Rapid Crack Detection Method of High-grade Cement Concrete Pavement

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Abstract. A new fast automatic repaired crack detection method of high-grade cement concrete pavement was realized through inhibition of groove, image enhancement, crack extraction and crack stitching in the low-resolution images using wavelet decomposition on the basis of in-depth feature analysis of repaired cracks. In addition, the modified crack identification algorithms were discussed in detail with joints, strip stains and traffic markings. It has significantly improved the processing speed by reducing image resolution and the applying one-dimensional convolution template instead of two-dimension. Large sample tests showed that recognition rate close to 94%.

1. Introduction
Repairing cracks are cement pavement image disease processing of the main research object, generally high-grade highway maintenance condition is good, most new cracks can timely treatment. The main object is repairing cracks in the road image, which occurs frequently. After 5 years of use on general cement pavement, the rate of repairing cracks has greatly increased, and as the service life increases, the rate of cracks will greatly increase. By identifying and repairing crack rate, thereby enhancing the pavement disease surveillance efforts.

2. Multi-Resolution Analysis

![Wavelet decomposition](image)

Figure 1. Wavelet decomposition to repair cracks

The width of repaired cracks, grooves, joints and new cracks in cement concrete pavement are different, and the contrast is different. Use wavelet to decompose images containing these targets into different resolutions for observation. As shown in Figure 1, after a layer of decomposition, the grooves, seams, and repaired cracks are still clear, but the new cracks have become blurred and unrecognizable; after two layers of decomposition, joints and repair cracks still can identify, but grooving becomes blurred; after three layers of decomposition, even grooving, seam grew dim. In summary, perform 2 layers wavelet decomposition on the original image. Thus, the image size is only 1/16 of the original...
image, and the interference of the groove to the image recognition is reduced greatly. In the following, the image decomposed by the 2-layer wavelet is called a low-resolution image.

3. Image Enhancement Denoising Method

3.1. Groove Suppression Method
Pan Yuli[1] according to the periodicity of cement concrete pavement grooves, proposed a method of eliminating grooves on cement concrete pavement based on two-dimensional Fourier transform, and applied for a patent for invention, however, using the method involved in Fourier forward and inverse transform, the computation is very large. Consider that the width of the groove generally slightly less than the width of repair cracks. From the perspective of operation speed and processing effect, in low-resolution images, grooving has a weak effect on repairing cracks. A smooth template in the spatial domain can be used to convolve the image to suppress horizontal stripes, grooves.

Use \(3 \times 3\) horizontal stripe removal template \(M_{\text{Vertical}}\) as follows:

\[
M_{\text{Vertical}} = \frac{1}{3} \begin{bmatrix}
0 & 1 & 0 \\
0 & 1 & 0 \\
0 & 1 & 0 \\
\end{bmatrix}
\]

Therefore, the essence of smoothing templates is to average the vertically adjacent three pixels, in low resolution image, repair the crack width is commonly 2 ~ 3 pixels, and the groove is generally 1 ~ 2 pixels, the two boundaries of the groove are often merged into one. Thus, the average processing of the three pixels has a good inhibitory effect on the groove, little effect on repairing cracks. More importantly, its calculation speed is much faster than the frequency domain filtering.

3.2. Fast Crack Image Enhancement Method
Crack enhancement is the most critical part of the entire identification process. There is a lot of research at domestic and overseas on the enhancement processing of road crack images. For example, Koutsopoulo[2](1993) used the differential imaging method; Siriphan Jitprasithsir [3] (1997) used the median filtering method; Zhang Juan [4] (2004) proposed a method using the "+" font and "X" font template filtering; Wang Taiping [5] (2008) proposed a "米" font window median filtering algorithm; Sun Bocheng[6] (2008) proposed a mask template with 9 kinds of image smoothing and enhancement based on a 5 × 5 window. The common feature of these algorithms is the construction of templates, which can be used to enhance the image convolution. In this paper, the large-scale LoG template is used to reinforce the cracks of cement pavement.

The LoG (Laplacian of Gaussian) algorithm is an algorithm for finding image edges based on the zero-crossing algorithm of the second derivative by Marr and Hildreth combined with Gaussian filtering, also known as the Mexican straw hat algorithm. Definition of two-dimensional Gaussian distribution function:

\[
G(x, y) = \frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}}
\]

Gaussian Laplace operator \(\nabla^2G\) Definition:

\[
\nabla^2G(x, y) = \frac{1}{2\pi\sigma^2}e^{-\frac{x^2+\gamma^2}{\delta^2}-\frac{1}{\sigma^2}}
\]

Where, \(\sigma\) is a spatial constant indicating the degree of smoothing; the larger the \(\sigma\), the larger the smoothing range. In practical applications, the original template is truncated to a finite size \(N\). Experiments show that, when \(N = 2\sqrt{2\pi\sigma+1}\), a better detection effect can be obtained.

Due to repair the crack width is bigger, for the LoG operator, \(\sigma\) needs to take a larger numerical value, so the amount of convolution operation will be very large. In order to increase the operation speed of the large-size LoG template, it is necessary to perform dimensionality reduction processing.
that is, decompose the two-dimensional filter convolution template into two one-dimensional row and column filters:

\[
V^2 G(x, y) = \frac{1}{\pi \sigma^4} \left( \frac{x^2 + y^2}{2\sigma^2} - 1 \right) \exp \left( -\frac{x^2 + y^2}{2\sigma^2} \right) = G_1 + G_2,
\]

(4)

When the template size more than 5, use the two one-dimensional rows and columns filter will be faster than the two-dimensional template. For an 11×11 LoG template, it can be decomposed into two row and column filters: \([0 1 5 17 36 46 36 17 5 1 0]\), \([-1 -6 -17 -17 18 46 18 -17 -17 -6 -1]\); Figure 2 shows the processing effect of using the above 11×11 template:

![Original image](image1.jpg) ![Enhanced effects](image2.jpg)

Figure 2. 11×11 LoG one-dimensional template enhancement effects

4. Crack Extraction

After imaging enhancement, use Otsu method to binarize. In addition to repairing cracks, there are residual grooves, stains, traffic marking edges and seams in the image, the geometry of these disturbing factors must be considered when extracting cracks. The gray value near the area is gradually removed by setting filter conditions. After binarization, using boundary tracking to obtain several connected areas, the area, perimeter, shape, direction, circumscribed rectangle, curve radian, etc. of each connected area can be calculated; its core problem is to mine feature descriptions with significant discriminatory effect, and to achieve the purpose of crack extraction by setting multi-layer conditional filtering. The filtering steps are shown in Figure 3.

![Crack extraction flowchart](image3.jpg)

Figure 3. Crack extraction flowchart

In the figure, \(l_{obj}\) is the length of the target area, \(W_R\) is the width of the circumscribed rectangle of the target area, \(H_R\) is the height of the circumscribed rectangle of the target area, \(W_{img}\) is the width of the entire image, \(H_{img}\) is the height of the entire image, \(C\) is the perimeter of the target area, \(C_R\) is the perimeter of the circumscribed rectangle of the target area, \(d_{obj}\) is the width of the target area, \(G_{obj}\) is the average grayscale of the target area; \(T_e\) is the threshold parameter and \(\gamma\) is the shape parameter of the target area. The whole process is divided into five steps to judge:

The first step is length discrimination. If the length of the detected target area is greater than 0.6 times the image width, it is considered to be a crack or a seam. This step of judgment is mainly for two kinds of targets, which are:

1. Horizontal and vertical seam segments, such targets generally have a large length;
(2) Long cracks

The second step is shape discrimination, which consists of a set of shape discrimination formulas, which consist of the width and height of the circumscribed rectangle of the target area. The first discriminant is for the horizontal crack segment, which requires more than 0.2 times the image width. And the width threshold is greater than or equal to the road surface size 0.6m. At the same time, the height is required to be greater than 0.1 times the image height. This height threshold is greater than or equal to the road surface size of 0.2m, which is equivalent to crossing about 10 notches. Noise such as stains is generally difficult to meet this condition. This condition is mainly for the case where there is an angle between the groove and the horizontal axis in the road surface image. And when the groove suppression effect is not ideal, the situation where the inclination angle is 5 degrees or less can be filtered out. The 4th discriminant has a width threshold of about 0.15m and a height threshold of about 0.5m. The second and third discriminants require a square with a width and height close to 0.4m x 0.4m, and most of the cracks are extracted by shape discrimination.

The third, fourth, and fifth steps are parallel judgments, so these three conditions must be met at the same time. They screened the crack segments that could not meet the shape and size requirements of the previous steps. At this time, most of the significant cracks have been extracted, leaving only small crack fragments with small size and unobvious shape features. These three conditions are for the following types of noise:

(1) The average grayscale threshold of the area is more-harsh than the segmentation threshold. It is hoped that the grooves that remain in the image will be further filtered. This is mainly based on the repair of cracks after LoG enhancement, which is more obvious than the grooves. Since the width of the repaired crack is wider than that of the groove, the concept of average grayscale is used. And the influence of the grayscale of the neighborhood is considered. This is beneficial for retaining the crack and further suppressing the groove.

(2) The average width of the crack is larger than the width of the groove, generally larger than 1 pixel. Using the width threshold will filter the groove area and other weak noises with an average width of only 1 pixel.

(3) The target circumscribed rectangle height threshold of 0.03H_{img} is approximately equivalent to the width of three grooves on the road surface. That is, the height of the target must be at least more than three groove widths. So that most of the grooves will be filtered; but when grooving and horizontal axis Angle more than 6 degrees Angle this condition is invalid. In addition, the height of the connected area formed after the groove is connected with the stain noise may also exceed this threshold. In view of this situation, filter by condition C<C_{R}. Normally, the circumference of the crack will be smaller than that of its circumscribed rectangle, and after several grooves are connected to noise, its area perimeter will exceed its circumscribed rectangle.

(4) The shape parameter is used to filter the stain noise of a strip with a small width or an ellipse with a large length and width. The judgment threshold is 3.2, got by assuming a rectangle with a size of 10 × 1, calculating its perimeter and area. The discriminant requires that the aspect ratio of the target shape is greater than 10: 1. Most of the band noise can be filtered, but some cracks with too small length will be filtered, too. Approximately from the aspect ratio requirements and crack width (2 pixels), the length of the crack segment requires at least 20 pixels before it can be extracted, converted to the actual size, about 0.2m.

5. Handling of Several Special Cases

Most of the crack repair fragments are gradually extracted through the five discrimination steps and related discrimination thresholds introduced in the previous section. However, due to the complexity of the road surface, the extracted crack images still need to be further optimized. The corresponding treatment methods are mainly introduced for the presence of seams, large-scale strip pollution and traffic markings.

5.1. Seam

The horizontal and vertical joints are the most basic constituent elements of the cement concrete pavement. In the pavement image, almost every two photos (image size: 2944 × 2048 pixels, each
pixel resolution is about 1mm) will appear a horizontal joint. The proportion of longitudinal seams in the image is also very high, and the implementation steps are as follows:

1) Image pre-processing: as discussed in detail above, in low-resolution images, horizontal de-striping is used to suppress notches, and large-scale LoG operators are used to enhance the image. At this time, cracks and seams in the image. The contrast with the pavement background is enhanced. In addition to the cracks in Figure 4a, it also contains horizontal seams and vertical seams. Through image preprocessing, the seams and cracks are enhanced at the same time, and other noise was suppressed.

2) Threshold-segmentation: use the maximum between-class variance method to get the best segmentation threshold $T_{Otsu}$, binarize the image by using this value.

3) Seam positioning: the method of precise seam positioning will be introduced in detail in Chapter 5. In this section, only the seam needs to be roughly positioned. It mainly uses the projection characteristics of the seam to perform horizontal and vertical projections on the binary image find the peak positions greater than the threshold values $P_h$ and $P_v$ in the horizontal and vertical projection curves, and locate them. The $P_h$ value is set to one-third of the image width, and the $P_v$ value is positioned to one-third of the image height. Row positioning is used for horizontal seams, and column positioning is used for vertical seams. After the seam is found, the row and column where it is located are shielded in the binary image.

4) Crack-extraction: after the seam is shielded, the discriminative method introduced in the previous section can be used to filter and extract the connected areas.

### 5.2. Long Stains

Long strip stains are generally caused by the leakage of dark pollutants carried by vehicles, or large-scale pollution caused by squeezing out maintenance materials, and sometimes polluting roads up to several kilometers in length. Such long strip stains, easy to be judged as a longitudinal crack, which leads to the true longitudinal crack of the road section cannot be correctly identified, the implementation steps are described as follows:

Divide the image with a grid, the grid size is about 0.05m of the actual pavement size, find the location of the grid with cracks, set the gray threshold $T_{nosie}$ for stain filtering, calculate the pixel ratio of the grid at that location that is less than $T_{nosie}$, set the statistical threshold $K_{nosie}$ for filtering the stain grid. When $n > K_{nosie}$ the current grid is considered to be stain noise pollution. The parameters $T_{nosie}$ and $K_{nosie}$ shall be determined through experiments.

### 5.3. Traffic Marking

Traffic marking is also a kind of special interference to crack identification. Traffic marking has a higher rate in certain sections, especially in mountainous sections with many bends and tunnels. Traffic marking is almost ubiquitous. Traffic marking is generally White, the black contrast with the crack is obvious, there is no difficulty in identification, the problem is that the edge of the traffic marking is also a strong edge, especially the longitudinal edge, but it is enhanced during the process of horizontal noise suppression. Therefore, after preprocessing, the edges of the traffic markings are still very obvious. For this situation, before doing LoG, a simple ridge wave judgment is added, which requires that the grayscale on both sides of the edge is either all greater than the edge grayscale, or all are smaller than the grayscale of the edge. So it is necessary to detect the direction of the edge. Since a very precise direction is not required, a simplified algorithm is designed as follows:

1) For the image after LoG, construct a 5 × 5 window, which stipulates that the center point is horizontal, top left-bottom right diagonal direction, vertical direction and top right-bottom left diagonal direction are 1 ~ 4 directions. Each direction contains 5 pixels, and the average gray value in each direction is calculated. The direction with the smallest gray average is the edge direction of the current pixel.

2) Using the method in $\Phi$, calculate the edge directions of all points in the image after LoG that are less than the segmentation threshold (the maximum inter-class variance method segmentation threshold), and make a ridge wave judgment on these points, first, take a point on the far side of the edge on the side perpendicular to the edge. If the edge direction is the "1" direction, then the direction...
of taking points is the "3" direction. The distance between the location of the point and the edge can be 2 to 3 pixels. When taking points, you can consider taking the gray of several points on each side. The average value of the degree is compared with the gray value on both sides and the gray value at the edge. If the gray values of the edge pixels are all greater than or less than the gray values of the points on both sides, then the edge is a roof-shaped edge, that is, a ridge wave; otherwise, it is a step edge. The edge at the traffic marking belongs to the edge, so it can be deleted when the edge is extracted.

6. Conclusions
(1) The main steps of the high-grade cement concrete pavement repair crack identification method include 3 × 3 horizontal stripe removal template suppression groove, large-size LoG template enhanced image, and five-step method to extract cracks; large sample tests show that the method recognition rate is 94%.

(2) After two layers of wavelet decomposition, the crack repair image can be clearly identified, and the influence of the groove has been weakened. Therefore, the crack repair identification in this resolution image will greatly reduce the amount of calculation and improve Recognize speed.

(3) Joints, long stains and traffic markings are the high-frequency interference factors in the cement concrete pavement. The research designed de-noising methods for these three noise characteristics.

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8. References
[1] Pan Yuli, Zhao Huaizhi. Method for removing groove of cement pavement image based on two-dimensional Fourier transform. Chinese Invention Patent,200810186635.X,2009.4
[2] Koutsopoulos.H.N, Downey. A .B. Primitive-based classification of pavement cracking images. J.J.Trans p.Eng, 1993, 19(3):136~143
[3] Siriphan Jitprasithsiri. Development of a new digital pavement image processing algorithm for unified crack index computation. A Dissertation Submitted to the Faculty of the University of Utah,1997
[4] Zhang Juan, Sha Aimin, Gao Huaigang. Pavement crack automatic recognition and evaluation system based on digital image processing. Journal of Chang'an University(Natural Science Edition),2004,24(2):18-22
[5] Wang Taiping, He Yuyao, Li Gang, Application of Median Filtering of Quasi-meter Window in Pavement Detection. Computer Measurement and Control,2008,16(2):150~152
[6] Sun Bocheng, Qiu Yanjun, Pavement crack image processing algorithm. Access Transportation Technology 2008,25(2):64~68