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Determination of seal coat deterioration using image processing methods

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HIGHLIGHTS

- We developed new system using digital image processing techniques.
- Bleeding deterioration on seal coat was determined accurately.
- This new system will encourage development in seal coat.
- This research will aid pavement engineers for pavement ratings.

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ABSTRACT

Seal coat is the most commonly used asphalt pavement type due to its low initial construction cost and ease of application in countries such as Turkey, Australia, South Africa and New Zealand. Seal coat deterioration occurs over time because of the effect of various factors such as weather, traffic, etc. The determination and assessment of deterioration is an important components of pavement management systems (PMS). This article presents, digital image processing (DIP) techniques as effective and reliable measurement techniques for the determination of bleeding deterioration in seal coats. The developed technique was applied to a total of 140 images, taken from four survey sites in four different Highway Districts. These images were obtained with an image acquisition device that was developed to take images for this study. Each image was classified in one of two categories, namely, bleeding or satisfactory. One hundred seal coat images were classified as bleeding surfaces and the others were satisfactory surfaces. The edge detection algorithm was developed using the image processing toolbox of Matlab software. Aggregate edge patterns of bleeding or satisfactory seal coat surfaces differ significantly. Therefore, in this study was examined the edges of aggregate particles using seal coat images. The results show that bleeding deterioration on seal coat was determined accurately using the developed algorithm in the scope of study. The results also indicate that this system is a promising tool in seal coat surface condition evaluation, potentially aiding pavement engineers in prioritizing seal coat projects in a quantitative rather than qualitative manner.

1. Introduction

Seal coat is an economical flexible pavement type which was constructed single or double layer aggregate-bitumen applied on a prime sealed granular pavement surface. Seal coats enable a waterproof surface to protect sub layers and smooth and high-skid-resistance surface for vehicles comfort and to protect the pavements against the damaging effects of the traffic and climate [1–6]. Seal coats are constructed on an unbound granular base in countries such as Turkey, South Africa, Australia and New Zealand [6–8]. In Turkey, 300,000 km of 385,000 km rural road network, and also 48,929 km of 64,865 km state highway network is formed by seal coat road pavement [9]. Seal coat is also used to as a preventive and maintenance alternative for purposes for bituminous hot mix pavements [10–11].

A certain time after a road has been opened to loading, climate, environmental factors, the use of unsuitable material, improper construction and design can cause deterioration which adversely affects driving comfort and the safety of the seal coats over the granuler base. The most common types of deterioration on seal coats are bleeding and raveling [12,13]. Bleeding refers to the rise of excess binder to the surface of the seal coat and is generally distinguished by black patches of excessive binder appearing on the pavement surface. In other words, a bleeding surface has a smooth, slick, shiny and glass-like appearance where the aggregates are less visible [12,14–26].

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Nomenclature

i	illumination function	$\circ$	opening process operator
r	reflectance function	$\cdot$	closing process operator
f	image function	m_y	the mean value of the new coordinate system
F	color image	C_y	the covariance matrix of the new coordinate system
g	gray scale image	a	$(m-1)/2$ (non-negative integer)
X	$1, 2, \ldots, N$	b	$(n-1)/2$ (non-negative integer)
Y	$1, 2, \ldots, M$	h	$0, 1, 2, 3, \ldots\ldots M-1$
M	number of row	k	$0, 1, 2, 3, \ldots\ldots N-1$
N	number of column	fg	filtered image
$f(x, y, 1)$	matrice related to red band	I	input image
$f(x, y, 2)$	matrice related to green band	O	output image
$f(x, y, 3)$	matrice related to blue band	I_{min}	the smallest gray level value of input image
$\emptyset$	empty set	I_{max}	the largest gray level value of input image
B	structural element	O_{min}	the smallest gray level value of output image
$\oplus$	dilation process operator	O_{max}	the largest gray level value of output image
$\ominus$	erosion process operator	β	gradient

Monitoring and evaluation of the deterioration is an important part of pavement management systems. Data collection on pavement surface conditions has traditionally been performed by trained people who walk or drive along the road and visually observe and record information on the condition of the road. This method of visual observation not only results in a waste of money and time but also puts the safety of the personnel at risk. In addition, the physical state of the personnel performing the survey may also affect the results. For this reason, objective methods are required to directly measure pavement conditions.

Today, image processing techniques, the use of which has increased over time, have shown a marked improvement in parallel with the advances in computer technology. Their scope of application has been steadily extended to various areas such as astronomy, remote sensing, medicine, electronics, biology, mineralogy and nanotechnology. In addition, the use of these techniques has resulted in advantages in terms of both time and economics.

In recent years, there has been a large increase in the number of studies conducted on image processing in highway engineering. These studies can be divided into two groups: the evaluation and classification of road pavement deterioration on the one hand, and of aggregate shape properties on the other hand. Studies on road pavement deterioration such as those on cracks constitute a large part of the studies related to image processing in highway engineering [27–33] in these studies, crack types have been identified and a classification method has been developed. When the studies on road pavement deteriorations were analyzed, it was established that they had focused on hot bituminous or rigid pavement materials and also we just one study found related to the deterioration of seal coat surfaces [34].

The main objective of this study is to determine the most commonly observed deterioration of seal coats, bleeding, through the method of image processing. For this purpose, first an image acquisition device was developed to take images of seal coat surfaces. Then, benefiting from expert opinions for pavement surface bleeding detection, 100 images were taken of bleeding seal coat sections, and, for comparison, 40 images were taken of satisfactory surfaces. An analysis was performed on all the images with an algorithm developed for this study and the images were classified.

2. Seal coat image acquisition device

An image can also be defined as the two-dimensional map of the three-dimensional (3-D) view. In light of this definition, this mathematical expression represents the image of an object point in x, y, z coordinates at any (t) time:

$$f(x,y,z,t,\lambda) = i(x,y,z,t,\lambda)\ r(x,y,z,t,\lambda) \tag{1}$$

Daylight is usually not very well suited for image processing in terms of illuminating a scene because the color and the intensity of the light changes with the time of day, the time of year and the weather conditions. Image processing systems are adversely affected by situations in which uncontrolled light cannot be avoided [35]. From the equation of the image (Eq. (1) [36]) we see that the illumination function is under the influence of a light source. It may be an artificial or a natural light source. The use of the sun as a source of natural light for image acquisition poses two problems. One of them, as can be understood from the definition of the image, is the (t) time and (λ) the wavelength in the illumination function. The analysis of an image taken at the same location at different times may reveal different values due to the fact that the intensity of the light from the sun (λ) varies at any (t) time. The second problem is the presence of shadows. Sunlight leads to the formation of shadows on aggregates at different points. Shadow is perceived as an artificial edge of the image during the processing. Therefore, it is thought that the results obtained are not fully accurate. This can be seen clearly in Fig. 1.

A closed system made of wood was designed to eliminate this unfavorable situation. An artificial light source was used because it was a closed system. 2×70 W metal halides were used as a source of artificial light. The light source and the design of the wooden system were determined after several trials, and a seal coat image acquisition device was developed (Fig. 2). The device has four tires and also images taken with this device is taken only device stationary. It does not work in motion. The device ensures that all the factors (camera, height, zoom, angle, lighting, and resolution) are kept constant in each of the images taken for the analysis of the seal coat surface (Table 1).

3. Digital image processing techniques

The methods and procedures employed to determine the aggregate edge images with high accuracy within the scope of this study are described in more detail below:

3.1. Binary image, gray scale image, color image

The brightness level of each pixel of the digital image is referred to as the *gray level*. The range of gray level is determined by the