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Bridge Surface Crack Detection Method under Multi-Scale and Multi-Perspective

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Abstract

According to the modern bridge health assessment and testing methods, compared with the traditional manual test to determine fracture, detection method based on digital image which applies digital image processing and pattern recognition technology to test and assess the bridge surface defect images has the characteristics of non-contact and high precision. Taking the grey-scale feature of the crack, this paper will put forward a kind of crack detection method based on multi-scale and multi-perspective. In view of the interference factors such as the holes, dirties and the others on the concrete pavement, we should analyze the characteristics of collected road surface images, and adopt DWT and NSST to resolve the source images from multi-scale, and then establish grey value similarity function, and withdraw the suspected crack information according to the similarity of contrast; second, remove the false crack use connected component measurement, and transfer the problem into graph theory problem; last, use the approximation coefficient of NSST domain, the fusion approximate coefficient of DWT domain and fusion detail coefficients to inverse, transform and rebuild fusion images so as to extract real crack. Through a lot of tests on the concrete pavement picture, experimental results show that this method can achieve real pavement cracks feature extraction, and enjoys a strong practicability.

Keywords: *Crack detection; Reachable matrix; Multi-scale decomposition; Active measure; Similarity*

1. Introduction

Transportation is the lifeblood of a country's economy, roads and bridges are the carriers to enable transportation unimpeded. Bridges, in particular, as a transport hub plays a vital role. With the increase of its service time, it is inevitable for the bridge structures to meet with all kinds of fatigue and damage which will lead to collapse and other serious accidents, this will cause a huge economic loss and personal injury. And most of the main bridge structure's defects are at the bottom of the bridge, this is particularly difficult for manual test and automatic test. So how to carry out regular inspections and health diagnosis on bridge structure will have important theoretical and practical value. Due to its design, construction, use and other reasons, structure of the concrete structure is hard to avoid cracks, this will affect its beauty, use and durability. When the crack width reaches a certain value, it may endanger the safe of the structure. As a result, the crack problem is a widespread concern. In order to control the harmful degree within the permitted range, detect the building on a regular basis and correctly evaluate the cracks on the surface of the concrete structure are essential. This will involve the crack detection on the structure surface.

Due to its high subjectivity, low accuracy and efficiency, the traditional artificial method to determine the length and width of the crack has been difficult to adapt to the demand for the developing road maintenance detection. With the continuous development of computer image processing technology, the measurement method based on image has gone deeply into the quantitative evaluation of the crack of concrete materials, and enjoys non-contact, convenient, intuitive, and accurate advantages. As the core technology, cracks extraction algorithm has become a research hotspot in the field of image processing and pattern recognition. Relevant literatures have carried out a lot of exploratory researches on the road and bridge cracks extraction method, and put forward some ideas of solving the problem. For example: in literature [1], computer tomography technology is employed to test the cracks in the log; in literature [2], the projection algorithm based on histogram is proposed, and at the same time, the morphological method is applied to eliminate the noise after segmentation. But for pavement images of low contrast ratio, the detection effect of this algorithm may produce larger mistake or omission; rapid Haar Wavelet Transform, rapid Fourier Transform, Sobel and Canny operator and other edge detection methods [3], I think that cracks in edge pixels is one of the largest local gradient changes, so it is particular difficult to extract weak information crack under strong noise background; target image segmentation method based on feature points and region growing proposed in literature [4] will gather the pixels with similarities to constitute a region, the innate defect of the region growing method is tending to cause excessive segmentation; literature [5] proposes a method combined Brown motion model with texture analysis which is used for pavement crack detection, the algorithm efficiency is not high and its effect on the discontinuous cracks is not so good; Zhang Hong, Dong Guoan and the others [6] constructed a kind of intelligence algorithm, seeds travelling, a lot of seeds fall into the 'joint' after random walking, so as to detect the cracks in the image. Based on gray scale and location, this paper defines the correlation coefficient between the pixels, all the suspected crack objects will be detected out on this basis. According to the continuity of the cracks objects, it will be further transformed into the problem of graph theory. Spectral clustering extraction will be applied to extract and express the cracks in the graph.

2. Multi-Resolution Transform

The ideal image fusion algorithm should use different fusion rules on low frequency and high frequency coefficients. Using multi-scale transform can make it easier to achieve the above requirements. The inherent ability of multi-scale transform, such as small wave and shear wave can resolve different geometrical features of signals into multiple directions sub-bands, and make them to be a hot technology in the field of image fusion.

2.1. Discrete Wavelet Transform

Discrete wavelet transform Is one of the most useful transformation successfully applied in the field of image fusion. It retains the details of the time domain and the frequency domain of the image. The image data of the discrete wavelet transform of are discrete. The spatial resolution and spectral resolution depends on the domain information.

WT (Wavelet Transform) can be considered as the calculation with the combination of wavelet transform and the fusion rule of two input pictures. And the picture can be rebuilt through IDWT. Two input images $I_1(X_1, X_2)$ and $I_2(X_1, X_2)$ can be expressed by the following formula:

$$I(X_1, X_2) = W^{-1}\left\{\Psi\left[W(I_1(X_1, X_2)), W(I_2(X_1, X_2))\right]\right\} \tag{1}$$

Among it, W , W^{-1} and Ψ are wavelet transform operator, inverse wavelet transform operator and fusion rule respectively. The spatial resolution of DWT will be smaller at low-frequency band, but bigger at the high-frequency band. At the same time, it has limited direction, and fail to use clear edges information.

2.2. NSST (Non-Subsample Shearlet Transform)

As for discrete wavelet $\psi \in L^2(R^2)$, its two-dimensional affine system is as followed:

$$\left\{\psi_{ast}(x) = \left|\det M_{as}\right|^{-1/2} \psi(M_{as}^{-1}x - t) : t \in R^2, M_{as} \in \Gamma\right\} \tag{2}$$

Among it, $\Gamma = \left\{ M_{as} = \begin{bmatrix} a & \sqrt{as} \\ 0 & \sqrt{a} \end{bmatrix} : (a, s) \in R^+ \times R \right\}$ is the two parameters inflation combination. Choose ψ and let it meet the requirement of:

$$\hat{\psi}(\xi) = \hat{\psi}(\xi_1, \xi_2) = \hat{\psi}_1(\xi_1)\hat{\psi}_2(\xi_2/\xi_1) \tag{3}$$

In this formula, ψ_1 is continuum wavelet, can meet $\hat{\psi}_1 \in C^{\infty}(R)$, and in the interval$(1, -1)$, $\hat{\psi}_2 > 0$ and $\left\|\hat{\psi}_2\right\| = 1$. After meeting these assumptions, ψ can be a continuum wavelet and $a \in R^+$, $s \in R$,$t \in R^2$, and then there will be

$$Sf(a, s, t) = \left\langle f, \psi_{ast} \right\rangle \tag{4}$$

It is called the continuous shear wave transform of $f \in L^2(R)$.

Through the sampling of the shear wave $Sf(a, s, t)$ in the appropriate set of discrete can get the discrete shear wave transformation model which can better handle the discontinuity of distribution. NSST includes two stages: NSP and SF. NSP can ensure the whole of the multi-scale process and can guarantee that each NSP decomposition level can get a low frequency image and a high frequency sub images. And then NSP can implement Iterative decomposition on the low frequency components class by class to capture the singularity of the image. In other words, NSP will produce K+1 pieces of low frequency images which are as same as the source images and K pieces of high frequency images, and K represents the number of the decomposition layers. On the other hand, the high frequency images produced by SF to NSP at the stage of ℓ will carry out multi-direction decomposition at each dimension, and will produce sub-images of 2^n direction. Figure 1 shows decomposition process of three layers of NSP and corresponding direction decomposition.

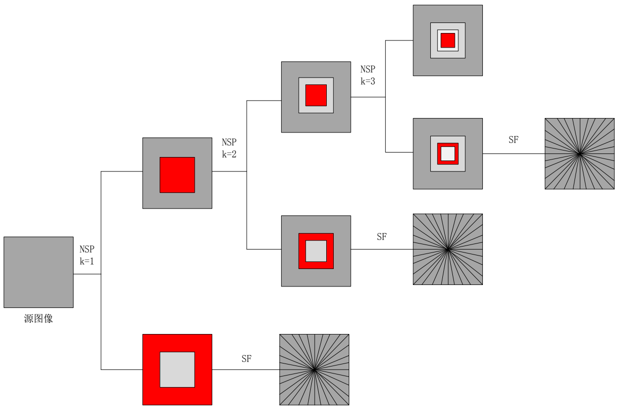

Figure 1. NSST Multi-Scale and Multiple-Directions Decomposition

3. Calculation of Similarity Matrix under Multi-Perspective

Pixel of the crack objects in the images has distinguished features both on its grey value and location relationship. In order to detect the crack in the image, we should carry out quantitative description on this feature first.

3.1. Similarity Function Based on Grey Value

In the digital image of cracks, compared with the surrounding non-crack pixel, the grey value of the crack area is significantly lower than the one of the background. And the cracks have similar grey value. Therefore, we can try to establish a function based on the grey value similarity distribution of crack area so as to meet the requirements of: (1) big similarity between the target points; (2) small similarity between the target point and background point; (3) small similarity between the background points. In order to get the function which can satisfy these requirements, we will reverse and transform the digital image (use 1 minus the original grey value), to let the grey value of the crack area be higher than the one of the background (no more description below), and then establish a similarity function based on the above conditions.

Suppose the grey value of each pixel of the image be $p_i, 1 \le i \le mn$, m and n means the height and width of the image respectively. We can define the grey value similarity of each pixel as

$$r_{ij} = p_i p_j e^{-c|p_i - p_j|}, \ 1 \le i, j \le mn \ ,$$

In this formula, c is constant, r_{ij} represents the grey value similarity between i th and j th pixel point. This function can satisfy the establishing requirement of the above function.

3.2. Establishment of the Similarity Matrix

According to the definition of similarity function, the similarity between the non-crack pixel points and all the pixels are very small, while the similarity between the crack pixel points is relatively big. Based on this relationship, crack extraction algorithm is designed.

First, we should calculate the similarity matrix $R = (r_{ij})_{mn \times mn}$. Due to the large quantity of pixels, the computational burden of R is heavy. So, under the condition that not affecting the crack extraction, we need to optimize the computing and storage problem of R , specific plan is as followed:

(1) The pixel of the image is two-dimension point which is convenient for the following processing to transform it into one-dimension point, its one-dimension order is

$$k = i + (j-1)m \ , \qquad (5)$$

In this formula, (i, j) is the two-dimension coordinate of this pixel, that is to say, the pixel points will be ordered according to head-tail order by column.

(2) Suppose the average grey value of $f(x, y)$ is $\bar{f}$, namely, $\bar{f} = \frac{\sum_{x=1}^{m}\sum_{y=1}^{n} f(x, y)}{mn}$, take threshold value $\lambda = b \times \bar{f}$, b as constant. As for the pixel points (non-crack pixel points) p_i, if their grey value is less than λ, we can directly compose $r_{ij} = 0, (j = 1, 2, \cdots, mn)$.

(3) As for the pixel point p, if its grey value is bigger than λ, we can calculate the similarity of it and between each point in its next area 8-, it and its similarity with the other pixel points are 0. Due to the symmetry of the similarity matrix, we only need to calculate correlation coefficient of p and 4 pixels at its bottom right (as shown in figure 2). We can see from Figure (5) that, the pixel order differences between p and p_6, p_7, p_8 and p_9 are 1, $m-1$, m and $m+1$. Therefore, R will be a 4 diagonal matrix, they are on secondary diagonal, $m-1$, m and $m+1$ diagonal lines (as shown in Figure 3).

P_1	P_4	P_7
P_2	P	P_8
P_3	P_6	P_9

Figure 2. Similarity Calculation Window

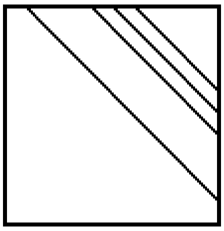

Figure 3. Matrix Non-Zero Element Distribution Diagram

4. Bridge Surface Crack Detection Method under Multi-Scale and Multi-Perspective

According to the similarity matrix R, seek the all connected components of the suspected crack in the images.

设 Suppose $\bar{R} = (\bar{r}_{ij})_{mn \times mn}$,

$$\bar{r}_{ij} = \begin{cases} 1 & \text{if} \quad r_{ij} > \mu \\ 0 & \text{if} \quad r_{ij} \le \mu \end{cases},$$

In this formula, μ is a given threshold.

Thus, $\bar{R}$ will be a $0-1$ matrix, it corresponds to a topological G taking the pixels as the node. Among them, there is edge connecting between the pixels whose similarity is bigger than μ. Therefore, the problem of finding cracks connecting components will be changed to the problem of finding all the connected sub graphs of G.

The scale of G is big. But its connecting relationship is very special (the the non-zero elements of its connection matrix lying on the four diagonals only). According to this, the algorithm of finding all the connecting sub graphs of G is proposed.

As for the matrix $\bar{R}$, expand a list of $\bar{r}_{i,mn+1} (i = 1, 2, \cdots, mn)$, and the value for this list are all 1 and use it to mark the points that not being extracted, as shown in Figure 4:

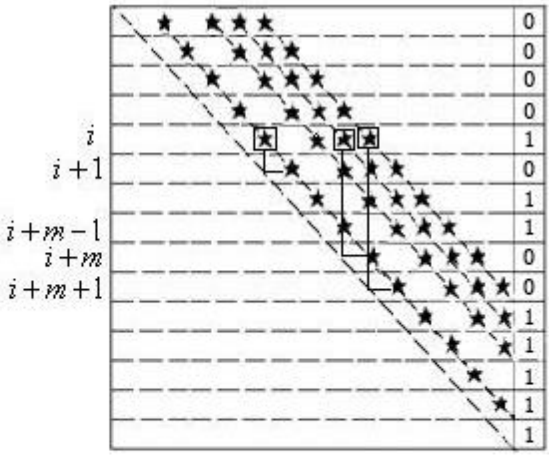

Figure 4. Connected Components Extraction Simulation Diagram

Find out the first line non-zero of last list of $\bar{R}$, set vector quantity as $T = (i+1, i+m-1, i+m, i+m+1)$, and $\bar{r}_{i,mn+1}$ 0, obviously, the horizontal sign at the infall of i th line and 4 diagonals is $T(k), (k = 1, 2, 3, 4)$, as for all the k, if $\bar{r}_{i,T(k)} = 1$, it means the node i in figure G connecting with node $T(k)$, and then turn to $T(k)$ line to find out all the nodes connecting with node $T(k)$, and so on. Find out all the nodes connecting with i directly or indirectly. These nodes will constitute a connected sub graph in figure G. The corresponding pixel in the image will constitute connected components (suspected crack).

Based on the condition that the large size of $\bar{R}$ and nonzero element only distributing on 4 diagonals, when we implement algorithm specifically, we can store with matrix A of $mn \times 5$, of which, the elements of 4 diagonal (0 will be added to the behind of each diagonal) will be placed at the first 4 lists of A. The $mn+1$ th line of $\bar{R}$ will be placed at the 5th column of A. In this way, the storage space will be greatly reduced, and make it possible for the crack detection of this algorithm among high-definition pictures.

Algorithm process is as followed:

Input: matrix A , $k = 1$;

Output: all the connected components l_k, $k = 1, 2, \cdots$;

Step1 For $i = 1 : m$ % all the lines of matrix A %

Step2 If $a_{i,5} = 1$ % judge if the i th line is being marked%

Step3 $[l_k, A] = conn\ (i, A, m)$;% Find out all the nodes connecting with i directly or indirectly%

Step4 End

Step5 $k = k + 1$;% Find out next connecting component %

Step6 End

Subroutine $[l, A] = conn(i, A, m)$, among it, i is the row-coordinate, A is the similarity matrix of $mn \times 5$, m is the height of m , return one connecting component l and marked matrix A .

Step1 $T = (i + 1, i + m - 1, i + m, i + m + 1)$;% node within the window of node i %

Step2 $l = \{i\}$;% type in the i th point 点%

Step3 $A(i,5) = 0$;% mark the i th line%

Step4 For $k = 1,2,3,4$

Step5 If $A(i, k) = 1\ \&\ T(k) \leq mn\ \&\ A(T(k), 5) = 1$

% Judge whether $T(k)$ is the unmarked point which is connecting to i in figure G %

Step6 $[l', A] = conn(T(k), A, m)$;% Find out all the nodes connecting with node $T(k)$ %

Step7 $l = union(l, l')$;% Combine all the nodes connecting with i directly or indirectly%

Step8 End

The framework is the combination mainly based on DWT and NSST these two kinds of orthogonal wavelet transforms. The result of this combination can be comparable to the traditional multi-scale decomposition method and it does not need too much scale transform. The basic steps of this algorithm: pretreatment; discrete wavelet decomposition; approximate coefficients decomposition of NSST domain, integration and inverse transform; approximate coefficient fusion, fusion and inverse transformation of fusion detail coefficients.

5. Experiment and Analysis

The above results show that this algorithm can preserve the characteristic information of the crack, and avoid strong noise interference, and its fast algorithm speed is helpful to the extraction of digital image cracks. While the other detection algorithm (such as sobel operator, region growing algorithm), either there is too much noise on the edges, or the crack information is lack, it is not conducive to extract crack. As shown in Figure 5, Figure 6:

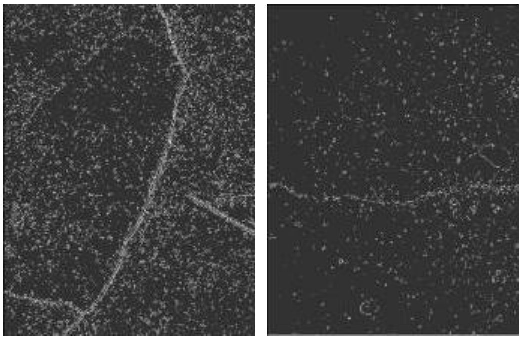

Figure 5. Sobel Operator

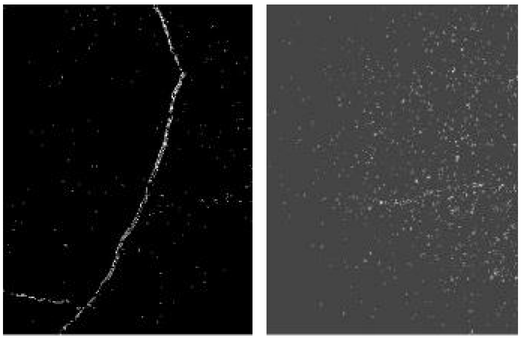

Figure 6. Region Growing Algorithm

It can be seen from the Figure 5 that basic crack information is maintained after the picture being processed by sobel operator, but the other edge information has not been suppressed which increases the difficulty of further extracting crack. In figure 6, region growing algorithm can get a better result when it is being used to process the cracks with little background interference like picture (a), but it almost lost all crack information when it is being used to process the crack with complex background like picture (b).

In order to better explains the effect of this experiment to extract cracks, several kinds of pavement crack extraction process are listed out below based on the algorithm in this paper, as shown in Figure 7. Four pictures of each row in Figure 7 are the original crack image, similarity-based extracted cracks, and pictures after removing the tiny component, cracks extracted by spectral clustering. Experiments show that this method is applicable to variety cases of the extraction of road surface cracks, such as the first and second line cracks images in the figure can almost extract the effective crack directly based on the grey value similarity, especially the background interference in the image of the second line can be effectively avoided. And in this paper, the method can effectively eliminate the strong noise interference of the white arrows and black oil in the third row images. Thus, we can see that the method in this paper enjoys strong anti-interference performance.

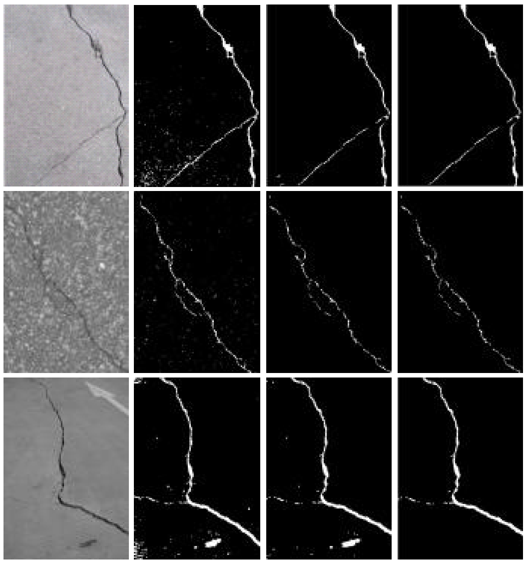

Figure 7. Cracks Extraction Process of the other Images

Missing detection rate under the condition that algorithm performance quantitative analysis and comparison of the unit image/image (False Positive per Image, FPPI), compare with the HOG characteristics obtained by normal tests**Error! Reference source not found.**, HOG and Local Binary Pattern (HOG + Local Binary Pattern, HOG+LBP), result is shown in Figure 8. Figure 8 shows that under the same FPPI conditions, the missing detection rate under multi-scale and multi-perspective algorithms in this paper is lower than the ones gotten by HOG, HOG+LBP, MHOG and other methods. But when FPPI is close to I, the missing detection rate obtained by the algorithm in this paper is gradually close to MHOG. After analysis, this is because the useful information of the latter part of the WTA hash code is being filtering which leads to the increasing of the missing detection rate.

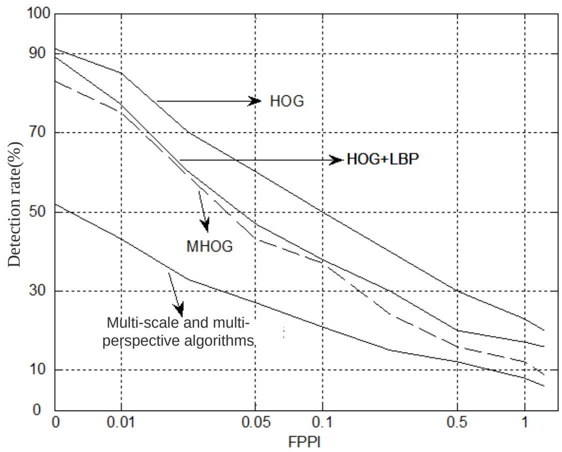

Figure 8. Comparison of Algorithm Testing Results

The detection efficiencies of the above all kinds of algorithm under complex background are as shown in form 1. It can be seen from form I that, the detection rate of the multi-scale and multi-perspective algorithms in this paper is higher than the one of HOG and the others, the detection time is much less than the one of HOG and the other algorithm. This is mainly because the image characteristics become sparser after its redundant information in the image features being filtered out using WTA hash code, so that the follow-up algorithm is relatively fast, and the detection time is reduced.

Table 1. Comparison of the Detection Efficiencies of Different Kinds of Algorithms

Method	Samples quantity	Accurate detection quantity	Detecti on rate	Average detection time
HOG	300	288	96%	23.69ms
MHOG		289	96.33%	51.71ms
HOG+LBP		289	96.33%	26.48ms
Multi-scale and multi-perspective algorithms		292	97%	6.53ms

5. Conclusion

Due to the complexity of the crack image background, usually we can't find a universal method to solve all the problems of digital image crack detection, we can only carry out specific analysis on specific images. This paper starts from the fracture of grey value relevance, establish crack gray feature similarity function, and use gray correlation to convert image into binary figure with crack information. This method is very successful in the organization structure, texture and edge feature points of different multimodal sensor images. In addition, the proposed algorithm can produce high quality fusion image in a less computation time. Unlike the existing image fusion method, this algorithm can even keep unchanged complexity of image when fuse images with larger dimensions. Experiments show that, the method in this paper can solve the crack detection problem with complex noise in the image background. But when there are too many slender objects which is similar to the cracks grey value in the image background, the algorithm may define it as crack. To this, we need to add into a priori knowledge about fracture. We will make further research.

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