Pavement Crack Distress Detection Based on Image Analysis

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Abstract—A detecting approach has been developed in view of the properties of cracks in the pavement image. Because of the uneven illumination, threshold causes difficulties in applications of pavement image segmentation. By analyzing the signal model, we can use bilinear interpolation to obtain the correction image based on the background subset which is extracted from original pavement image. Then, the segmentation threshold could be calculated by the histogram of the correction image based on statistical criterion. After the operation of binary segmentation, final crack distress can be achieved by sequential operation of spreading cracks and eliminating isolated noises. Experimental results show that the approach is also applicable for detecting blocky distress.

Keywords: pavement crack distress detection; gray correction; bilinear interpolation; noise elimination

I. INTRODUCTION

The detection of pavement crack distress plays an extraordinary role in maintaining highway pavement. The expenses of maintenance will be reduced greatly if the distress is detected and mended at the initial appearance period [1]. Traditional detecting methods based on artificial vision cannot meet the need of rapid development of the road for its low-efficiency, non-precision, inconvenience and etc. Therefore, an automatic detecting approach of pavement crack distress based on image analysis has been given in this paper.

II. PAVEMENT IMAGE PREPROCESSING

An ideal image should map brightness of each pixel to the corresponding gray value linearly. However, the influence of focusing distance or light intensity may lead to the degradation of the image quality. As is shown in Fig. 1(a), images shoot by high speed camera are always more brighter in the middle area and darker in the surrounding area. Consequently, it is difficult to correct the original pavement image by a simple mapping function.

A. Image enhancement

Traditional methods of image enhancement are using histogram to extract information from image. The image in Fig. 1(c) is the histogram-equalized result. The feature is evident that extensive white area appeared. Although the histogram-equalized method increased in contrast over the entire intensity scale, the segmentation algorithm could be a more difficult task in sequent processing.
Figure 1: (a) An original pavement crack distress image, and (b) its histogram. (c) histogram-equalized image, and (d) its histogram.

Take into consideration that an original pavement image consists of three parts [2]: background signal, noise signal and crack signal. The last two could be received by subtracting the background correction signal from all parts. Based on the additive model, we can split the original image into $32 \times 32$ blocks first. With the adjustment of the image, the size of block template should be modified accordingly. Then, we can remove high-value signals and low-value signal of each block on certain regions which range from 20% to 25%. And the key pixel value of each block could be achieved by calculating the middle gray value or the average gray value of the rest pixels in the block. Tian & Huhns [3] put forth an interpolation method for a subpixel order measurement. Consequently, the background subset can be obtained by performing bilinear interpolation to the key value of each block. Based on the above improvement algorithm, we could get a background image with the even illumination condition.

B. Bilinear interpolation

In mathematics, bilinear interpolation is one of the basic resampling techniques. The key idea is to perform linear interpolation in two directions on a coordinate system, that is to say, first in the x-direction, then in the y-direction. If we want to calculate the value of the function $f$ at the point $P = (x, y)$, and it is assumed that we know the value of the four neighborhoods of $P$, then the interpolation formula in matrix operations simplifies to:

$$f(x, y) = [1 - x] [x] [f(0, 0) f(0, 1)] [1 - y] [f(1, 0) f(1, 1)]$$

From Figs. 2(a) and (b), it can be seen obviously that the light intensity of the pavement image becomes more evenly after the gray correction.

III. CRACK DISTRESS DETECTION

A. Features of the crack distress

Linear crack is a normal formation of the numerous pavement distresses, such as: longitudinal crack, crosswise crack, reflective crack and network crack. The detecting system for acquiring pavement images which uses high rapid and precise cameras may bring back lots of noise signal influenced by external factors. Generally speaking, the crack distress image has the following properties:

- The non-uniform pavement materials may lead to the textures of pavement unevenly. There are clear variations in crack and background influenced by the severity of crack distress or the grease of road surface.
- The pixel amounts of crack are less than that of background.
- Gray value of pavement and that of crack overlap to each other partially.
- Pavement image contains a large amount of information including noises produced by different sizes or intervals of pavement material, which are a kind of random, high frequency and low amplitude signals.

B. Threshold segmentation

Resulting from the features of the crack distress, edge detection is by far the most common approach for detecting crack distress, such as the Roberts operators, the Prewitt operators, and the Sobel operators. However, the traditional approaches of edge detection do have some limitations which lead to unsatisfactory answers.

It is assumed $I(p), p = (x, y)$ stands for the grayscale pavement image that has been corrected, $w$ and $h$ indicates the weight and the height of the image respectively, and then the algorithm of threshold selection has four steps as shown:

Step 1: Calculate the histogram of Fig. 2(a), namely $H(i), i < 255$.

Step 2: Since threshold varies from 1 to 254, according to the threshold set $\varphi = \{t_1, \ldots, t_n\}, t_i = t_{i-1} + 1, n < 255$, calculate $\text{Sum}_i$ from $t_i$ to $t_i$, in which $\text{Sum}_0 = 0$ and $\text{Sum}_n = \text{Sum}_{n-1} + H(t_i)$.

Step 3: Repeat Step (2) until $\text{Sum} > \theta \times w \times h$, and then $t_i$ is the just threshold. Here, the values of $\theta$ could range from 0 to 1.

Step 4: Make a two-valued segmentation to the correction image on $t_i$, as shown:

$$P'(x, y) = \begin{cases} 255, & P(x, y) \leq t_i \\ 0, & P(x, y) > t_i \end{cases}$$
Figure 3: Two-valued segmentation image, in which (a) $\theta$ is 0.02, and (b) $\theta$ is 0.08.

It is seemed that the details of the crack distress are more reversed as the $\theta$ increased from Figs. 3(a) and (b). However, the result of two-valued segmentation image has more noises. Here the value of $\theta$ is set to 0.04.

C. Point spread operation

From Figs. 3(a) and (b), we can also see that there are a large amount of noises in the two-valued segmentation images. Then we should eliminate these noises to extract crack distress adequately.

The grayscale intensities of crack distress pixels may lead to removal of targets when eliminating noises by the threshold $t$, so we could perform point spread operation first to fill up the gaps of targets:

Step 1: In view of each background pixel $(P_{xy} = 0)$ in image, calculate background numbers of its neighborhood as $B_{xy}$ by a mask of size $3 \times 3$.

Step 2: Then amend the grayscale of each pixel in the $3 \times 3$ mask as below:

$$P'(m,n) = \begin{cases} 0, & B_{xy} < \tau, 1 \leq \tau \leq 7 \\ 255, & B_{xy} \geq \tau \end{cases}$$

In the above equation, $P'(m,n)$ is the gray value of the pixels, which are the neighborhoods of point $P(x,y)$. And $m$ and $n$ indicate the coordinate value of x-direction and y-direction as following:

$m = \{x-1, x, x+1\}$

$n = \{y-1, y, y+1\}$

Figure 4: Two-valued segmentation image, in which (a) $\theta$ is 3, and (b) $\theta$ is 7. Here the value of $\theta$ takes 3.

D. Eliminating isolated noises

As shown in Figs. 4(a) and (b), point spread operation is similar to morphological dilation. In image processing applications, dilation and erosion are used most in combination [4]. The former expands cracks and the latter shrinks them. Suppose that isolated noise signals exist less likely as single point and cracks have certain continuities, then we could eliminate isolated noises like opening operation as following:

Step 1: In view of each target pixel $(P(x,y) = 255)$ in image, calculate target numbers of its neighborhood as $N_{xy}$ by a mask of size $k \times k$.

Step 2: Then compare $N_{xy}$ with threshold $t_{N}$, and amend the grayscale of each pixel in the $k \times k$ mask as following:

$$P'(m,n) = \begin{cases} 255, & N_{xy} \geq N_{i}, N_{i} = v \times k \times k, 0 < v < 1 \\ 0, & N_{xy} < N_{i} \end{cases}$$

$$x - \left[ \frac{k}{2} \right] + 1 \leq m \leq x + \left[ \frac{k}{2} \right] - 1$$

$$y - \left[ \frac{k}{2} \right] + 1 \leq n \leq y + \left[ \frac{k}{2} \right] - 1$$

The value of $k$ is taken by the size of image, which is 5 here. In accordance with the accuracy of cracks to be gotten, Figs. 5(a) and (b) show the result by taking different values of $v$. 

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Figure 5: Eliminating isolated noises, in which (a) $\nu$ is 0.2, and (b) $\nu$ is 0.8.

Figure 6: The end result of pavement crack distress detection, in which $\nu$ is 0.4.

IV. EXPERIMENTS

In accordance with the above approach, it could detect not only the single linear distress but also the blocky or massive distress.

Figure 7: (a), (c) and (e) Original pavement images which contain massive distress. (b), (d) and (f) Detecting result are obtained by the above approach correspondingly.

During different phases, most of the cracks which the width is more than 2mm can be detected in case of the pavement image have good quality. However, the qualities of the detecting results may be affected by the actual factors, which lead to an unsuccessful detecting to a large gathering of cracks.

V. CONCLUSIONS AND COMMENTS

The crack distress processing based on previous approaches make it possible to detect pavement image automatically. An important area for further research is to build models from multiple pavement images, which can have further advantages that parameters from multiple image conditions could be combined into a single parameter.

The detection performance could be further improved by adding new feature types to crack details. For example, blocky or isolated noises could be eliminated by method of straight line fittings and the crack could be refined further by analyzing distress skeleton.

REFERENCES


