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Evaluation of pavement surface drainage using an automated image acquisition and processing system

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ABSTRACT

Network level evaluation of pavement surface drainage plays a crucial role in the improvement of pavement safety and reducing accident rates. Hydroplaning, as the main considered cause of accidents in wet weather conditions, is a consequence of the low quality draining in the pavement surface. Since no automated system currently exists for the pavement drainage evaluation, this work was conducted to present a new system to assess the quality of the surface drainage process. To this end, an innovative device is presented to simulate the saturation condition of the pavement surface and acquire photos from the drainage process of the pavement surface after saturation. Next, an image processing method was applied to produce proper indices for drainage quality assessment. The preprocessing and enhancement of images was performed using shearlet transform. The rate of surface drainage progress was evaluated by three indices extracted from the images. Finally, pavements were classified into three categories according to the indices extracted for their surface drainage. The validation of the proposed method by the confusion matrix shows the high performance of the system in simulation and assessment of surface drainage of the road pavements.

1. Introduction

1.1. Background

One of the most important parameters influencing road safety is the climatic (wet or dry) conditions of the pavement surface [1–8]. Many researchers proposed a relationship between accidents and weather conditions [9–11]. In areas with long intervals between precipitations, after a dry period, the number of accidents increases during the first precipitation [12]. In wet conditions, the layer of water covering the pavement acts as a lubricant and reduces the contact between the tires and the pavement surface [13]. Therefore, the friction decreases and the pavement surface exhibits a lower friction than the dry-pavement surface. In addition to this lubricating effect of water at high speeds, lack of drainage facility in the presence of certain depths of water film may result in hydroplaning. Hydroplaning is a phenomenon, which occurs when water film is developed between the tires of the vehicle and the pavement surface. This phenomenon results in the reduced traction and disables the vehicle from responding to actions such as steering, braking, or accelerating [14]. Accordingly, hydroplaning is considered as the main cause of accidents in wet weather conditions [13].

Many studies demonstrated the relationship between wet pavement crashes and characteristics of pavement surface texture [15–18]. Due to the importance of pavement texture characteristics in the safety of roads, the pavement surface is required to be monitored continuously. Two important surface characteristics are microtexture and macrotexture. Macrotexture refers to the coarse-scale texture irregularities of the pavement surface that affects the hysteresis component of the friction. These irregularities are associated with the void area between aggregate particles. The magnitude of this component will depend on the size, shape, and distribution of coarse aggregates used in pavement construction, the nominal maximum size of aggregates and the particular construction methods used in the implementation of the pavement surface layer [4,19].

Microtexture refers to fine-scale texture irregularities in the surface of the aggregate particles that are measured at the micron scale of harshness and are known to be mainly a function of aggregate particle mineralogy. Stone particle smoothness or harshness depends on these irregularities. The magnitude of microtexture depends on the initial roughness of the aggregates surface and the resistance of the aggregates against the polishing action of traffic and environmental factors. The adhesion component of the friction is influenced by microtexture [19].

Wet pavement friction is influenced by both macrotexture and

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microtexture of the pavement surface [20]. Macrotexture that is an overall asphalt mixture characteristic reduces dynamic hydroplaning development by providing channels for removal of water [21]. Microtexture that is primarily an aggregate surface characteristic reduces the viscous hydroplaning development by draining the viscous water film between tire and pavement [22].

The drainage process is controlled by the shape of microasperities [23]. Savkoor showed that amplitude and number of microasperities on pavement surface controls the drainage of the water film between tire and pavement [24].

Ong et al. proved that using materials with better microtexture reduces the chance of hydroplaning [22]. Their study showed that in the pavements comprised of coarse aggregates with high microtexture in the range of 0.2 mm to 0.5 mm, hydroplaning occurs at a 20% higher speed. Horne also reported that hydroplaning could be delayed in pavements with a good microtexture [25]. Pelloli found that the amount of microtexture is determinant on the relationship between friction coefficient and the water depth accumulated on the surface [26].

Implementing corrective actions in hazardous areas can reduce the rate of these accidents. Mataei et al. [27] reviewed various methods applied for measuring pavement surface texture. According to their work, there are a number of tests, procedures, and devices available for evaluation of the pavement surface texture. These methods mainly consist of field tests, high-speed and laboratory tests, and low-speed approaches. The locked wheel test is a method for measuring friction force at 100% slip situation. In addition, the sideway force test is another technique for friction force measurement through a wheel rotating with a 20° yaw angle along the motion direction [4,5,15]. The fixed slip test is conducted to measure the friction force of the constantly slipping wheel, whereas the variable slip test measures the friction force at any desired slip [4,15,28]. Methods applied for measuring pavement surface texture are divided into two groups of contact and non-contact methods. In the contact methods domain, two laboratory testers including British Pendulum Tester (BPT) and Dynamic Friction Tester (DFT) are typically applied. Through these tests, the pavement surface friction is measured by determining the loss in kinetic energy of a sliding pendulum or rotating disc when in touch with the roadway surface and converted to a frictional force. Measuring friction at various speeds gives the DFT device the ability to measure the speed dependency of the pavement friction [1,4,15].

The OutFlow Meter Test (OFT) and Sand Patch Test (SPT) are the most popular methods that measure the macrotexture of the pavement surface with contact. In OFT, a transparent vertical cylinder with a rubber ring under it, is placed on the pavement surface. Then, water is allowed to flow into the pavement, and the required time for passing a determined volume of water in the transparent vertical cylinder is recorded. Also referred to as outflow time, this parameter, which is attributed to pavement macrotexture, indicates the ability of the pavement surface to drain water and shows how fast water depletes from the surface [2–4,28–31].

In addition, the sand patch test is a volumetric method for macrotexture measurement, through which a known volume of a homogeneous material (sand, glass beads, or grease) is spread on the pavement surface and the resulting area is measured. Eventually, by dividing the initial volume by the area, Mean Texture Depth (MTD) is calculated via this test [2,4,15,28]. In the non-contact methods, the circular track meter (CT Meter) and vehicle-mounted laser devices are the most common [2,28,29].

The CT Meter is a laser-based device for measuring the mean profile depth (MPD) of a pavement at a static location. This device can be used both in the laboratory and field. However, the CT Meter cannot measure the MPD of a pavement at highway speeds [3,15,29,31]. Therefore, vehicle-mounted laser devices were developed to measure the macrotexture by vehicle movement at the wheel pass line and without disrupting traffic flow [2,4,29]. Recently, the image-processing techniques are increasingly applied to develop a non-contact method for pavement texture assessment [32,33].

Table 1
Methods for measuring pavement surface characteristics [27].

General classification	Methods	
Field measurement	locked wheel test	
	sideway force test	
	Fixed slip test	
	Variable slip test	
Portable and laboratory testers	Contact	British Pendulum Tester (BPT)
		Dynamic Friction Tester (DFT)
		OutFlow Meter Test (OFT)
		Sand Patch Test (SPT)
	Non-contact	Laser-based
		Image based

Table 1 summarizes the classification of the mentioned methods applied for measuring pavement surface characteristics. It is noteworthy that none of these methods are capable of evaluating pavement surface drainage.

The methods summarized in Table 1 have many advantages which present them as traditional texture measurement methods. However, deficiencies in some of these methods like BPT, SPT, DFT, and OFT make them unreliable. Being time-consuming, requiring traffic control and expert operators, unrepeatable results, requiring high memory for data storage and expensive equipment are among these drawbacks. Therefore, researchers, trying to cover these shortcomings, have recently presented new methods for pavement texture measurement.

De Leon Izeppi et al. presented a new low-cost system for pavement surface texture measurement using a stereo vision camera [34]. Also, Elunai et al. proposed a method based on image processing to estimate the road surface texture coarseness distribution from its edge profiles [35]. Wang et al. introduced a low-cost portable laser device that calculates the profile of the pavement surface texture and records the mean profile depth (MPD) by scanning the road surface [29]. Elsewhere, Elunai et al. suggested using autocorrelation and Wavelet Transform (WT) as two new image processing methods for measuring texture depth [31]. Zelelew et al. recommended a WT approach for analysis and interpretation of the macrotexture data obtained using a circular track meter (CT Meter) device [36]. Pidwerbesky et al. suggested replacing the sand circle test with a safe and reliable approach by presenting an image processing based method using Fast Fourier transform (FFT) [37]. Finally, Cigada et al. proposed a laser-based method using two identical industrial laser triangulation displacement transducers [38]. These cases are examples of recent achievements of researchers in presenting new methods and procedures for the evaluation of pavement surface texture.

The aggregate imaging system (AIMS) introduced by Masad et al. is one of the recent methods for measuring the aggregate texture directly using a microscope and a digital image processing technique [39]. This method is an important development in texture measurement methods as it allows measuring physical characteristics of the aggregate. This advanced technology consists of an automated video system that directly analyzes texture, angularity, and the shape of aggregates. Victor et al. compared the results obtained by conventional tests and the aggregate image measurement system (AIMS) for measuring texture characteristics of aggregates and hot mix asphalt (HMA)s [40]. The results showed that, in relation to the microtexture of field asphalt samples, AIMS gives a good correlation with the results from the British pendulum.

In addition to surface texture, other factors affect the surface drainage such as rutting, pits, cross and longitudinal gradients, surface signs and colors, type of materials and bitumen, etc. This study is focused on surface texture.