the surface of the pavement or indirect estimations, based on other characteristics of the pavement (e.g. the friction may be considered an indirect measure of the texture in the micro and macro range). Nevertheless, the limitations of the most common methods to quantify texture are currently well recognized [6]. For example, it has been demonstrated that the sand patch test [7], that is used to estimate the Mean Texture Depth (MTD), does not have a good repeatability, due to the strong dependency of the method with the experience of the operator [8]. Moreover, even for the laser profilometer methods, such as the Circular Track meter [9], the resulting profile characterization, given only in terms of Mean Profile Depth (MPD) [10], could be strongly affected by irregularities in the profile [8]. Besides, it has also been highlighted that to improve the capability to understand the tire-pavement interaction complexity, it is necessary to conduct planar and three-dimensional analyses at the surface, such as spacing and distribution of the profile heights [8]. All these reasons have led researchers to develop innovative methods for the assessment of surface texture, which take advantage of techniques that ensure high repeatability results at reduced overall costs.

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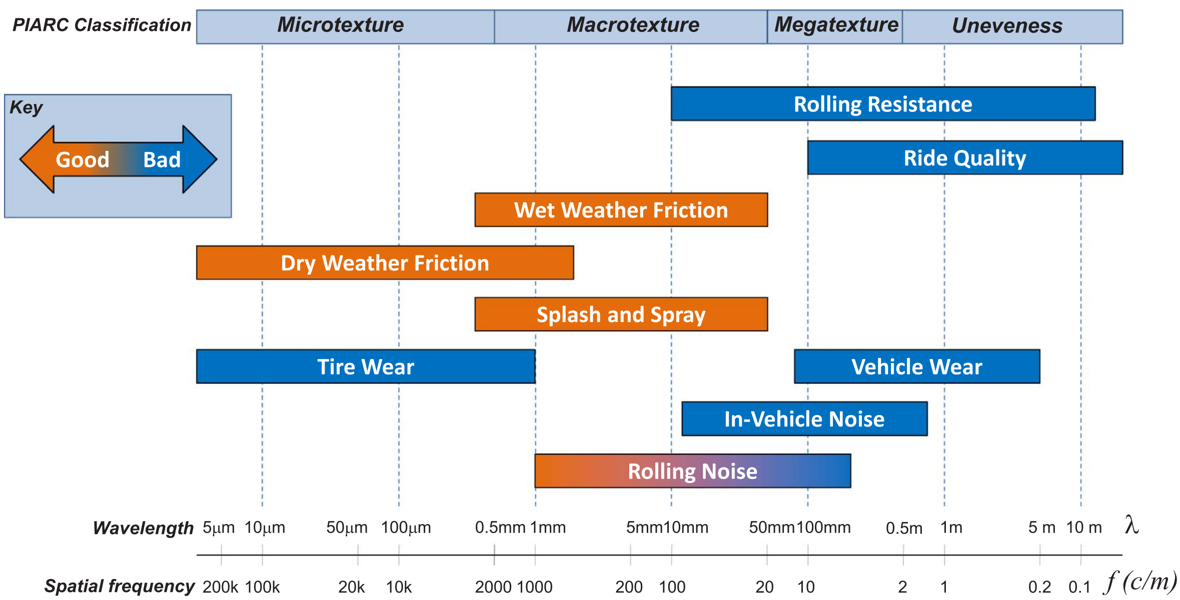

Fig. 1. Connection between the texture wavelengths and various tire-pavement interactions [2].

Some of these attempts provide the quantification of the pavement surface texture of the pavement surface using analysis of photographic images. The idea of using image-analysis techniques goes back to the 1970s, where stereophotographs were used to describe pavement surface textures and to photo-interpret skid resistance through the introduction of a texture code number directly related to the measured skid number [11]. Several other works were conducted during the following decades using similar approaches or principles [12,13]. More recently, the feasibility of the photometric stereovision technique for the characterization of the surface texture was demonstrated by Slimane [14], whose method includes an improvement of the heights map extraction from rough textured surfaces through the application of the generalized Lambertian method. The results from this approach, in terms of texture features, were found to be comparable with those obtained through laser acquisition techniques. In a different work, Neaylon [15] attempted to study sprayed seal distress mechanisms using stereo photography tools.

Digital camera images have also been used to quantify surface conditions of pavement structures. Gransberg et al. [16], for example, evaluated the surface condition of seal coated pavements during pavement maintenance operations in over 100 Texas projects. The proposed technique was based on processing images of 340 × 600 pixels using two-dimensional Fast Fourier Transform (FFT) and employing the maximum FFT as a predictor of performance for the investigated pavement sections.

In a more complex application, El Gendy and Shalabi [17] used a four-source photometric stereo system to conduct a three dimensional (3D) reconstruction of the pavement surface, which was later used to compute the corresponding MPD. This work also evaluated the effect of the wavelength range on the estimation of macrotexture indicators. The validation of image-based techniques for reconstructing the actual 3D characteristics of the pavement surface was also investigated in [18]. Through laboratory and field experiments, the authors proposed a new area-based macrotexture indicator to provide substantial information on friction and noise characteristics of the surface. In another recent effort, a method based on stereo-vision-based technology was presented as an alternative to the more conventional texture-measuring systems [19].

Dondi et al. [20] implemented a 3D laser scanner system to reconstruct the macrotexture of surface pavements. According to the authors, the 3D data acquired through this method could be used to derive information on mixture laying, as well as volumetric and surface studies involving adherence, tire-pavement grip and compressing level. In the study of Praticò and Vaiana [21] the relation between the mean profile depth from a laser acquisition of the surface, and the mean texture depth, from the sand patch test was modeled. Moreover, a macrotexture prediction model, based on mix design-related factors, was set up and validated [22].

Several other applications of image analysis techniques to evaluate texture conditions can be also found in works related to the evaluation of interfaces between pavement layers [23,24].

In general, the previously described works have proved that image-based techniques are suitable for the characterization of the surface texture of pavement structures. Even more, several of them – especially those using volumetric and areal measurements – have demonstrated to provide more accurate results than traditional techniques.

The novelty of this work compared to the previous image-based methodologies reported in the literature is the possibility of using different types of cameras – including compact and smartphone cameras – with no restriction on the external light condition and on the positioning of the camera with respect to the surveyed pavement. Consequently, this methodology could be easily implemented and used at low cost to obtain a degree of accuracy suitable for the measurement of macrotexture indicators. Moreover, a new methodology was proposed to evaluate the Mean Texture Depth starting from the Digital Surface Model of the surveyed pavements. The methodology was validated comparing these indicators with the actual Mean Texture Depth measured with the sand patch method.

2. Objectives

The main objectives of this work are:

- Propose a Digital Surface Model (DSM) to characterize pavement texture; the method is based on the acquisition of digital photos that are processed using a commercial computer vision software.
- Calculate a *digital* Mean Texture Depth (MTD) index from each DSM and compare it with the *measured* Mean Texture Depth (MTD) obtained through the sand patch method, in order to evaluate the reliability and the accuracy of the new proposed digital MTD parameter.
- Compare the results acquired using five different photographic devices on the same pavement sample to evaluate how the different equipment can influence the results.