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Crack Image Segmentation Based on Improved DBC Method

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ABSTRACT

With the development of computer vision technology, crack detection based on digital image segmentation method arouses global attentions among researchers and transportation ministries. Since the crack always exhibits the random shape and complex texture, it is still a challenge to accomplish reliable crack detection results. Therefore, a novel crack image segmentation method based on fractal DBC (differential box counting) is introduced in this paper. The proposed method can estimate every pixel fractal feature based on neighborhood information which can consider the contribution from all possible direction in the related block. The block moves just one pixel every time so that it could cover all the pixels in the crack image. Unlike the classic DBC method which only describes fractal feature for the related region, this novel method can effectively achieve crack image segmentation according to the fractal feature of every pixel. The experiment proves the proposed method can achieve satisfactory results in crack detection.

Keywords: Crack detection; image segmentation; differential box counting

1. INTRODUCTION

In civil engineering, pavement survey is vital for pavement maintenance systems (PMS) that ensure ride quality and traffic safety. As one of most common distress, crack detection always is an essential part of pavement survey. With the development of computer vision technology, crack detection based on digital image segmentation method arouses global attentions among researchers and transportation ministries.

In 2003, the Distress Identification manual for the long term pavement performance (LTPP) Program is regarded as a comprehensive guideline in the inspection of pavement distress, particularly for the project level studies [1]. An analysis on the effectiveness is provided about four crack detection techniques: fast Haar transform (FHT), fast Fourier transform (FFT), and other three edge-detection techniques including Sobel, LoG and Canny[2]. After a detailed analysis of the advantages and disadvantages of the traditional threshold segmentation algorithms on pavement crack image, an improved segmentation method based on the combination of multi-threshold averaging and multi-directional mathematical morphology is proposed [3]. In order to quantify crack patterns, the software called Crack Image Analysis System(CIAS) has been developed [4]. Also, Youquan introduces a new method combined with the mathematical morphology to detect the road crack image[5].

However, many researchers are still struggle to achieve reliable crack detection results. Since the crack characteristics including random shape and complex texture in pavement image, the traditional methods for crack detection are difficult to get stable and effective results. To solve these problems, this paper proposes a novel crack image segmentation method based on the DBC (differential box counting) method. Unlike the traditional threshold-based or edge-based segmentation algorithm, this algorithm can effectively accomplish crack segmentation according to the crack fractal feature.

The remaining part of the paper is organized as follows: Section 2 describes the fractal feature applied in digital image processing. Then, a novel crack segmentation method based on improved DBC is proposed. Section 3 is for the experimental results, and section4 concludes the paper. Section 5 mainly presents the related programs that support for this paper.

2. CRACK IMAGE SEGMENTATION BASED ON FRACTAL FEATURE

In fractal geometry theory, self similarity is an essential property of fractal in nature. Fractal dimension provides a way to measure self-similarity and presents the texture feature. Nowadays, the fractal feature has been applied in texture analysis and segmentation, shape measurement and classification, image and graphic analysis in other fields [6].

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Aim to crack random shape and complex texture, an improved crack segmentation method based on fractal feature is studied. Unlike the traditional threshold-based or edge-based segmentation methods[8], the proposed method can effectively accomplish crack segmentation according to the fractal feature.

2.1 Fractal Feature applied in image processing

Among the definitions on fractal fracture, the DBC method was considered as a better method, especially in the application of image processing and analysis[9]. According to the fractal geometry theory, the fractal fracture is calculated based on the self-similarity concept. The fractal dimension of the set F is defined as:

$$\dim F = \lim_{r\to 0}\frac{\log N_r(F)}{\log(1/r)} \tag{1}$$

Where $N_r(F)$ is the least number of distinct copies of F in the scale r, the union of $N_r(F)$ distinct copies must cover the set F completely.

In DBC method, an image of size $M\times M$ is partitioned into non-overlapping blocks of size $s\times s$, where s is an integer between 1 and $M/2$. For each block, there is a column of boxes of size $s\times s\times h$, where h is the height of each box, $G/h = M/s$, and G is the total number of gray levels.

Let the minimum and maximum gray level in the (i, j) th block fall into the k th and l th boxes respectively. The boxes covering this block are counted in the number as

$$n_r(i, j) = l - k + 1 \tag{2}$$

Considering contributions from all blocks, N_r is counted for different values of r as:

$$N_r = \sum_{i,j} n_r(i, j) \tag{3}$$

Then, the fractal dimension can be estimated from the least squares linear fit of $\log(N_r)$ versus $\log(1/r)$.

2.2 Improved Crack Segmentation Method

In traditional DBC method, the selection of block is critical. The size of block maybe flexible, but it also determines the scale, height based on Equation $r = s/M$ and $G/h = M/s$. Moreover, it will lead a direct consequence for the results [10].

Accordingly, the DBC method only can describe fractal feature of related region, not for signal pixel. Intuitively, a small size of block can present more details about the pixels in the region. The large size of block can reflect the feature in a lager region. For example, When $s = 4$, it presents the fractal feature of pixels in the 4×4 region. When $s = 8$, it reflects the feature in the 8×8 region. Even the smallest size block is 2×2, it only exhibits the fractal feature four pixels, not one pixel.

However, the crack information in digital image contains rich texture and rich detail. It may miss many crack information according to traditional DBC method. Therefore, we need to find an appropriate way to describe the fractal feature of pixel. Mathematically, when $s = 1$, it is no meaning to calculate fractal feature for one point. However, in digital image theory, it expresses the fractal feature of one pixel. Therefore, we proposed novel method to define the fractal feature of one pixel.

Consider the image $f(m,m)$ as a 3D surface plan with $[x, y, f(x, y)]$, and (x, y) denotes the pixel position and $f(x, y)$ denotes the pixel gray level, where $(x, y)\in(m,m)$, as shown in Figure1.

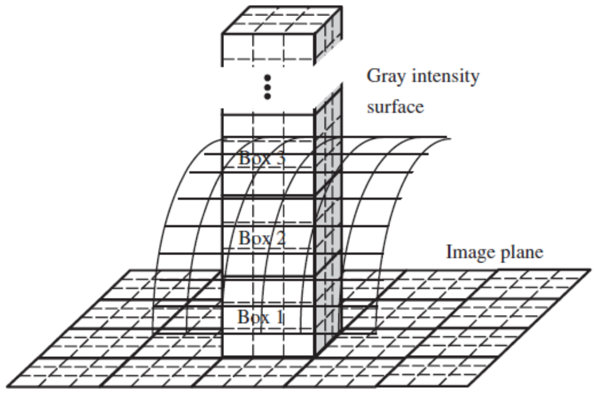


Figure 1 Explanation on improved DBC method

1. Blocks selection

The image plan is divided into overlapping blocks of size $s \times s$, where s is an odd integer between 1 and $m/2$. The block moves just one pixel along image x or y direction every time. So, there are also $m \times m$ overlapping blocks in image plan. Besides, the edge pixels in image use zero pixels to filling the block. The related block is defined as:

$$I_s(i, j), (i, j) \in (m \times m) \tag{4}$$

$I_s(i, j)$ denotes the $(i + j)$ th block based on the size $s \times s$.

2. Boxes counting based on new blocks

For each block, there is a column of boxes of size $s \times s \times h$, where h is the height of each box, and G is the total number of gray levels.

$$G/h = M/s \tag{5}$$

Let the minimum and maximum gray level in the (i, j) th block fall into the k th and l th boxes respectively. The boxes covering this block are counted in the number as:

$$n_s(i, j) = l - k + 1 = [\max I_s(i, j) - \min I_s(i, j)]/\mathrm{h} + 1 \tag{6}$$

Where, $\max I_s(i, j)$ and $\min I_s(i, j)$ means the maximum and minimum gray level in $I_s(i, j)$ block respectively.

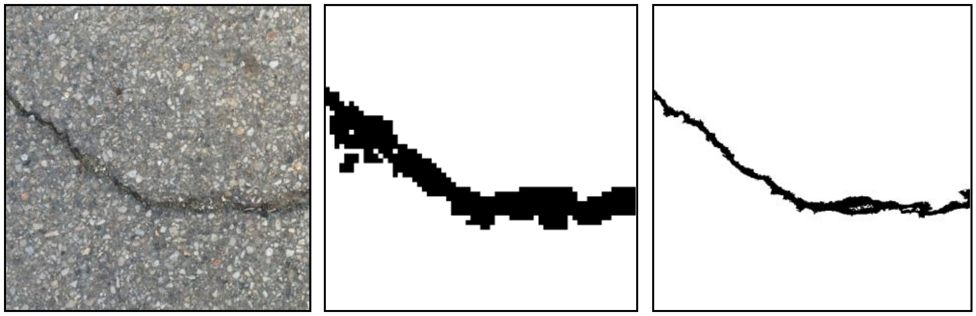
3. Pixel fractal feature estimation.

$$f_d(x, y) = n_s(x, y) \tag{7}$$

Where, $f_d(x, y)$ denotes the DBC for the pixel $f(x, y)$.

The fractal feature of one pixel is estimated by its neighborhood information in the related block, which can consider the contribution from all possible direction. Since the block moves just one pixel along the image direction every time, the block could cover all the pixels. For the edge pixels in image, zero pixels are used to filling as a whole block. On the bias of the mentioned procedures, image enhancement is applied before crack segmentation.

After segmentation by our proposed method, the crack is presented as black part in pavement image as show in figure 2. The figure 2(a) is the original image, and figure 2(b) present the result based on the classic fractal dimension (FD) method. As we can see, this crack segmentation is thick and exhibits the over segmentation because it based on the fractal feature of related region. The proposed method segmentation presented in figure 2(c) has better result which contains satisfy crack shape and texture.



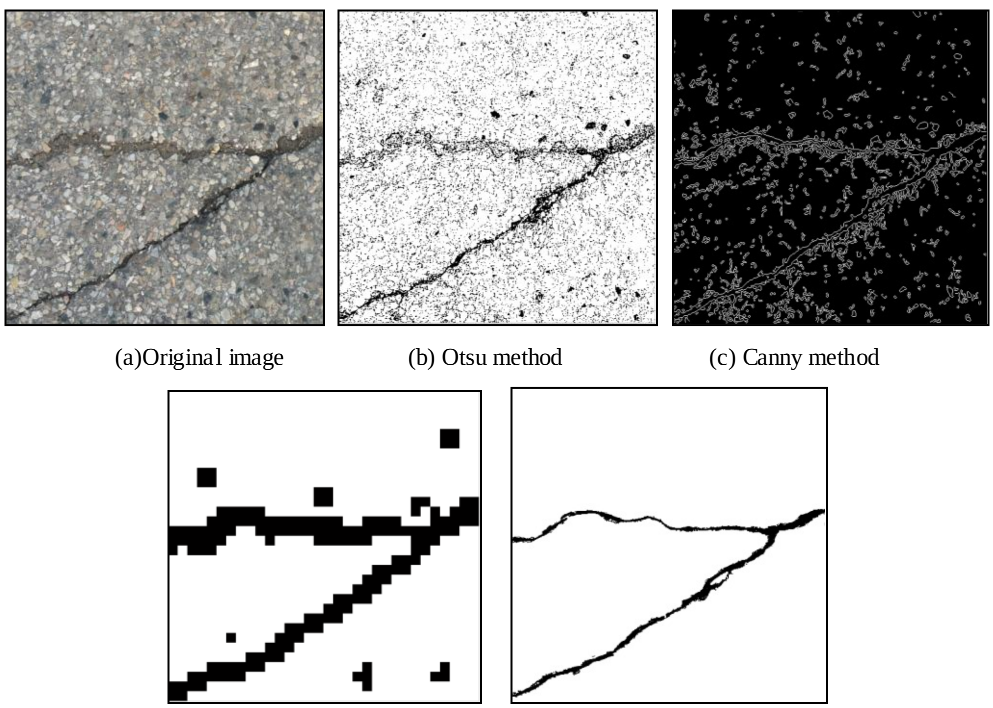
(a)Original image (b) DBC method (c) Proposed method

Figure.2 Crack segmentation based on proposed method

3. EXPERIMENT AND RESULTS

In order to verify the proposed method performance in this paper, a series of crack detection tests have been carried on sample pavement images. In this experiment, some differential classic segmentation methods are compared with the proposed methods. All of the image segmentation methods were implemented in MatLab, and the results are shown in figure 3.

As shown in figure 3, the original crack image is shown in figure 3(a). The figure 3(b) presents the result of Otsu which is a typical threshold segmentation method, and the classic edge-based segmentation method Canny is applied in figure 3(c). Moreover, compare with classical DBC method is shown in figure 3(e), the proposed method is in figure 3(d).



(a)Original image (b) Otsu method (c) Canny method

(d) DBC method (e) Proposed method

Figure 5 Comparison on different crack image segmentation methods

Otsu is very sensitive about the noise and easy to make wrong segmentation between the target and background in figure 3(b). Although Canny operator has a good completeness of crack maintains, it is still sensitive to the noise size and shape, which lead a low correctness in crack segmentation as the gap between grey values of crack and neighbourhood is not so obviously in figure 3(c). The crack segmentation based on fractal dimension in figure 3(d) is thick and exhibits the over segmentation because it based on the fractal feature of related region. The proposed method segmentation presented in figure (e) has better result which contains satisfy crack shape and texture.

For the above comparison results, three related evaluation criterions including completeness, correctness and F-measure are used to evaluate the accuracy of the crack detection. Completeness is defined as the percentage of the reference date which is detected during crack extraction. Correctness represents the percentage of the extracted crack data which is correct. F-measure is an overall evaluation criteria based on Completeness and Correctness. Their formulae are:

$$cpt = \frac{L_{TP}}{L_{TP} + L_{FN}}, \quad crt = \frac{L_{TP}}{L_{TP} + L_{FP}}, F = 2\frac{cpt \cdot crt}{cpt + crt} \tag{8}$$

Where, L_{TP} , L_{FP} , and L_{FN} , are the true positive, false positive and false negatives, respectively. Specifically, L_{TP} denotes the number of pixels in the actual crack image, L_{FP} is for the non-crack pixels as crack, L_{FN} presents the crack pixels which are undetected.

Table 1. Objective analysis of the first column of figure 3

Algorithms	Completeness	Correctness	F-measure
Otsu	0.875	0.652	0.726
Canny	0.798	0.454	0.578
DBC method	0.924	0.788	0.850
Proposed method	0.945	0.957	0.951

For Completeness, the compared four methods are with no obvious distinguished differences. The Completeness of Otsu and DBC method are 0.875 and 0.924 respectively, which present a little high than Canny (0.798). The proposed method is 0.945 which did not exhibit much better than other four methods. Although the other four methods have good references on Completeness, they all over segmented the crack. Therefore, our method is far beyond other four methods in Correctness. The Otsu method is only 0.652, the Canny and DBC method also are just 0.454 and 0.788, while the proposed method is up to 0.957. For F-measure, the proposed method can reach up to 0.951, while the others are all only less than 0.850.

According to the comparison, we can see that the traditional methods can no longer satisfy the requirements of crack segmentation. They still have many spot noises and fraud edges, which would cause a lot of difficulty to measure crack parameters. Generally, the method proposed in this paper can achieve satisfying result in crack image detection.

4. CONCLUSION

According to the crack feature in pavement image, a novel crack image segmentation based on DBC method is introduced in this paper. The proposed method can estimate every pixel fractal feature based on neighborhood information which can consider the contribution from all possible direction in the related block. The block moves just one pixel every time so that it could cover all the pixels in the crack image. Unlike the classic DBC method which only describes fractal feature for the related region, this novel method can effectively achieve crack image segmentation according to the fractal feature of every pixel. The experiment shows the proposed method can achieve satisfying results in crack detection. Based on the experiment analysis, the traditional methods can no longer satisfy the requirements of crack segmentation. They still have many spot noises and fraud edges, which would cause a lot of difficulty to measure crack parameters. The experiment verifies the method proposed in this paper can achieve satisfying result in crack image detection.

5. ACKNOWLEDGEMENT

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