Research on bridge defect detection technology based on image processing technology

Zhongyang Sun[a], Gongwen Li[a,*], Xianming Zhang[a]
[a] China Merchants Chongqing Highway Engineering Testing Center Co., Ltd. Chongqing, 400067.

ABSTRACT

At present, cable-stayed bridges and suspension bridges are widely used in highway traffic construction in China because of their beautiful lines and strong spanning ability. Cable is an important part of cable-stayed bridges and suspension bridges, and it is the key stress component of this kind of bridges. The traditional method of bridge crack detection mainly relies on manual field investigation, which has the disadvantages of high risk, low accuracy and low efficiency. At present, many crack measurement systems based on digital image processing technology are mostly semi-automatic or highly dependent on manual work, with low efficiency. In this paper, the crack image obtained in the field in the engineering test is used to enhance and de-noise the crack from the image preprocessing, including color image to gray image, image enhancement and image wavelet thresholding de-noising. At the same time, the corresponding contrast image of the crack is given. Then, an adaptive multi-scale watershed segmentation algorithm is proposed. First, the filtered image is processed by multi-scale gradient transformation, Then the gradient image is transformed by adaptive marked watershed transform, and finally the obtained image is combined with improved regions to effectively suppress the over-segmentation phenomenon.

Keywords: Image processing technology; Bridge defects; Detection technology

1. INTRODUCTION

For a long time, the scale and firmness of concrete bridges have increasingly become an indispensable symbol to measure the comprehensive strength of the country, the development of science and technology and modern civilization. While China's economic construction is developing rapidly, the role of the transportation industry in social development and economic take-off has gradually become apparent, and bridges are a major hub of the transportation industry, It plays an important role in the transportation industry [1]. The development of bridges is closely related to people's living standards. Bridges are the product of people's life practice and are closely related to people's life. Bridge is a part of the road and has its own development in ancient, modern and modern times [2]. Therefore, the construction and maintenance of bridges have always been an important guarantee for the safe and efficient life of the people. However, due to the aging and aging of some bridges, the phenomenon of damage is becoming more and more serious, and a large number of old bridges have been difficult to adapt to the growing requirements of the times [3].

According to relevant information, the number of dangerous bridges in China has reached more than 4,000 recently, totaling 130,000 meters, and the original load standard is also very low. After the concrete bridge is put into use, it will inevitably be affected by various natural forces (such as earthquakes and strong winds) and manpower, or the aging of its own building materials, which will cause damage to the bridge [4]. If the bridge damage is not detected and repaired in time, it will form a safety hazard, which will greatly threaten the passing vehicles and the property safety of the people. According to incomplete statistics, more than 90% of bridges damaged every year are caused by cracks [5]. With the increasing size and complexity of bridge structure and the increasingly strict quality requirements, the crack problem of bridge structure has become a quite universal technical problem. However, it is inefficient to recognize the structural damage of the bridge, so that it can be effectively controlled and repaired in time, and to determine which structural members can safely use their expected life, and manual operation is also dangerous [6].

*happywang1@foxmail.com

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In industrial engineering, it has been successfully applied to the research of detecting the surface deformation and damage of components, blade area and complex stress of components. At present, there is a key problem facing the whole world, that is, the bridges still in use show insufficient bearing capacity, performance degradation, damage and other problems [7]. Especially in recent years, with the rapid development of our country, the number of highway traffic has increased sharply, and there are more and more medium-large and heavyweight vehicles, and the requirements for bridges are becoming higher and higher; Secondly, the original highway bridge was very old, and the design standard was very low at that time. In addition to aging, damage and other objective reasons, it was difficult to meet the requirements of modern highway transportation. In view of the shortcomings of current bridge detection technology and the advantages of digital image technology in China, it is of great significance to carry out the research on automatic identification technology of bridge cracks based on image processing technology to ensure the safety of bridge operation, reduce the detection cost and promote the rapid development of China's transportation industry [8].

In this paper, aiming at the periodic detection task of bridge crack diseases, a rapid detection system for bridge cracks, which is suitable for a long distance, simple to operate, fast and accurate, is developed by comprehensively using image acquisition technology, image recognition technology and image signal analysis technology.

2. BASIC THEORY OF CRACK DETECTION IN IMAGE PROCESSING

2.1 Basic principle of image defogging

In recent years, morphological image processing methods have gradually developed into an important research area. Watershed algorithm is an image segmentation algorithm based on morphology. When analyzing and studying the characteristics and filtering methods of the bridge crack image, the traditional current filtering algorithm cannot eliminate the noise information in the image while maintaining the integrity of the image structure, while the mathematical morphology as a nonlinear filtering method can better solve this problem [9]. For example, if necessary, the target image can be corroded and then expanded; You can also perform the expansion operation on the target image, and then perform the corrosion operation. If the structural elements used here are the same, they have the same shape and size. It can be said that the main disadvantage of concrete is its poor tensile strength and easy to crack [10]. The same is true of a large number of concrete bridges. Some cracks are very thin, even difficult for human eyes to see clearly, which is not too harmful to the use of the structure and can be allowed to exist. However, some cracks will cause concrete carbonization under the action of service load and other physical and chemical factors, which will greatly weaken the strength and stiffness of concrete and have great security risks. This kind of cracks must be paid attention to and controlled as necessary. Up to now, image segmentation is still a classic problem. For different objects, there is no universal image segmentation algorithm, and there is no unified standard to evaluate the quality of segmentation. At present, although there are a lot of image segmentation algorithms and a lot of analysis conclusions on the evaluation of segmentation effect, there is still a lot of research space for image segmentation because of the difficulty and complexity of the problem itself, such as different segmentation methods for different objects and different effects. The fracture image acquisition system consists of computer vision system (lighting system, camera, lens, image acquisition card, etc.) and mechanical control system. Figure 1 shows the overall structure of the image acquisition system.

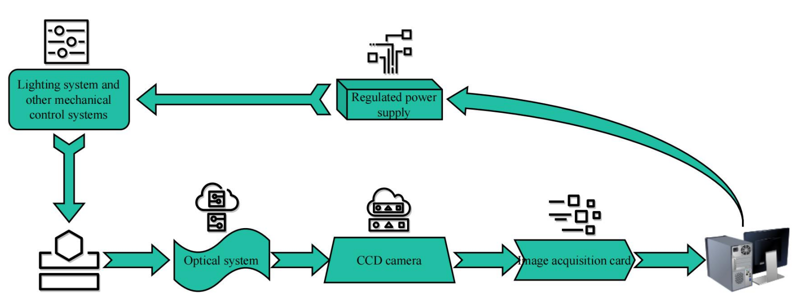

Figure 1. overall structure diagram of the system

In order to get an accurate image of the cable surface of the bridge at the same time. Through the above pictures, we designed a parallel image acquisition sensor array composed of four CCD cameras, which are in the same plane and placed in four directions of the cable respectively, and each acquisition end is flush with the vertical plane of the cable. In the inspection, the whole array is installed on the cable crawling mechanism. As the mechanism continues to climb, the acquisition array transmits the complete images around the cable surface at the same time to the DSP system for synthesis, processing and defect identification. In the detection, the positioning information of each defect image acquisition detection is provided by the photoelectric encoder and counter of the position detection device. In this way, at this resolution, speed and coverage, the image acquisition system must be able to process more than 200,000,000 pixels per second. This means that the memory on the inspection vehicle must have the capacity of storing 719,928,000,000 pixels higher than bytes and processing these inspection pictures every hour. However, in practical applications, it seems to have high requirements for hardware. Since the whole system will run on the running test vehicle, the AC and DC power supply of various equipment must be considered. Therefore, it is necessary to select appropriate regulated power supply and dimming power supply to power the lighting system, CCD and computer. The CCD camera has a high requirement for the light condition of the measured bridge. Too strong or too weak light is not conducive to the imaging of bridge surface defects in the CCD camera. CCD converts optical signals into electrical signals with the help of optical system to form a video signal image acquisition card to complete the modular conversion function of image analog video signals. The sampled and quantized digital images are processed in the computer. The selection of light source is described in detail below.

2.2 Image and digital image

An image is an entity that is obtained by observing the objective world with various observation systems and can directly or indirectly act on human eyes to produce vision. There are many forms of images, which can be visible to the naked eye, invisible, abstract or concrete. But in essence, it can be divided into analog images and digital images. Analog images include optical images, photographic images and television images. Among them, remote sensing, technical diagnosis, autonomous navigation of smart cars, medical plane and stereo imaging, and automatic monitoring are some of the fastest developing directions. The most concentrated manifestation of this progress is the emergence of many products applying this technology in the market. In fact, from digital image processing to digital image analysis, the core of image recognition technology is the extraction of information contained in digital images and various related auxiliary processes. Digital image recognition is mainly used to assist engineering work, optical character recognition (ORC), product quality inspection, face recognition, automatic driving, automatic interpretation and understanding of medical images and landform images. Image recognition is an extension of image analysis. It classifies the targets according to the relevant descriptions (features) obtained in image analysis, and outputs the target category label information (symbols) that we are interested in. Generally speaking, the process from image processing to graphic analysis to image recognition is a process of abstracting all the information contained in the image and refining the data of the interested part. As shown in figure 2.

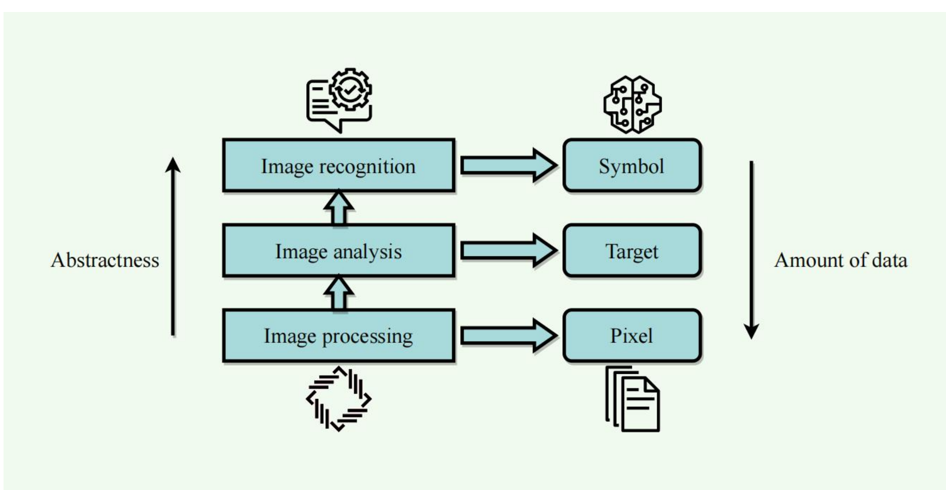

Figure 2. Relationship between digital image processing, analysis and human identification

At present, the application scope of digital image processing technology is expanding and has penetrated into all fields and industries, even in our daily life, and its role cannot be ignored. Some typical applications are shown in Table 1. The detection of bridge beam cracks in this paper is an aspect of typical industrial applications.

Table 1. Typical applications of image processing

Related fields	**Typical applications**
Safety monitoring	Fingerprint verification, access control system based on face recognition
Industrial control	Wireless product detection and automatic product classification
Medical care	X-ray enhancement, CT, MRI, automatic detection of lesions
Life entertainment	Automatic detection of smiling faces based on facial expression recognition, automatic driving of cars, handwritten character recognition
Related fields	Typical applications

The principle of the image acquisition card is to convert the video signal into digital format available to the computer after AD conversion, and transmit it to the video memory and memory in real time through the CPI bus. It can make the image acquisition process basically do not occupy CPU time, so that the CPU has more time to do image acquisition processing and calculation. Because the image needs to be processed in real time in the process of image acquisition, the performance of the image acquisition card has a great impact on the performance of the entire image acquisition system.

3. BRIDGE DEFECT DETECTION TECHNOLOGY BASED ON IMAGE PROCESSING TECHNOLOGY

3.1 Threshold segmentation of image

Digital images can be divided into gray-scale images and color images. Color image and gray image can be transformed into each other, and the process of transforming color image into gray image is called gray processing. The three components of color image R, G and B determine the color of each pixel. If R=G=B, the color (R,G,B) represents a black and white color. The value of R=G=B is called gray value. Gray image is a special color image with the same R,G,B G and B components. Generally, the camera system only has a certain brightness range, and we call the ratio of the maximum brightness to the minimum brightness as contrast. Because the brightness of the system that forms the image is limited, the problem of insufficient contrast often appears, so the visual effect of people watching the image will become poor. So at this time, we need to enhance the contrast of the image. Image segmentation is to extract the meaningful features of an image, such as edges and regions, which is the basis for further image recognition, analysis and understanding. Therefore, in order to extract the crack information more accurately, it is necessary to segment the crack by threshold. That is, by setting the threshold, the pixel points are divided into several categories according to the gray level, so as to achieve image segmentation. After the image is opened, the convex structure that does not match the shape of the structural element will be filtered out, and the matching part will be retained; However, after the image is closed, the concave structure that does not match the shape of the structural element will be filtered out, and the matched part will be retained. That is to say, the opening operation and closing operation can be called morphological filter in essence, and the image can be smoothed in different ways.

Let $f(x),(x \in Z^n)$ represent the input image, B represents the structural element, and $B \subset Z^n$, then the OC filter and the CO filter can be defined as follows.

$$OC(f(x)) = (foB \bullet B)(x) \tag{1}$$

After image acquisition, each frame image obtained by the system is the image of the cable surface in a certain direction. For the cylindrical-like cable, the image acquisition in each direction is the plane projection in its vertical direction. Therefore, the closer the obtained image is to the boundary in the horizontal direction, the greater the difference between the texture details and the actual surface. At the same time, 720 × 576 size surface image, based on its horizontal centerline, only the projected part of the image with a 90-degree angle of view is intercepted as the effective part (i.e. 510 in the middle × 576). In the YUV color system, Y is the specified visibility, which is a grayscale image sample synthesized by RGB color; U and V are respectively the blue component and the red component, representing the color information of the image. The conversion relationship between YUV color system and our commonly used RGB (Red, Green, Blue) color system can be expressed by formula 2.

$$\begin{cases} Y = 0.299R + 0.58G + 0.132B \\ U_b = -0.165R - 0.28G + 0.462B \\ V_R = 0.662R - 0.515G - 0.01B \end{cases} \tag{2}$$

The human visual system is more sensitive to the perception of brightness changes than the brightness itself. The human visual system can connect the perception of brightness with the perception of visible edges. The contrast between two visible indications can only be detected when they are considered to be in the same visible plane, so it is the result of the interaction between brightness and edge. If they are regarded as having different distances from the eyes, their relative brightness is difficult to compare.

Definition 2: Let X represent the image to be processed, and $\{B_i\} = \{B_1, B_2, L, B_n\}$ represents a sequence of structural elements, and it is limited to $X、\{B_i\} \subset E^2$ or Z^2. Then, the expansion operation and erosion operation using multiple structural elements can be defined as follows:

$$X \oplus \{B_i\} = \overset{n}{\underset{i=1}{I}} X \oplus B_i \tag{3}$$

Define the opening operation and closing operation using multiple structural elements as follows:

$$Xo\{B_i\} = \overset{n}{\underset{i=1}{U}} XoB_i \tag{4}$$

Based on the above properties, a multi-angle and multi-structure element morphological filter is designed by the following method: The goal of this paper is to segment the crack information in the bridge crack image, so the crack information should be retained as much as possible during filtering, and the target information should not be damaged as much as possible. In general, only the signal matching the structural element can be maintained during filtering, because the crack information is linear, Therefore, the linear element is selected as the structural element of this test.

3.2 Experimental setup and result analysis

In order to objectively evaluate the advantages of image defogging algorithm as a preprocessing algorithm for crack detection, this paper will compare the impact of image defogging, histogram equalization and guided filtering on the detection performance. The defogging algorithm is implemented by GPU programming, and the minimum filter and mean filter are optimized. The efficiency of the algorithm before and after optimization is compared × The 1080 image processing time is reduced to less than 30 milliseconds, with the acceleration effect of real-time processing, which can enhance the crack image while image acquisition, and improve image quality. For the case of fixed scale coefficient and reduced image resolution, the actual physical size corresponding to each pixel point increases, and the physical size corresponding to the tensor field increases, which more reflects the linear significance of the wide cracks in the local neighborhood, and can detect the wider cracks. At the same time, the decrease of precision by 0.01 indicates that multi-scale detection fusion brings about some false detection.

It can be seen that after the scale fusion method in this paper, the crack detection results are composed of the results of multiple scales, which means that there are some points in the detection results that are not on the artificially marked ground truth. However, for the problem of crack detection, it is important to detect all potential crack pixels and further improve the recall rate, rather than to improve the accuracy, reduce the integrity of the results and cause cracks to be missed. As shown in Figure 3 and Figure 4.

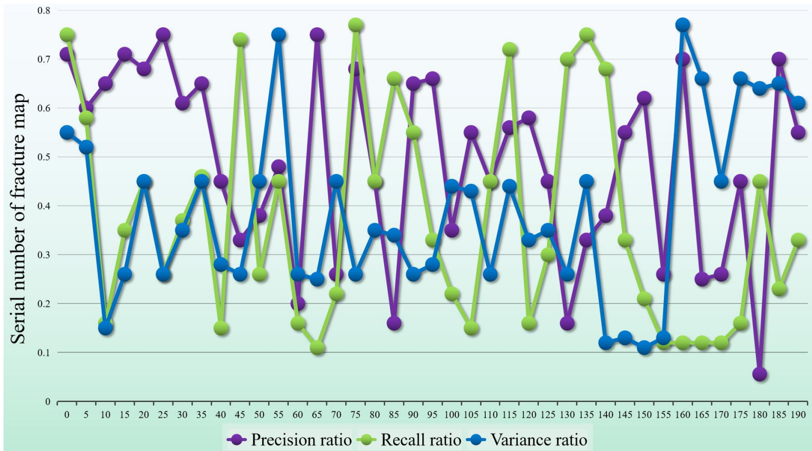

Figure 3. Evaluation diagram of multi-scale detection results of fracture images

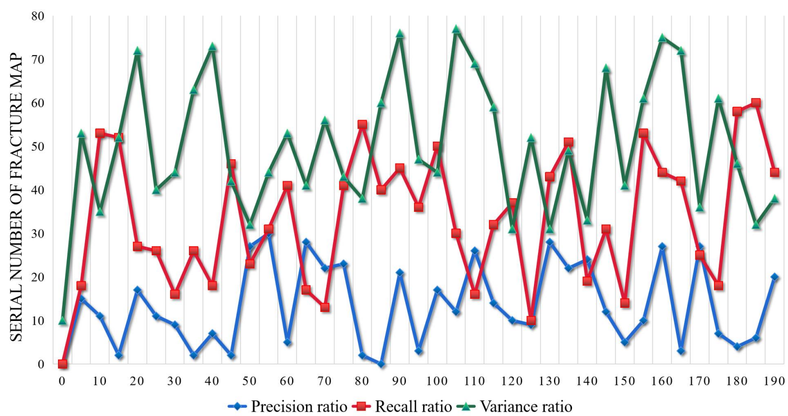

Figure 4. Comparison diagram of multi-scale detection results of fracture images

Experimental analysis: by observing the error analysis diagram in Figure 5.10 and comparing the two sets of data, it can be clearly found that the measurement error of canny operator iteration method is significantly better than that of threshold gray level iteration method, especially when the measurement distance is far away, the accuracy of the former is far better than the latter.

Aiming at the diversity and complexity of bridge crack image noise, this paper proposes an improved watershed segmentation algorithm for bridge crack image. Before watershed segmentation of bridge crack image, the original image is transformed into gray image, and then the gray image is filtered by multi-angle and multi-structural element morphological filter. The multi-scale gradient object is obtained from the filtered image, and then the gradient image is segmented and transformed by adaptive labeling. Then, after watershed transformation, the improved fisher distance region merging algorithm is used to merge the regions and complete the segmentation process. From the experimental results, it can be seen that this algorithm not only restrains the noise in the bridge crack image reasonably, but also obtains the crack information basically intact, and also has strong adaptability to the asphalt pavement image. While restraining the over-segmentation phenomenon, it also preserves the edge fine structure in the image well, and obtains an ideal segmentation effect, which has strong practicability, flexibility and robustness.

4. CONCLUSION

With the rapid development of China's economy, the construction of roads and bridges is playing an increasingly important role in the development of modern construction. However, the daily monitoring and maintenance of roads and bridges is a complex system engineering project, and there are still problems of one kind or another, and the degree of restriction and influence on the development of China's economic construction has become increasingly obvious. It is imperative to detect bridge cracks, and the traditional manual crack detection is inefficient and inaccurate. With the development and maturity of computer vision and digital image processing technology, these technologies are more and more used in bridge crack measurement. The advantages of image vision, such as non-contact and high accuracy, make the bridge crack measurement achieve good results. This system aims at the characteristics of the on-site detection of bridge cables, meets the real-time requirements of the detection system, and can stably realize the parallel acquisition, synthesis, identification and storage of the cable surface image data, providing a solution for the rapid intelligent detection of the cable surface defects and damage. The test shows that cracks with a length of less than 2mm will be considered as noise removed, so this detection method is not suitable for the detection of small cracks.

REFERENCES

[1] Yang, G., Wu, J., Hu, Q., Rapid detection of building cracks based on image processing technology with double square artificial marks:. Advances in Structural Engineering, vol.22, no.5, pp.22 (2019).

[2] Gao, M., Wang, X., Zhu, S., et al., Detection and Segmentation of Cement Concrete Pavement Pothole Based on Image Processing Technology. Mathematical Problems in Engineering, vol.38 ,no.7, pp.17 (2020).

[3] Yang, G., Wu, J., Hu, Q., Rapid detection of building cracks based on image processing technology with double square artificial marks. Advances in Structural Engineering, vol.11, no.5, pp.30 (2018).

[4] Chen, C., Li, D., Research on the Detection and Tracking Algorithm of Moving Object in Image Based on Computer Vision Technology. Wireless Communications and Mobile Computing, vol.60, no.4, pp.7 (2021).

[5] Xue, B., Wu, Z., Key Technologies of Steel Plate Surface Defect Detection System Based on Artificial Intelligence Machine Vision. Wireless Communications and Mobile Computing, vol.44, no.2, pp.19 (2021).

[6] Liu, W., Chang, X., Liang, J., et al., Defect Inspection Research on Fabric Based on Template Correction and Primitive Decomposition. IET Image Processing, vol.13, no.20, pp.33 (2019).

[7] Yang, F., Chen, W., Li, S., et al., Research on a defect detection method on carbon composite laminates based on digital shearography. Journal of optical technology, vol.40, no.4, pp.13 (2022).

[8] Lin, J., Wang, D., Tian, H., et al., Surface defect detection of machined parts based on machining texture direction. Measurement Science and Technology, vol.32, no.2, pp.51 (2020).

[9] Wang, G., Chen, J., Gao, F., et al., Research on the Infrastructure Target Detection of Remote Sensing Image Based on Deep Learning. Radio Engineering, vol.27, no.6, pp.29 (2018).

[10] Feng, W., Liu, H., Zhao, D., et al., Research on defect detection method for high-reflective-metal surface based on high dynamic range imaging. Optik, vol.55, no.4, pp.28 (2020).