Research on crack detection of bridge deck based on computer vision

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ABSTRACT: Bridge deck crack is the most serious bridge deck disease. To reduce the time, cost, and money cost of bridge deck crack detection, computer vision technology is combined with bridge deck crack detection. First of all, the main ways of obtaining bridge surface images are analyzed. Then, the algorithms of image enhancement, image noise reduction, image segmentation, crack extraction and recognition, and crack feature extraction in bridge deck crack detection based on computer vision are summarized respectively. Finally, the existing detection methods are reviewed, and the problems encountered in the research process and future research directions are further discussed.

1. Introduction
As an important component of China's highway transportation system, bridges cannot be replaced in people's daily travel. Relevant literature data show that more than 90% of the bridges are damaged due to cracks[1]. For the bridge in service with defects, how to achieve efficient and rapid crack detection and identification has become the key. The traditional bridge deck crack detection work is performed by inspectors, which manually mark the cracks and visually identify the width of the cracks; this method is expensive, time-consuming, dangerous, labor-intensive, and subjective[2].

Nowadays, with the rapid development of computer technology and the continuous improvement of computer hardware performance, the bridge deck crack detection technology based on computer vision has been widely used. This technology aims to use the computer instead of manual, to achieve efficient, accurate, and low-cost automatic detection of bridge cracks. This paper analyzes the principle of bridge deck crack detection research based on computer vision from four aspects of image acquisition, image preprocessing, crack extraction and recognition, and crack feature extraction. Combined with the existing bridge deck crack detection methods based on computer vision, this paper puts forward the problems encountered in the current research and the future research direction.

2. Image acquisition
Obtaining a bridge deck image is the first step of crack detection research. The traditional image acquisition is usually done by manual maintenance and inspection and stored after taking photos by naked eye recognition, which has strong subjectivity and low integrity of data preservation. Also, for large bridges, it is often necessary for detection personnel to go to dangerous locations, so the safety factor is very low. The bridge detection vehicle, unmanned aerial vehicle, wall climbing robot, non-contact detector, and other technologies greatly eliminate the above-hidden dangers. Bridge inspection vehicles mainly include folding arm type and truss type. Folding arm type is simple in structure, easy to operate, and flexible in operation, but its operation platform area is small, and its operating range is...
limited, and its work efficiency is low, so it is often used in the detection and maintenance of small bridges; truss type is complex in structure, and its manufacturing cost is expensive, but it greatly improves the work efficiency and is generally used in the detection of large bridges. The use of remote control or automatic flight of unmanned aerial vehicle for bridge detection can hover at any designated location, high flexibility, easy maintenance; wall climbing robot small size, high efficiency, low cost, can enter the dangerous work area, professional personnel can remote real-time or offline safety detection work; vehicle CCD camera can collect pictures real-time into the computer or storage system, real-time or offline processing, and analysis; non-contact detector field workload is small, post-processing intuitive, high precision measurement results.

3. Image preprocessing

3.1 Image enhancement

Image enhancement refers to the purposeful enhancement of the overall or local features of the image, improving the clarity of the image or enhancing some features, suppressing the uninterested parts of the image to meet the needs of some special analysis. Image enhancement mainly includes two directions: spatial domain enhancement and frequency domain enhancement[3].

3.1.1 Spatial domain enhancement

Spatial domain enhancement is a direct image enhancement algorithm, which is generally used for local enhancement of digital image, including neighborhood enhancement algorithm and point operation algorithm. The neighborhood enhancement algorithm is divided into image smoothing and image sharpening. The former is generally used to eliminate image noise, and the common algorithms include mean filter, median filter, and spatial filter; the latter is used to highlight image edge, and the common algorithms include gradient operator method and second derivative operator method, and so on. Point operation algorithm includes grayscale correction, grayscale transformation, and histogram correction.

3.1.2 Frequency domain enhancement

Frequency domain image enhancement is an indirect image enhancement algorithm based on two-dimensional Fourier transform, which is generally used for global image enhancement. The most widely used methods are low-pass filtering and high-pass filtering. Low-pass filtering only allows low-frequency signals to pass through to achieve the purpose of de-noising, while high pass filtering can enhance the high-frequency signals at the edge, both of which can achieve the purpose of improving image clarity.

3.1.3 Other image enhancement algorithms

Yin[4] proposed the SFC method for the first time, repeatedly and alternately using the improved histogram gray stretching, four neighborhood average smoothing, and Laplacian sharpening for image enhancement processing, while effectively removing noise, sharpening edges and improving image contrast, and comparing the processing results with the traditional enhancement algorithm, the results are shown in Figure 1; Sun [5] proposed a mask smoothing preprocessing method. By calculating the variance of each mask, the gray mean value corresponding to the template with the minimum variance is taken as the new gray value of mask smoothing output. This method effectively protects the edge of the crack based on reducing image noise and improving image quality. The enhancement result of the crack image is shown in Figure 2; Wang et al. [6] proposed LOF algorithm and improved level set algorithm, which can effectively enhance the crack information, so that it can extract complete cracks in the subsequent processing process, and avoid crack leakage. The effect is shown in Figure 3.
3.2 Image noise reduction

Image noise can be understood as "the factors that hinder people's sense organs to understand the
received information". Due to the interference of the external environment, the influence of the bridge deck's situation, and the vibration of acquisition equipment, the collected image inevitably contain a lot of noise, which will increase the difficulty of road image processing. At this time, it is necessary to adopt a reasonable way to eliminate the noise [7]. Image noise reduction methods mainly include median filtering, mean filtering, and Wiener filtering.

3.2.1 Median filtering
Median filtering is a common nonlinear filtering method, and it is also the most commonly used preprocessing technology in image processing technology. It can overcome the blur caused by the linear filter, effectively remove the noise and keep the good edge characteristics, to obtain a satisfactory filtering effect.

3.2.2 Mean filtering
Mean filtering is a typical linear filtering algorithm, it means to give a template to the target pixel on the image. The template includes the adjacent pixels around it (eight pixels around the target pixel as the center forming a filter template, that is, including the target pixel itself). Then the average value of all the pixels in the template is used to replace the original pixel value, the main method used is the neighborhood average method.

3.2.3 Wiener filtering
Wiener filtering was first proposed by N. Wiener in 1942. As a common method for restoration of degraded images, the essence of Wiener filtering is to minimize the mean square value of estimation error (defined as the difference between the expected response and the actual output of the filter). Wiener filter can suppress Gaussian noise and multiplicative noise obviously, but at the same time, it is easier to lose the edge information of the image, and has no suppression to salt and pepper noise.

Wang et al. [8] compared the processing results of the above several different filtering algorithms, and the results are shown in Figure 4:

![Figure 4. Comparison of different filtering methods.](attachment:image.png)

(a) Original image (b) Neighborhood Average Method (c) median filter (d) wiener filtering

3.2.4 Other image noise reduction methods
Dorafshan et al. [9] proposed a method combining deep convolution neural network and edge detector to reduce noise by 24 times. Wang et al. [6] developed a shadow and noise removal algorithm, GRS,
which can deal with cracks with uneven intensity and complex structure, and avoid transforming shadow information into background information. Fujita et al. [10] proposed a background subtraction algorithm based on the median filter for denoising, and the processing effect is shown in Figure 5.

![Figure 5. Denoising effect of background subtraction algorithm based on the median filter. (a) Original image (b) Manual tracing (c)Proposed method](image)

3.3 Image segmentation

Image segmentation is the process of separating the object from the background[11]. The three most widely used principles of image segmentation are region-based image segmentation, clustering-based image segmentation, and edge-based image segmentation.

3.3.1 Image segmentation based on region

The threshold segmentation method is mainly divided into global and local two parts, the current application of threshold segmentation methods is developed on this basis, including minimum error method, maximum correlation method, maximum entropy method, moment preserving method, Otsu maximum inter-class variance method, etc. Otsu maximum inter-class variance method is the most widely used.

3.3.2 Image segmentation method based on Clustering

Based on the basic features of gray and other pixels, the clustering method divides the image into regions according to certain rules, judges the region of the pixel, marks and segments it. The clustering method includes hard clustering, probabilistic clustering, fuzzy clustering, and the most commonly used is the fuzzy c-means algorithm, namely the FCM algorithm.

3.3.3 Image segmentation based on edge

The edge feature of the image has strong stability, so it is important to extract the edge feature of the image for image processing. As the most basic operation to detect local significant changes of image, the first-order differential operators commonly used in edge detection include Roberts operator, Prewitt operator, Sobel operator, and the second-order differential operators include Laplace operator, Log operator, and Canny operator. The canny operator is considered to be the best edge detection operator at present, but in the field of bridge crack detection, its disadvantage is that it is easy to generate pseudo cracks or lose some real details of the image edge.

Lei et al. [12] have done processing analysis and comparison for the above edge detection operators, as shown in Figure 6.
Figure 6. Edge detection operator processing effect comparison chart.
(a) Original image (b) Roberts operator (c)Prewitt operator (d)Sobel operator
(e) Laplace operator (f) Log operator (g) Canny operator (h) iterative algorithm (i) OTSU operator

3.3.4 Other image segmentation methods
Xu et al. [13] improved the filtering parameters of the Canny iterative algorithm, selected the minimum variance as the standard constant factor of measurement, combined with the derivative of the window mean, effectively eliminated the noise, improved the adaptability of the algorithm, and retained the edge information; Wang et al. [14] combined the improved local adaptive Otsu threshold segmentation method with Sobel edge gradient detection to remove isolated noise points, to extract crack edge information and obtain crack feature texture information, as shown in Figure 7; Zou et al. [15] proposed a road crack segmentation algorithm based on crack tree, which can obtain crack information in the road image with non-uniform illumination, as shown in Figure 8; Lei et al. [12] proposed an improved segmentation algorithm, which combines adaptive segmentation, edge detection, and double threshold Otsu to improve the accuracy of crack recognition, as shown in Figure 9.

Figure 7. Comparison between traditional algorithm and improved algorithm.
(a) Traditional Canny operator processing results (b) Improved algorithm processing results
Figure 8. Results of pavement crack segmentation algorithm based on crack tree.

Figure 9. Image segmentation effect of improved Lei algorithm.
(a) Original image (b) Improved algorithm processing results

4. Crack extraction and recognition

4.1 Morphological processing
Dilation and erosion are two basic dual operations in morphological processing. The erosion operation will make the target object shrink along the surrounding area and eliminate the boundary points; the expansion operation will make the target object diffuse to eliminate the small holes in its neighborhood [16]. Firstly, the binary image is corroded and then expanded, which can eliminate the noise without changing the size of the original crack. Figure 10 shows the processing effect. Peng et al. [17] proposed a new morphological operation to enhance the continuity of the crack by performing different corrosion expansion operations on the crack region and non-crack region while maintaining the crack width with a given tolerance.

Figure 10. Morphological processing effect.
(a) Before corrosion (b) After erosion (c) After dilation
4.2 Crack connection
In the actual environment, due to the influence of weather, light, and so on, some of the cracks collected tend to present a state of fracture discontinuity; and in the process of image processing, the connectivity of cracks is easy to be destroyed, and the commonly used crack connection methods are Minimum Spanning Tree method and KD tree method.

4.2.1 Minimum Spanning Tree
The purpose of the Minimum Spanning Tree algorithm is to solve the shortest path problem of a weighted digraph or undirected graph [18]. To realize the shortest connection of the crack unit, the Minimum Spanning Tree algorithm can be used to process the refined crack image to realize the shortest connection of the crack unit. Common algorithms include the Prime algorithm and the Dijkstra algorithm. The results of the Minimum Spanning Tree algorithm are shown in Figure 11. However, the Minimum Spanning Tree method will connect the pseudo cracks while connecting the cracks, and also deal with the pseudo cracks. The general pseudo cracks processing is based on the variance value of the pixel distribution of the pseudo cracks and the actual cracks. Due to the randomness and uncertainty of the cracks, the distribution of the pseudo cracks is quite different, but the pseudo cracks are on the contrary.

![Figure 11. Effect picture of minimum spanning tree connection crack. (a)Crack skeleton (b) Minimum spanning tree method](image1)

4.2.2 KD tree
The main principle of the crack connection algorithm based on the KD tree is to connect the crack endpoints that meet the specified threshold conditions. By finding the endpoint of each crack segment and the nearest adjacent endpoint, judge whether the pixel threshold between different endpoints is less than the specified threshold, if it is less than the specified value, connect the two endpoints; finally, fill the connected area between cracks according to the gray characteristics of the crack image, to obtain a complete crack image [19], the treatment effect is shown in Figure 12 below.

![Figure 12. Crack join algorithm based on KD tree. (a) The processed binary image of crack (b) Crack connection based on KD tree](image2)

5. Crack feature extraction
The purpose of bridge deck crack detection is to get the relevant parameters of cracks, to judge the safety
of cracks according to the relevant provisions. In this paper, two characteristic parameters of fracture length and width are discussed.

5.1 Length
The most common method of crack length measurement is the number of pixels method, which first refines the crack image to obtain the skeleton image of the crack, and then counts the sum of the number of white pixels in the thinned image to get the pixel length of the crack. The pixel length is multiplied by the actual value of each pixel to get the actual length of the crack.

Zhou et al. [20] used the subsection summation method to calculate the pixel distance between two points by using the coordinates of two adjacent pixels of the crack skeleton line and multiply it by the pixel resolution to get the actual length of the crack. Xia[21] sets a ruler on the surface of the bridge or uses other natural buildings as rulers to calculate the proportion coefficient between the number of pixels and the length of the ruler, through which the length information of the crack can be calculated.

5.2 Maximum width
Zhan[22] uses the principle of corrosion operation because each corrosion makes the crack be stripped a circle, by recording the number of times required for the image crack to be eliminated by corrosion operation at the widest part and multiplying by the width of the target to be stripped in each corrosion operation, the maximum width of the crack can be obtained.

According to Douglas Peucker algorithm, Zhou[23]marked the refined cracks by segments, calculated the minimum circumscribed rectangle of the segmented connected area, counted the number of white pixels on the vertical line of the circumscribed rectangle, took the maximum value as the maximum width of the crack, and multiplied by the actual size of each pixel to get the maximum width of the crack. Han[24] proposed a maximum width detection method, which uses the gradient direction of edge pixels as the normal direction of the edge, calculates the crack width at each point of the edge, and locates the maximum crack width. The principle is shown in Figure 13; Nishi Yama et al. [25] proposed to set up a reflection target around both sides of the crack as a ruler and recognize the distance between the circles of the reflection target as the width of the crack.

6. Bridge deck crack detection method based on computer vision
Sha et al. [26] used convolution neural network technology to establish the disease recognition model through structural design, pre feedback algorithm, and sample test and took the training output as the training sample of crack feature extraction. He extracted the crack features from 12800 512 × 512 pixel images. The average error of crack length extraction was 4.27%, and the average error of crack width
extraction was 9.37%. The severity of the disease was accurately judged up to 98.99%; Han et al. [24] used 14000 training samples for 5-fold cross-validation, the average accuracy rate of fracture identification was 98%, and the average comprehensive evaluation index F1 measure was 91%; Cha et al. [27] proposed a convolutional neural network based on deep learning for crack damage detection, and trained and tested 322 original images taken under uncontrolled conditions. The accuracy of the trained network for crack recognition of 32K and 8K images is 98.22% and 97.95% respectively; Li et al. [28] proposed an end-to-end model named Skip-Squeeze-and-Excitation Networks (SSE-Nets). It is mainly composed of the Skip-Squeeze-Excitation (SSE) module and the Atrous Spatial Pyramid Pooling (ASPP) module. He selected 4856 images as a training set and 1213 images as a test set to obtain multi-scale features from crack images, to improve the accuracy of crack detection. The detection accuracy of this model is as high as 97.77%; Xu et al. [29] proposed an end-to-end crack detection model based on the convolutional neural network, which consisted of 2068 bridge crack images. Taking the advantage of atrous convolution, Atrous Spatial Pyramid Pooling module and depth wise separable convolution, the crack detection accuracy of 96.37% can be achieved without pre-training; Li et al. [30] proposed an improved encoder-decoder network structure with new functions, and it named as R2CE-Net. Recurrent residual convolutional neural network block was used to replace the standard convolution of the original encoder module. Sliding window technology was used to expand and establish their bridge crack dataset, the precision of crack recognition reached 99.28%; Yang et al. [31] proposed a new Feature Pyramid and Hierarchical Boosting Network for pavement crack detection. By processing five different data sets, the superiority and generalization of this method are proved; Zou et al. [32] proposed a novel end-to-end trainable deep convolutional neural network for automatic crack detection by learning high-level features for crack representation. This method achieved over 0.87 ODS F-measure value on the test datasets in average (harmonic mean of accuracy and recall) on the test data set; Gao et al. [33] used a convolution neural network as the core algorithm to build the corresponding database. The convolution neural network architecture for bridge crack detection consists of three convolutions and pooling layers, two groups of Dropout, and full connection layers. The algorithm test accuracy is 93.6%; Dan et al. [34] applied the two-dimensional amplitude and phase estimation method (2D-APES) algorithm to image processing. By setting appropriate conversion frequency range, filtering the low-frequency components, reconstructing the frequency-domain image and enhancing the edge information, carried out the automatic recognition of crack target, and the effective recognition rate was up to 90.5%; Je-Keun et al. [35] designed a cantilever vehicle bridge substructure crack detection system, the crack detection rate is as high as 96.7%, and the average error is controlled within 0.023 mm; Wang et al. [36] developed a bridge bottom crack detection platform based on tethered creeping unmanned aerial vehicle, which meets the requirements of ultra-high endurance and stability, and the calculation accuracy of crack parameters is less than 0.1 mm; Zhang et al. [37] proposed a visual detection method of concrete bridge deck cracks based on the combination of one-dimensional convolution neural network and Long Short-Term Memory (LSTM) in the image frequency domain. The accuracy of the model for training, verification, and test data is 99.05%, 98.9%, and 99.25% respectively.

7. Problems encountered in the research and future research directions

7.1 Problems encountered in the research

The above-mentioned image acquisition methods of bridge deck cracks are easy to be limited by the weather, which affects the extraction and recognition of subsequent cracks, leading to the coexistence of watermark and cracks. And given the complex natural lighting conditions and difficulty to control the shooting angle, there is still a lot of room for improvement in the accuracy of bridge deck crack identification.

A deep convolution neural network uses large data sets to extract and learn image features through convolution operation in a supervised way and then uses backpropagation to minimize the classification error on the training set to jointly optimize the network parameters, and finally realizes the crack extraction [18]. However, in the practical engineering application of bridge deck crack detection and
recognition, the workload of crack data annotation is huge, which leads to the small number of open sample data sets in this field, which cannot effectively support the application of deep convolution neural network.

7.2 Future research directions
Under the premise of certain accuracy, there are still some questions to ponder. How to accurately locate the cracks on the bridge deck and visualize all the crack information of the bridge deck, and achieve the bridge deck crack detection and crack information management all intelligent management. At present, most of the bridge deck detection systems aim at the bridge deck cracks, and the cracks are only one form of bridge deck disease. It is worth thinking about how to extend the intelligent detection of this kind of cracks to all kinds of bridge deck diseases.

8 Conclusions
This paper summarizes the common image acquisition methods in the field of bridge deck crack detection, and leads to the image processing methods based on computer vision, including image enhancement, image denoising, image segmentation three steps, expounds their respective principles and algorithms, introduces the crack connection and feature recognition methods applied to crack recognition, and summarizes the existing methods based on computer vision. Finally, the existing problems and future research direction of this method are expounded.

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