Brief Introduction to Crack Collection and Identification Methods for Tunnel Lining

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Abstract

Tunnel plays an active role in improving traffic efficiency and relieving urban traffic pressure, and the diagnosis and treatment of lining diseases is a key part to ensure the safe operation of tunnel. This paper expounds and analyzes the identification criteria of lining cracks, image information collection and crack information recognition, and briefly discusses the treatment of lining diseases. The main contents of this paper are as follows: 1. Cite the hazard rating indicators of tunnel cracks in some national tunnel maintenance regulations. 2. Analyze the current mainstream ways of acquiring tunnel image information. 3. Introduce the crack identification process and give the calculation effect diagram of part of the method.

Keywords

Tunnel Detection; Tunnel Image Processing; Crack Identification.

1. Introduction

Since entering the 21st century, China's tunnel construction and operation technology has been greatly developed, and the mileage of railway and highway tunnels has steadily increased. Among them, 3,611 railway tunnels were built during the "12th Five-Year Plan" period, with a total length of about 6,038km[1]. In 2020, China's tunnel construction market will reach 400.8 billion yuan, and in 2021 it will reach 375 billion yuan. By the end of 2022, there will be 24,850 national highway tunnels with 26,7843 extension meters, an increase of 1,582 and 2,085,400 extension meters. The rapid development of tunnel traffic has made China the country with the largest number of tunnels in the world, with 1,752 long tunnels, 7,951,100 long tunnels, 6,715 long tunnels and 11,172.82 million long tunnels[2]. With the passage of time, a considerable part of the tunnel has entered the maintenance stage, statistics, in the sub-health of the highway tunnel accounted for about 30%[3], in the future for a long period of time, China's tunnel as a whole are faced with complex detection and maintenance tasks.

2. Identification Criteria for Tunnel Lining Cracks Section Headings

China's current standards include "Highway tunnel maintenance Technical Code JTG H12-2015"[4], "Urban rail transit tunnel structure maintenance Technical standard CJJT-289"[5] and "Railway bridge and tunnel building deterioration assessment Part 2"[6]Taking CJJT-289 Technical Standard for Structural Maintenance of Urban rail Transit Tunnels as an example, the evaluation standards for crack damage of the main structure are summarized in the following table.

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Table 1. Evaluation criteria of structural health for initial tunnel inspection

Excavation mode		Evaluation standard				
		Health level 1	Health level 2	Health level 3	Health level 4	Health level 5
Open cut method	Failure crack	There is no	The surface surface is slightly cracked, mainly with dry shrinkage and warm shrinkage cracks or a few slight circumferential cracks	The cracks are mainly circumferential cracks, and there are a few longitudinal cracks or oblique cracks	Local longitudinal cracks or oblique cracks, due to cracks or crushed concrete there is the possibility of falling blocks	The cracks are densely developed, there are many longitudinal cracks or oblique cracks, and the blocks have appeared due to cracks or crushing
	Construction joint, deformation joint	There is no	There are slight crushing, misalignment and wet stains in individual joint positions, which have no impact on the structure	Crushed, misset, sparse distribution, sustainable development may appear block; The water leakage is small, the water quality is clear, mainly soaked and dripping	Many joints are crushed and misaligned, some concrete blocks have appeared, obviously misaligned; Local line leakage, surge current or sediment leakage; There is a small amount of hanging water on the roof	The joints are seriously crushed and misaligned, and the concrete blocks appear in many places, which has affected the building boundary. Seepage water leakage is serious, mainly line leakage, surge current, accompanied by leakage sediment; There is obvious ice hanging on the roof
Shield method	Segment failure	There is no	The surface layer is slightly cracked, and there are a few slight circumferential cracks	The cracks are mainly circumferential cracks, and there are a few longitudinal cracks or oblique cracks	Local longitudinal cracks or oblique cracks, due to cracks or crushed concrete there is the possibility of falling blocks	cracks are densely developed, there are many longitudinal cracks or oblique cracks, and the blocks have appeared due to cracks or crushing
	Segment joint	There is no	There are slight crushing, misalignment and wet stains in individual joint locations or deformation joints, which have no effect on the structure	The distribution of crushing and missetting is sparse, and the phenomenon of falling block may occur in continuous development	There are crushing and misalignment in many places, and some concrete blocks have fallen and obvious misalignment. Local joints open, water stop strip off line leakage, surge flow or leakage of sediment; A small amount of hanging ice appears at the top	There are serious crushing, misalignment, and concrete blocks in many places, which have affected the building boundary; Seepage water leakage is serious, mainly line leakage, surge current, accompanied by leakage sediment; Visible ice hanging on top

3. The Process of Tunnel Lining Crack Image Acquisition and Recognition

3.1 Tunnel Image Analysis

After the construction of the lining surface is unified with reinforced concrete, a layer of cement is applied on its surface, if there is no disease or other pipeline facility type characteristics, the lining surface is generally smooth and feature-free. It is difficult to find feature points to match such images, so they can be divided into two categories, namely, feature region and unfeature region[7].

In the tunnel scene, cracks can be divided into temperature cracks, dry shrinkage cracks, load deformation cracks and stubble-joint cracks according to different causes. According to the crack trend, it can be divided into oblique, circumferential, longitudinal and network cracks. The inclined cracks and longitudinal cracks are mostly distributed near the arch and waist of the tunnel, which are usually cracked under the shearing stress of the secondary lining concrete. Circumferential cracks can be divided into through type and non-through type. In most tunnel construction gaps, through type circumferential cracks will be formed, which is caused by the shrinkage caused by the change of concrete volume and belongs to the characteristics of concrete itself. The mesh crack is also called irregular crack, its form is mostly from the center point leads to a number of cracks, the width is narrow, the length is short, its cause is generally due to the rapid evaporation of concrete water, thus forming a gradient arrangement of dry and wet stratification on the concrete surface[8].

3.2 Tunnel Image Acquisition Method

At present, the mobile tunnel inspection vehicles mostly use digital photography, laser scanning and other visual technology to collect lining cracks, water leakage, deformation and other disease characteristics. Domestic Tongji University[9], Shandong University[10], Wuhan Optics Valley Excellence Technology Co., LTD.[11], Southwest Jiaotong University, etc.,[12] have established mobile detection technology to collect images to identify tunnel disease characteristics.

The main method is to use industrial camera as the core part of tunnel image acquisition, with auxiliary light source, positioning system and other components. Due to the limited field of view of a single camera, multiple cameras must be used for simultaneous acquisition operations. A curved rigid sensor frame is installed on the acquisition vehicle to carry the camera, and a torus model is built for the acquisition tunnel. The Angle and orientation of the camera's field of view are determined by test. If the required shooting length is L, the section length of a single camera is l_i,Requires $\sum_{i=1}^{n} l_i = l_{total} > L$, In order to complete the camera calibration work, at the same time, the light source is arranged to assist the lighting to carry out the collection operation. The working process is that when the calibrated acquisition vehicle enters the tunnel, the industrial camera and auxiliary light source are turned on, and the tunnel image information is collected along the tunnel axis.

3.3 Tunnel Image Processing Flow

Crack recognition is a typical linear target extraction task in computer vision, and its recognition methods can be divided into segmentation algorithm based on crack features, graph theory analysis based on crack global features, and machine learning algorithm based on hand-selected features. In this paper, segmentation algorithm based on crack features is used to identify cracks. Specifically, digital image processing methods such as threshold segmentation and edge detection are used to detect crack linear targets according to the gray level, gray gradient and histogram of cracks.

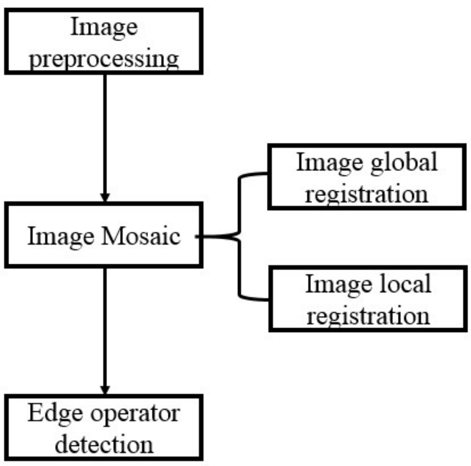

Figure 1. Image processing flow chart

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3.3.1 Image Preprocessing

There are two purposes of image preprocessing: one is to improve the image quality, that is, to reduce the filtered noise; the other is to highlight the object features, that is, to enhance the image contrast and highlight the edge features of the disease[13].

There are several common ways of image filtering operation, which are often compared or improved according to different noises, and then the specific method is determined. The basic method is neighborhood average method, also called mean filtering. The method performs average convolution operations on images in the spatial domain, and its expression is as follows:

$$g(x,y) = \frac{1}{M} \sum_{m,n \in S} f(x,y)$$

In the formula $f(x,y)$-the gray value of a pixel in the image,

$g(x,y)$-the gray value of the pixel after processing,

M-is the total number of pixels contained in field S,

S-is a predetermined neighborhood.

This method sets up a 3×3、4×4convolution kernel for N points, the values in the nucleus are added together and averaged to replace the value of the N point. On this basis, Gaussian filtering performs mean filtering by weighting the elements of the neighborhood, and median filtering replaces the value of a point with the median value of each point in the neighborhood.

The method of image enhancement generally uses histogram equalization[14], which changes the gray histogram of the original image from a relatively concentrated gray interval to a new image with uniform distribution in the gray range.

The principle is as follows: suppose that the total number of pixels in an image is n, the number of gray values is L, The gray value of $n_k$pixels is k_i, Therefore, its probability is:

$$P(k_i) = \frac{n_k}{n}$$

The transformation function is expressed as:

$$T(k_i) = \sum_{j=0}^{k} P_r(k_j) = \sum_{j=0}^{k} \frac{n_k}{n}$$

By gradually adjusting the image pixels, the number of pixels of a certain gray value is basically the same in the gray area, which is suitable for the image with gray distribution concentration and the background is too bright or too dark.

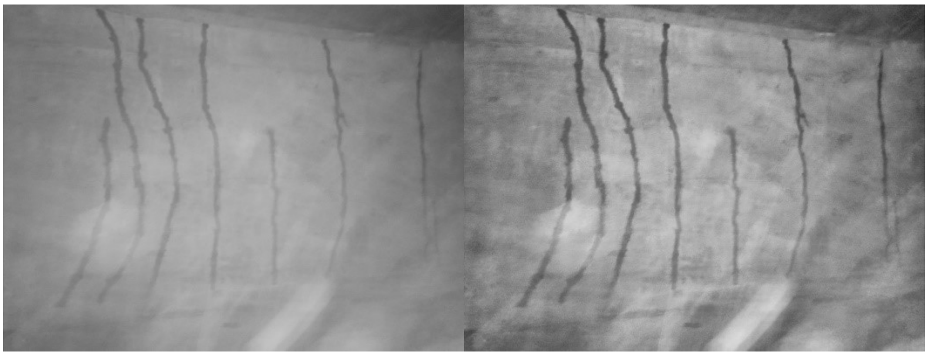

Figure 2. Histogram equalization effect comparison

For image enhancement, another method is to use the Retinex algorithm, whose core is to adjust the contrast and brightness of the image while preserving the details of the image[15]. The algorithm can be implemented in three different ways: single-scale Retinex(SSR), multi-scale Retinex(MSR) and multi-scale adaptive Gain Retinex(MSRCR). The SSR algorithm assumes that the light variation of the image is concentrated on the low frequency component, so the image is filtered once to remove the low frequency component, and the obtained middle and high frequency component is enhanced. MSR breaks down the image into different scale images and enhances each scale image to preserve different scale details. MSRCR integrated SSR and MSR algorithm, line decomposition into different scale images, and then use adaptive gain function to enhance each scale image.

The theoretical basis of the algorithm is that the object color is determined by the reflection ability of red, green and blue light, and is not affected by the reflected light intensity and uneven illumination. It is considered that the image is represented by the incident component information $L(x,y)$ and the reflected part information $R(x,y)$.

$$I(x,y) = R(x,y)*L(x,y)$$

As for the single-scale Retinex algorithm, its algorithm flow:

1) Converts the input image to a logarithmic space: $I_{\log} = In(I+1)$,

2) Gaussian smoothing of logarithmic images: $I_g = G*I_{\log}$,

3) Calculate the illumination image: $L = I_{\log} - I_g$,

4) Computed reflection image: $R = I_{\log} - L$,

5) The illumination image and reflection image are exponentially transformed:

$$L_{\exp} = \exp(L) - 1 \quad R_{\exp} = \exp(R) - 1$$

6) Brightness adjustment of the output image: $P = \frac{R_{\exp}}{\max(R_{\exp})} x255$.

Where O is the output image and $\max(R_{\exp})$ is the maximum value in the reflected image. First, the reflected image is normalized to the [0,1] interval, and then enlarged to the [0,255] interval to enhance image contrast and detail. The following is a comparison image of the enhanced effect of this method.

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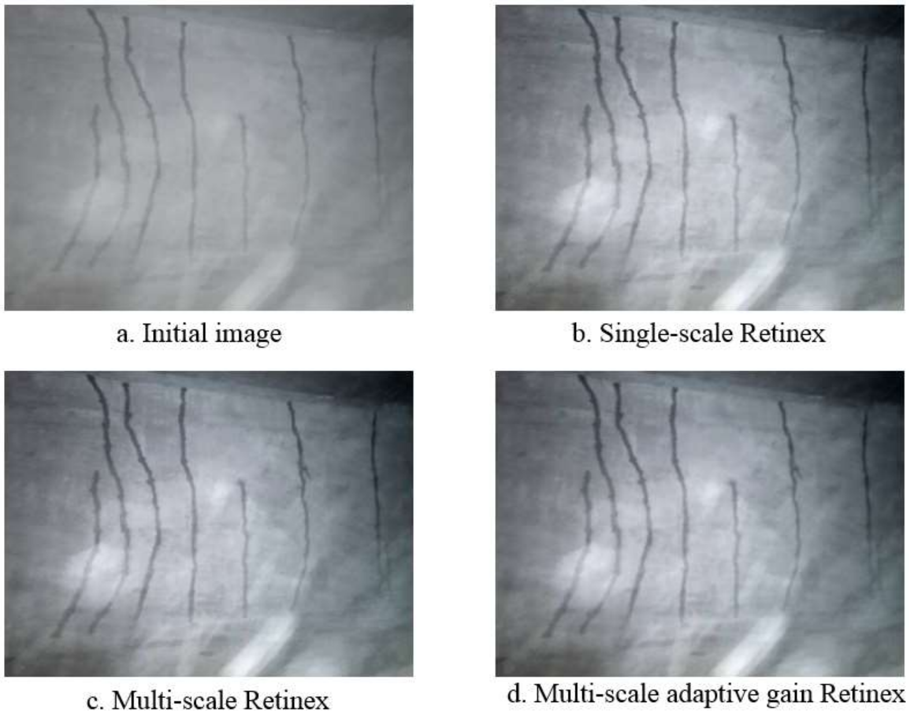

Figure 3. The Retinex algorithm enhances the effect

3.3.2 Image Mosaic

Image Mosaic is to synthesize a wide field of view panorama by combining several images with overlapping areas through various methods. The tunnel lining sequence images obtained by the above acquisition methods are orderly arranged and overlapping, and a complete tunnel lining panorama should be assembled to further determine the fracture characteristics and damage degree of the lining surface and locate the disease location. It can be divided into feature-free regions for global registration based on tunnel model, and feature-containing regions for local secondary registration[7].

For most areas of the tunnel, the lining surface has no obvious features. In practice, the working distance of cameras in the camera frame is different, and the working distance of the top camera will be larger than that of the camera shooting the arch wall on both sides. If the same focal length camera is used, the field of view and resolution of the camera shooting the top of the tunnel will be larger. Therefore, in actual operation, the top camera will use a long focal length lens, but it can not make its field of view completely consistent. Based on the above situation, the featuresless areas are aligned according to the midpoint position of the image, the minimum overlapping length on the cross section is selected as the effective length, and the effective areas are clipped out for overlay fusion.

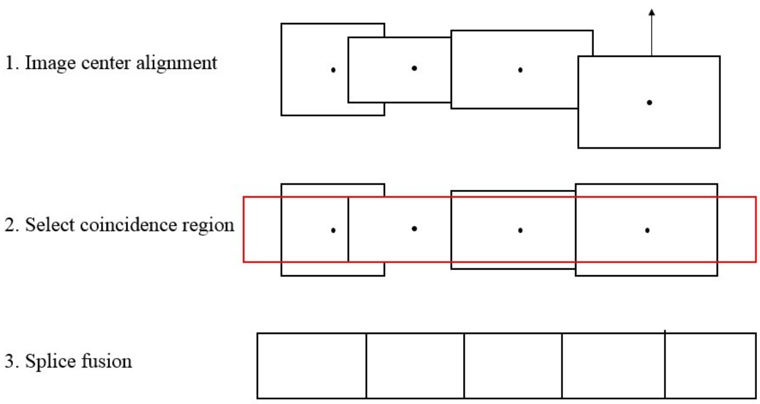

Figure 4. Global fusion diagram

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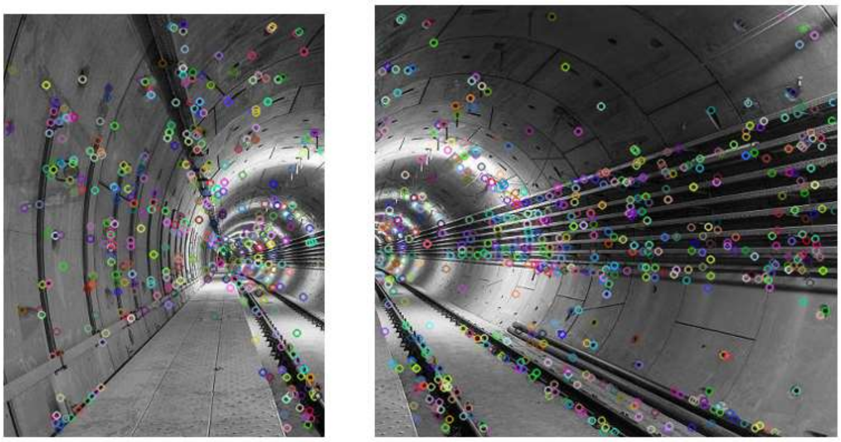
Second, in the assessment of tunnel health, one long crack and several short cracks have different effects on the evaluation results. In order to accurately assess the tunnel condition, it is necessary to carry out local secondary collation registration of images.

The method commonly used is to extract feature points for matching by using scale-invariant feature transform (SIFT)[16], which is interpreted as the key points extracted by SIFT method have Scale invariance and rotation invariance. By looking for the orientation and direction of extreme feature points in different scale Spaces, the local features of the image are extracted by constructing feature point descriptions, which are generally corner points, edge points, dark spots or bright spots.

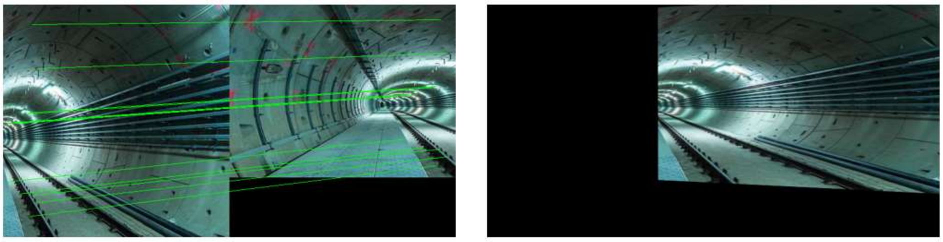
SIFT feature detection is mainly divided into extreme value detection of scale space, searching images on all scale Spaces to identify potential points that are invariant to scale and rotation. Generally, the acquisition in scale space is realized by Gaussian fuzzy.



a. Feature point recognition (left) b. Feature point recognition (right)

Figure 5. SIFT key point results

The result of key points in Figure 5(a) and Figure 5(b) is used for violent matching to generate a set of feature point pairs. At the same time, when matching two or even multiple tunnel images, it is necessary to establish a transformation model from the original image to the reference image. In order to ensure the accuracy of model parameters, the RANSAC algorithm is used to process abnormal data inconsistent with the actual model and screen out reliable data point pairs.



a. Match key points b. Splicing results

Figure 6. Image registration result

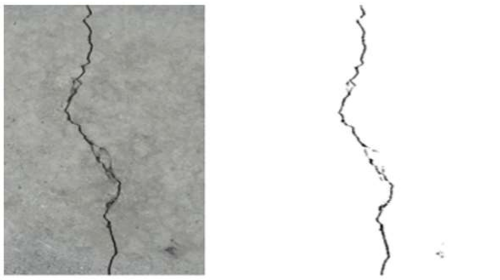
The calculation constructs a homologous transformation matrix, which is a 3*3 non-singular matrix.

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

After expanding the formula, the solution requires 8 nonlinear equations, that is, at least four groups of corresponding points can be solved. The matrix represents the mapping relationship of a plane point in the world coordinate system and in different images. The original image is transformed by the matrix and the result is obtained by combining.

3.3.3 Crack Detection

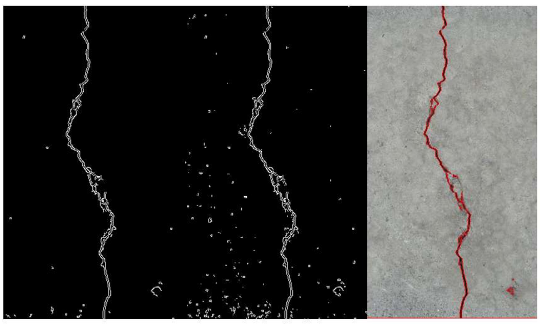
There are many methods for crack detection, the more common ones are threshold segmentation and gray histogram threshold segmentation algorithm, which uses edge detection operators such as Scharr edge detection operator, Sobel edge detection operator, Laplacian edge detection operator, Canny edge detection operator and so on[17]. The result is shown below:



a. Master drawing b. After threshold segmentation

Figure 7. Threshold segmentation result

Canny operator is generally used when edge detection is used[18]. This method has good anti-noise ability and detection performance[19].The method smooths the image by Gaussian filter; Calculate the gradient intensity and direction of image pixels; Non-maximum suppression is used to eliminate the stray response caused by edge detection, and two thresholds are set up to determine the real edge. Then, by judging whether the adjacent pixels of the pixel exceed the threshold, the isolated weak edge is suppressed.



a b c

Figure 8. Canny operator effect diagram

4. Conclusion

In this paper, the hazard rating indexes of tunnel cracks in the tunnel maintenance regulations of USA, Germany, Japan and our country are discussed. Aiming at the mobile tunnel image acquisition devices of some universities in China, this paper analyzes the mainstream ways of acquiring tunnel image information. The methods of image information processing, splicing and crack recognition are briefly introduced, and the algorithms are given to compare images.

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