Image processing-based measurement of pavement macrotexture depth with sand patch test

Xác định độ nhám bề mặt đường sử dụng kỹ thuật xử lý ảnh và thí nghiệm rắc các

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Abstract
This research work utilizes image processing techniques and sand patch tests to measure pavement macrotexture. Image processing techniques including median filter, Sobel edge detector, and circle fitting are used. The newly developed method is able to compute the pavement macrotexture depth index based on image of sand patch test. This image processing-based method is developed in Visual C#.NET framework 4.7.2. The newly developed program has been tested with real-world image samples.

Keywords: Asphalt pavement; Macrotexture depth; Image processing; Automatic measurement.

Tóm tắt
Nghiên cứu của chúng tôi sử dụng các kỹ thuật xử lý ảnh và thí nghiệm rắc cát để đo lường độ nhám bề mặt đường nhựa. Các kỹ thuật xử lý ảnh được sử dụng bao gồm bộ lọc trung vị, phương pháp xác định cạnh Sobel, và thuật toán xác định vật thể tròn. Phương pháp của chúng tôi có thể tính toán hệ độ nhám bề mặt một cách tự động từ ảnh của thí nghiệm rắc cát. Phương pháp mới đã được xây dựng với ngôn ngữ Visual C# và nền tảng .NET 4.7.2. Các mẫu ảnh thu thập từ thí nghiệm thực tế được sử dụng để kiểm chứng chương trình.

Từ khóa: Đường nhựa; Độ nhám bề mặt; Xử lý ảnh; Đo lường tự động.

1. Introduction

Pavement texture strongly affects skid resistance and noise of road. Hence, assessment of surface macrotexture is required to obtain information regarding these two important aspects [1]. Sand patch test (SPT) is often utilized to estimate the mean texture depth index of asphalt pavement. This test is employed for determining the average depth of pavement surface macrotexture [2]. Measurements of pavement surface macrotexture can be used to characterize the pavement surface texture.

The procedures of the SPT can be simply conducted with low cost. It involves spreading a specific volume of sand on a clean and dry pavement surface. The area covered by the sand is measured and used for characterizing the pavement surface voids [3]. The employed material is often round, dry, clean sand which has the particle diameter varies between 0.15mm and 0.30mm [4]. The volume of sand (V) is evenly spread over the pavement surface to form a circle. The diameter of the circle is often measured on four axes and the value of the diameter (D) gets averaged [5]. The pavement mean texture depth index (MTD) is computed from V and D the as follows [4]:

$$MTD = \frac{4V}{\pi D^2} \tag{1}$$

where V = 25000mm^3 is the volume of sand used. D is the diameter of the sand patch circle measured in mm.

Table 1. Inference of surface property based on MTD values

MTD values	Surface property	Scope
MTD < 0.20	Very smooth	Not recommended
0.20 ≤ MTD < 0.45	Smooth	Velocity < 80km/hrs.
0.45 ≤ MTD < 0.8	Moderately smooth	80 ≤ Velocity < 120 km/hrs.
0.80 ≤ MTD ≤ 1.20	Rough	Velocity ≥ 120 km/hrs.
MTD > 1.20	Very rough	Bad surface condition

The surface texture property inferred from the MTD index is presented in Table 1. The computed MTD is used to categorize road surface into five classes: very smooth, smooth, moderately smooth, rough, and very rough. However, SPT is time-consuming and requires traffic interruption [6]. Hence, there is a practical need to reduce the amount of time used for conducting this test. This can help minimize the duration of traffic interruption. This study proposes to apply image processing techniques to shorten the amount of time required in the SPT. After the sand is spread on the pavement surface to form a circle, an image of the sand patch is taken by a digital camera. The camera is mounted on a tripod with a fixed distance above the pavement surface. Image processing techniques, including median filter, Sobel edge detection, and circle fitting, are then used to automatically estimate the diameter of the sand patch and derive the MTD index.

2. The proposed approach

The image processing-based method used to estimate the diameter of the sand patch and derive the MTD index is divided into four steps:

(i) Convert an original image to a grayscale image
(ii) Noise removal using a median filter
(iii) Image binarization using Otsu method
(iv) Sobel edge detection
(v) Circle fitting algorithm: Finding center of a circle and estimating the radius of the circle

In the first step, an original color image is converted to a grayscale image using the following equation:

$$g = 0.2989 \times r + 0.5870 \times g + 0.1140 \times b \tag{2}$$

where g is the gray channel. r, g, and b denote the red, green, and blue channels, respectively.

In the next step, a median filter is used to remove the dot noise and smooth the image. Median filtering is a very widely employed in digital image processing because this method helps preserve edges which are important for the task of interest. This filter runs through each pixel in the image and replaces each pixel with the median of neighboring pixels. Herein, the neighborhood of a pixel is specified by a window of the size 5x5 pixels.

The third step involves the image binarization process based on the Otsu method [7]. The Otsu method is highly effective in thresholding an image and separating the object of interest from the background [8-10]. In the next step, the Sobel edge detection algorithm [11] is used to reveal the pixels lying on the boundary between the sand patch and the surrounding asphalt pavement. This method first smooths the image and then computes the partial derivatives to perform the edge detection [12]. Fig. 2.1 provides a demonstration of the image processing process.

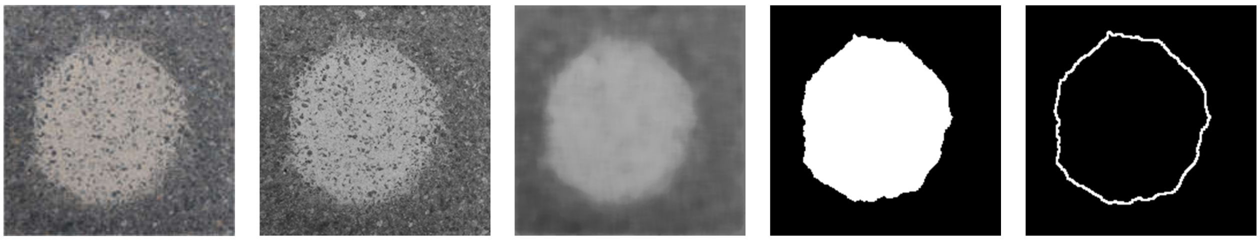

(a) (b) (d) (d) (e)

Fig. 2.1 Demonstration of the image processing process: (a) original image, (b) grayscale image, (c) noise removal using median filter, (d) Otsu algorithm-based image binarization, and (e) Sobel edge detection

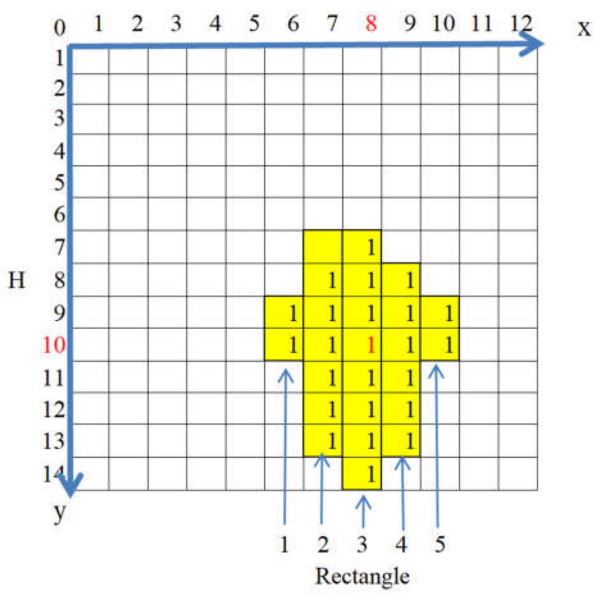


Fig. 2.2 Demonstration of the process used to calculate the centroid of the sand patch (The red point denotes the centroid of the object.)

The last step involves a circle fitting algorithm. This algorithm can be broken down into two steps: finding center of a circle and estimating the radius of the circle. The coordinates of the center of the sand patch are approximated as the centroid of the sand patch object (refer to Fig. 2.1d). Herein, the object is divided into a number of rectangles (refer to Fig. 2.2) and the centroid of the set of these rectangles is computed as follows:

$$x_c = \sum_{i=1}^{W} x_i \times A_i \tag{3}$$

$$y_c = \sum_{i=1}^{W} y_i \times A_i \qquad (4)$$

where x_c and y_c are the coordinates of the centroid of the sand patch. x_i and y_i are the coordinates of the centroid of the i^{th} rectangle.

The radius of the circle is then estimated by averaging the distances from the centroid of the sand patch to the points locating on the edge. Accordingly, the diameter of the sand patch is computed as follows:

$$D = 2 \times \frac{\sum_{k=1}^{N} \sqrt{(x_k - x_c)^2 + (y_k - y_c)^2}}{N} \qquad (5)$$

where N is the number of points on the edge (refer to Fig. 2.1e). x_k and y_k are the coordinates of the k^{th} point on the edge. Using the value of D, the MTD index is computed via the equation 1.

3. Experimental results

The image processing-based method used to compute the value of D and the MTD index has been coded by the authors in Visual C#.NET framework 4.7.2. The computer program has been used to compute the MTD indices obtained from three SPT experiments. The experimental results are summarized in Fig. 3.1. The operation of the complied computer program is illustrated in Fig. 3.2. It is noted that to convert the value of D from the unit of pixels to mm, a conversion scale factor (α) is required. Herein, conversion scale factor α is equal to 1.5 meaning that one pixel corresponds to 1.5mm. Accordingly, the actual diameter Da is calculated as follows:

$$D_a = \alpha \times D \qquad (6)$$

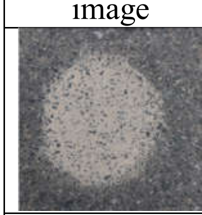
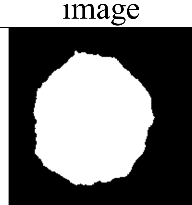
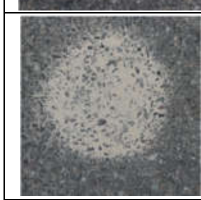
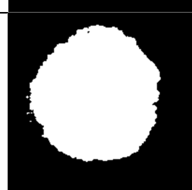
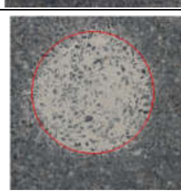
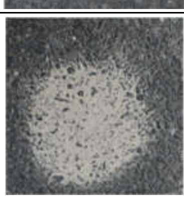
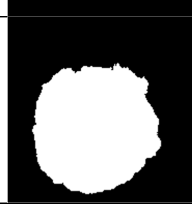
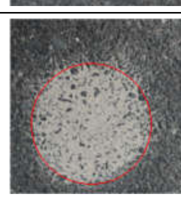
Original image	Binarized image	Circle fitting result	D (mm)	MTD	Execution time (s)
			101.38	0.77	5.248
			105.18	0.72	5.012
			92.92	0.92	4.540

Fig. 3.1 Experimental results

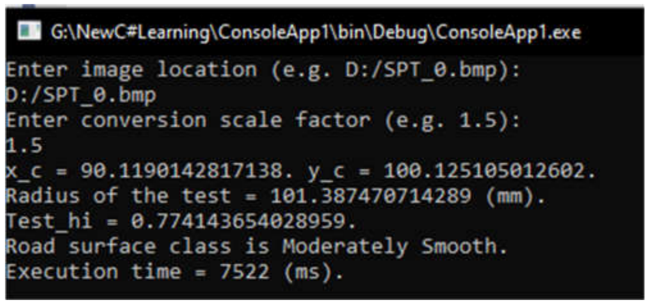


Fig. 3.2 Inputs and outputs of the developed computer program

4. Conclusion

This paper has constructed an image processing-based approach for estimating the MTD index based on images of the SPT. Image processing techniques, including the median filter, Sobel edge detection, and circle fitting are used. The new method has been developed in Visual C#.NET framework 4.7.2 and tested with three cases. It is expected that this method can help improve the productivity and consistency of the SPT.

Supplementary material

The developed program has been deposited at: https://github.com/NhatDucHoang/IP_MTD.

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