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Application of Internet of Things Technology and Convolutional Neural Network Model in Bridge Crack Detection

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ABSTRACT With the development of information technology, the Internet of Things (IoT) has the characteristics of strong permeability, large use of action, and good comprehensive benefits. It promotes the development of the IoT technology in the detection of structural engineering. It is conducive to the development of intelligent, refined, and networked structures. Crack is the most common threat to the safety of bridges. Historical data show that the safety accidents caused by cracks account for more than 90% of the total bridge disasters. After a long period of engineering practice and rigorous theoretical analysis, it was found that 0.3 mm is the maximum allowable for bridge cracks. If the width exceeds the limit, the integrity of the bridge will be destroyed, and even a collapse accident will occur. Therefore, it is very important to identify cracks in bridge structure effectively and provide effective information for structural disaster reduction projects in time. Based on the structure of the IoT and the structural characteristics of the bridge engineering, this paper analyzed the practical application value of the IoT technology in the crack identification of bridge structures and established a bridge structure health monitoring system based on the IoT technology. On this basis, this paper also studied a digital and intelligent bridge crack detection method to improve the efficiency of bridge safety diagnosis and reduced the risk factor. First, the collected bridge crack photographs were preprocessed, the bridge crack convolution neural network classification model was established, and the model was simulated and trained using MATLAB. The bridge crack classification was obtained. The simulation results showed that the overall accuracy rate was greater than 90%.

INDEX TERMS Internet of Things technology bridge cracks convolution neural network image processing.

I. INTRODUCTION

With the rapid development of China's transportation industry, the density of highway networks has continuously increased, and large-span bridges have continued to emerge. However, due to the complex environment of the bridge structure and its construction process, the bridge project will inevitably produce various risk factors [1]. These risk factors are likely to cause adverse effects on bridges and even cause collapse of bridges, endanger people's lives and cause damage to property. Therefore, it is of great significance to carry out damage identification and early warning of the bridge structure and grasp the health status of the bridge operation in time. The health diagnosis of modern bridges is currently a hot topic in engineering and academia. There are more than 800,000 large and small highway bridges in China. More than 1/3 of the bridges are structurally flawed, with varying degrees of damage and functional failure. Many of these bridges are in urgent need of safety monitoring, health diagnosis and maintenance reinforcement. Since the 1950s, people have realized the importance of health diagnosis, but due to the backwardness of early detection methods, they have been limited in their application. However, in recent decades, many countries and research institutes have realized the importance and urgency of studying the health diagnosis of bridge structures [2]. The use of effective means for testing and assessing the health status of existing bridges, repairing and controlling damage, and establishing long-term safety inspection, vibration, and damage control systems for newly built bridges which have become research hotspots in academic and engineering circles at home and abroad [3].

From the perspective of research and application, the current method of damage identification of structures can be mainly divided into two categories: damage identification methods based on static forces and damage identification methods based on dynamic characteristics [4]. However, the loads that the structure bears during service are often varied. Therefore, errors are unavoidable in the process of data collection and processing. At the same time, due to the limitations of the algorithm, these detection methods often encounter problems in practical applications.

With the development of intelligent identification terminal technology, the Internet of Things (IoT) technology has been applied in structural security monitoring [5]. The intelligent terminal recognition technology realizes real-time monitoring of construction sites, how to process and analyze the information of intelligent terminals, and evolves them into security early warning signals. Internet of things technology can be automatically identified and tracked through intelligent terminals, network data transmission, and computer warnings. Analyze the system, realize digitization, information construction and management, and monitor the safety status of the structure in real time and in all aspects.

The Internet of Things is the fastest-growing industry in recent years. It can also be seen from the government's recent plans that research on the Internet of Things technology will have a greater investment in the next few years [6]. The development of Internet of Things technology will also inevitably bring about changes in related industries. Therefore, the active exploration of the application of Internet of Things technology in various related fields will attract more and more attention along with the popularity of Internet of Things technology. For engineering quality inspection, the application of Internet of Things technology improve the efficiency and accuracy of inspection work and it will become the future development trend.

II. INTERNET OF THINGS TECHNOLOGY INTRODUCTION

The concept of the Internet of Things was first proposed by Professor Kevin Ash-ton at the Massachusetts Institute of Technology in 1991. In 1999, the "Automatic Identification Center" of the Massachusetts Institute of Technology (MIT) gave its basic meaning, that is, to pass all items through radio frequency. Identification and other information sensing devices were connected to the Internet for intelligent identification and management. With the deepening of research, the content of the Internet of Things had changed a lot. Today's Internet of Things refers to a variety of information-sensing devices, such as radio frequency identification (RFID) devices, infrared sensors, global positioning systems, laser scanners, etc. That will have a certain level of perception, computational capabilities, and execution capabilities. A huge network formed by the combination of network facilities and the Internet, so that all items are connected with the network and realize information transmission, coordination and processing, so that the system can automatically identify, locate, track, and monitor objects in real time. Based on the Internet, the Internet of Things realizes the integration of the physical world and the digital world, and extends the networked objects from people to all objects, thereby realizing the networking of "things and things."

The structural framework of the Internet of Things can be divided into four levels: perception layer, network layer, processing layer, and application layer [7]:

A. PERCEPTUAL LAYER

The sensory layer is the physical contact layer and the basis of the Internet of Things. It is also the biggest difference between the Internet of Things system and traditional information systems. Its main function is to realize the perception, recognition, monitoring or data collection of objects. It is composed of various types of sensors in various buildings, power grids, dams, and road networks, such as two-dimensional bar code, radio frequency identification (RFID) tag, RFID reader, camera, and Machine to machine M2M. Devices and various embedded terminals and other sensor networks. The sensory layer changes the situation in which the traditional information system has high internal processing power and low external sensing capability, and it achieves sensitive, reliable, and complete physical sensing with low power consumption, small volume, and low performance.

B. NETWORK LAYER

The network layer is the information transmission layer and it is a relatively mature part. Its main role is to carry out information transmission between the sensing layer and the processing layer. It is a fusion of various communication networks and Internets which are composed of various wired and wireless point, fixed and mobile gateways. It mainly includes 2G, 3G, 4G communication networks, the Internet, radio and television networks, and wireless networks.

C. TREATMENT LAYER

The processing layer is an intelligent processing layer and implements intelligent processing of massive information, such as the Internet of things management center, resource center, cloud computing platform, and expert system, including directory services, management U-Web services, modeling and management, content management, and space. Information management, etc., to achieve support for the application layer.

D. APPLICATION LAYER

Based on the perception layer, network layer, and processing layer, the Internet of Things technology can realize ubiquitous and intelligent applications. Through the application layer, the Internet of Things realizes the deep integration of information technology and various industries such as smart logistics, security monitoring, green agriculture, disaster monitoring, public safety and telemedicine.

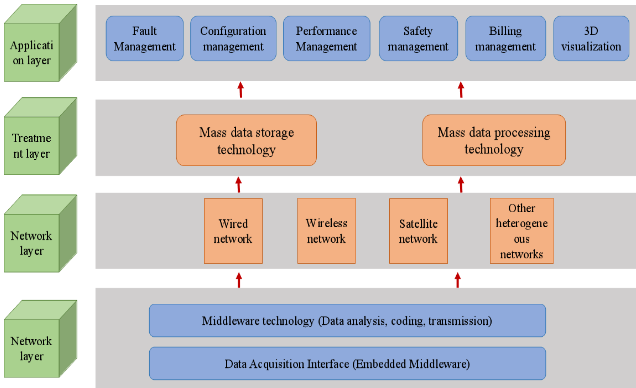

FIGURE 1. The structure of the Internet of things.

Compared with the traditional Internet, the Internet of Things has its distinctive features. First of all, it is the wide application of various sensing technologies. Massive types of sensors are deployed on the Internet of Things. Each sensor is an information source. Different types of sensors capture different information content and information formats. The data obtained by the sensor has real-time nature, periodically collecting environmental information according to a certain frequency, and constantly updating the data. Second, it is a kind of ubiquitous network built on the Internet. The important foundation and core of the Internet of Things technology is still the Internet. Through the integration of various wired and wireless networks and the Internet, the information of objects is delivered in real time and accurately. The information collected by sensors on the Internet of Things needs to be transmitted through the network. Since the number is extremely large, massive information is formed. During the transmission process, in order to ensure the correctness and timeliness of the data, it is necessary to adapt to various heterogeneous networks and protocols. In addition, the Internet of Things does not only provide sensor connections, but it also has the ability to handle intelligence, enabling intelligent control of objects. The Internet of Things combines sensors and intelligent processing, and utilizes various intelligent technologies such as cloud computing and pattern recognition to expand its application fields.

III. RIDGE STRUCTURE DAMAGE IDENTIFICATION INTERNET OF THING

Based on the content of the Internet of Things, combined with the characteristics of the bridge structure, this paper defines the damage structure of the bridge structure as a comprehensive perception of the damage situation of the structure through the information sensing equipment, the ubiquitous interconnection of structural security impact factors (load, displacement, service life, use environment, etc.). Through specific networks and information exchange, communication, processing, analysis, to achieve intelligent identification, positioning, tracking, monitoring, control, management and decision-making of the integrated computing platform. The establishment of bridge structure damage identification network has broken through the traditional management mode of personnel monitoring, the management blind spot which is difficult to be learned and controlled in the process of bridge structure health monitoring is mastered, through the technology of IoT, the information space, the bridge structure and the management space are highly fused, and the "informational gap" between the bridge structure and the decision management is exceeded, which effectively improves the safeguard ability of the digital structure health monitoring.

Structural damage identification of bridge structures the framework of the network is shown in FIG. 2.

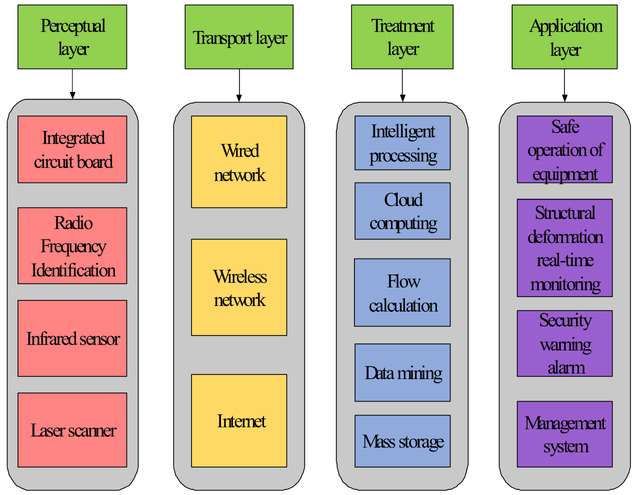

FIGURE 2. Structure diagram of Internet of things for bridge damage identification.

As can be seen from FIG. 2, the reason why the technology of IoT can be applied to the safety management of construction works is due to the following three points:

(1) The full and perceptual layer utilizes the intelligent terminal technology to obtain the object's information, including position, displacement, state and so on. This function can be used to acquire and master the whole information of facilities, equipment, environment, structure or components, so as to analyze and control the safety status of the bridge structures.

(2) The comprehensive implementation of bridge structure health monitoring not only should be prevented in advance, but also should be monitored in real time. The network layer in the IoT technology can reliably transfer and share the information between objects in real time, so as to grasp the security status of the structure site in time and accurately, take effective measures to eliminate the hidden danger and avoid the occurrence of safety accidents.

(3) The data collected in the field is huge and complex, and the efficiency of data processing is the key part of the application of IoT. The processing layer uses intelligent computing technology to process and analyze the massive data and information collected, so as to realize the intelligent control of the object. After the collected data is transmitted through

the network to the monitoring and processing platform of the processing layer, the system can evaluate the status of the field quickly by embedding intelligent algorithm, database and fuzzy rules, and the result is analyzed.

In summary, the application of IoT technology in the safety management of bridge structure. The process is shown in FIG. 3.

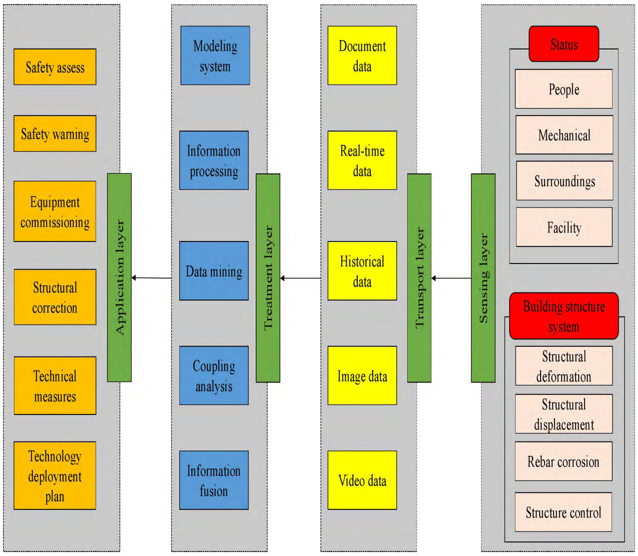

FIGURE 3. The application process of the Internet of things for bridge damage identification.

IV. APPLICATION OF CONVOLUTION OF CONVOLUTION NEURAL NETWORK IN BRIDGE STRUCTURAL DAMAGE IDENTIFICATION

A. THE INTRODUCTION OF CONVOLUTION NEURAL NETWORK

Convolution neural Network (CNN) is one of the ground-breaking research results which is inspired by the knowledge of biological neuroscience and based on the principle of artificial neural network, and it is a kind of artificial neural network system with deep learning ability, compared with traditional method, convolution neural network has strong applicability and Feature extraction and classification at the same time, strong generalization ability, global optimization training parameters and so on, it has become a research hotspot in the field of machine learning [8], [9]. When used in image classification, the set of small neurons in the convolution neural network is connected with a small region of the input image, which is called the local sensation field as shown in FIG. 4. Send some sets of overlapping flat spread to W get the original image better representation, each layer of the network repeats this process, because of this, the network can tolerate some distortion of the input image.

The convolution neural network also contains a lower sampling layer, the pool layer, which is used to combine the output of the neuron cluster, and the following sampling technique is shown in FIG. 5. All layers in a neural network are fully connected was for its existence of billions of

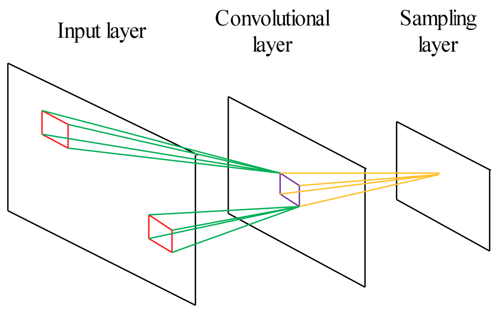

FIGURE 4. Local experience domain technology diagram.

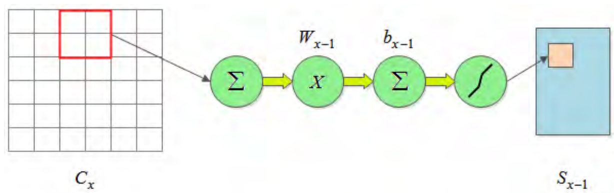

FIGURE 5. Down sampling technique.

parameters, the convolution neural network uses the convolution operation of the small area and shares the weights in the convolution layer, and the same weight recombination is used in each pixel of the layer, which reduces the required memory size and improves the performance [10]. Some time delay neural networks also use very similar structures, especially in some image recognition or classification tasks, because the "tile" of the neuron output can be easily timed, which is useful for image analysis.

Compared with other image classification algorithms, convolution neural networks use relatively few preprocessing, because it is also used in the study of filters, and the traditional algorithm is too much care about the design of manual features. There is no need to rely on prior knowledge and the difficulty of manual feature design is the main advantage of convolution neural network compared with traditional algorithm. As shown in FIG. 6:

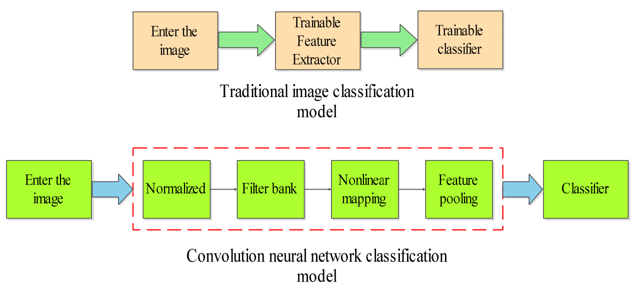

FIGURE 6. Model comparison.

1) CALCUALATION OF CONVOLUTION LAYER

In the convolution layer, the feature map of the upper layer is convolution operation with a learning convolution kernel, the results are input into an activation function, and finally the output is composed of a new feature graph, in which different convolution cores get different feature graphs, and each output feature graph may have a combined convolution of multiple feature graphs [11]. The calculation of the convolution layer is as follows:

$$X_j^l = f\left(\sum_{i\in M_j} X_i^{l-1} \times K_{ij}^l + b_j^l\right) \tag{1}$$

Here X_j^l represents the j feature map of layer l, K_{ij}^l is the convolution kernel function, $f()$ is the activation function, and the traditional convolution neural network makes the sigmoid function active and b_j^l is the bias parameter. M_j represents a collection of selected input feature graphs from which a combination is selected as an input feature graph each output feature graph has a bias coefficient, but for a particular output-holding graph, the convolution cores of each input feature graph of the convolution are together, that is, the input feature map of the output feature graphs a and b has c, But they are derived from c by a sum of different convolution cores.

2) CALCULATION OF CONVOLUTION LAYER GRADIENT

The general convolution layer l will be followed by a lower sampling layer $l + 1$, according to the above BP algorithm, if we want to get the weight of the convolution layer update, we need to first get the layer of each neuron error signal δ, and in order to get the need for the next layer of the neuron error signal sum to get δ^{l+1}, Then multiplied by the corresponding weights of these connections W, multiplied by the activation function f of the input μ of the neuron in the l-layer, the error signal δ^l of each neuron in the l-layer can be obtained.

However, after the convolution layer is the lower sampling layer, the error signal of the neuron node in the sampling layer corresponds to the size of the sample window in the output feature graph of the convolution layer, so each neuron of the feature map in the layer is connected with only one neuron in the corresponding feature map in the $l + 1$ layer [12].

Therefore, we need to sample the sample layer corresponding to the feature map to get l layer of error signal, so that the size of the convolution layer and the size of the feature map. The weights of the feature graphs of the lower sampling layer are all taken the same constant l, so the error signal β of Layer δ can be obtained by e from the result of the previous step, and match the corresponding feature graph of the lower sample layer, we can repeat this process to get the error signal b_j^l of each feature graph j in the convolution layer:

$$\delta_j^l = \beta_j^{l+1}\left(f'\left(u_j^l\right) \bullet up\left(\delta_j^{l+1}\right)\right) \tag{2}$$

In which, for a sample operation, through the above formula we can sum up the gradient of the bias base by the error signal in the layer:

$$\frac{\partial E}{\partial b_j} = \sum_{u,v}\left(\delta_j^l\right)_{uv} \tag{3}$$

Finally, the weight gradient of convolution kernel can be arrived by conventional BP algorithm, because many connections in convolution neural networks are weighted values, for a given weight, we need to make a gradient for all connections associated with that weight, and finally sum these gradients:

$$\frac{\partial E}{\partial K_{ij}^l} = \sum_{u,v}\left(\partial_j^l\right)_{uv}\left(p_i^{l-1}\right)_{uv} \tag{4}$$

Here p_i^{l-1} is a small block multiplied by the K_{ij}^l element in the convolution in X_i^{l-1}, and the value of the *(u,v)* position of the output convolution feature graph is the result of a small block of the upper *(u,v)* position multiplied by an element of the convolution kernel. We can do this with the convolution function in Python without having to wade through our own effort to remember which chunk of the output feature map each neuron corresponds to the input feature graph:

$$\frac{\partial E}{\partial K_{ij}^l} = rot180\left(conv2\left(X_i^{l-1}, rot180\left(\delta_j^l\right), \text{"valid"}\right)\right) \tag{5}$$

Here, the rotation feature map is to cross correlation rather than convolution, and the output back to rotate, send samples in the forward propagation of the convolution, the convolution kernel will be in the direction of the predetermined.

3) GRADIENT CALCULATION OF THE CONVOLUTION LAYER AND THE LOWER SAMPLING LAYER

The principle of the lower sampling layer is simple, each output feature chart size is a reduced version of the size of the input feature map:

$$X_j^l = f\left(\beta_j^l down\left(X_j^{l-1}\right) + b_j^l\right) \tag{6}$$

Where *down( )* is the lower sampling function and the sample window is n^*n, the output feature graph is reduced by n times to reduce the resolution to achieve scaling invariance. Each output feature graph has its own multiplicative offset parameter β and additive bias parameter b.

In order to calculate the error signal of the sample layer feature map, we must first find out which small block in the sensitivity feature map of the current layer corresponds to which pixel of the next layer's sensitivity feature map, and then use the reverse propagation algorithm to compute [13]. The error signal of the current sub sampling layer is recursively obtained by the error signal of the next layer:

$$\delta_j^l = f'\left(u_j^l\right) \bullet conv2\left(\delta_j^{l+1}, rot180\left(K_j^{l+1}\right), \text{"full"}\right) \tag{7}$$

Before the calculation, we need to rotate the volume kernel 180 degrees, so that the convolution function can be related calculations, full for the total convolution function, it can deal with the convolution boundary, the missing pixel to complement 0. Next you get a gradient of to and b:

$$\frac{\partial E}{\partial b_j} = \sum_{u,v}\left(\delta_j^l\right)_{uv} \tag{8}$$

$$\frac{\partial E}{\partial \beta_j} = \sum_{u,v}\left(\delta_j^l \bullet down\left(X_j^{l-1}\right)\right)_{uv} \tag{9}$$

Similar to the BP algorithm, the weight update from time t to t + 1 moment in the convolution neural network can be obtained from the following calculation form:

$$W(t+1) = W(t) + \eta\delta(t)\,x(t) \tag{10}$$

Where η is the learning rate, $x(t)$ is the input of the neuron, and $\delta(t)$ is the error term.

B. APPLICATION OF CONVOLUTION NEURAL NETWORK IN CLASSIFICATION OF BRIDGE CRACKS

Concrete cracking has become one of the important factors affecting the service life of engineering structures.There are many kinds of cracks in concrete structure, the cause of formation is not all different, harmfulness also has significant difference, so the treatment methods of different types of cracks are different.At present, in our country, the bridge crack detection mainly relies on the artificial visual inspection, the dangerous coefficient is very large, in view of this situation, this paper studies a digital and intelligent detection method to improve the safety diagnosis efficiency of bridges and reduce the risk coefficients.

Concrete structure bridge in the use of the process will produce longitudinal, transverse, oblique, vertical, horizontal, surface, deep or through the various types of cracks.The depth, location and direction of fractures vary with the cause, the width, depth and length of the cracks are different, no regularity, and some are closed or enlarged by the influence of temperature and humidity changes.

Crack repair methods, according to the specific circumstances, for the structural bearing capacity of the general small cracks have no effect, can be cleaned after the crack, with epoxy slurry grouting or surface brushing closed;If the crack cracking is large, the eight groove should be drilled along the crack, and the 1:2 or 1:2.5 cement mortar shall be wiped after washing, or be embedded with epoxy clay; Because of the temperature, drying shrinkage, creep and other structural changes caused by the cracks, the impact on the structure of the bearing capacity is small, the use of epoxy mortar or anti-corrosion paint to brush the crack parts, or add a glass cloth for surface closure treatment; For structural cracks with structural integrity and waterproof and seepage control requirements, the cracks should be repaired by cement pressure grouting or chemical grouting in accordance with the crack width and depth, and used simultaneously in the surface sealing and grouting; Serious cracks will obviously reduce structural stiffness, should be based on the situation of prestressed reinforcement or reinforced concrete enclosures, steel sets or structural adhesives bonded steel plate reinforcement and other methods.Therefore, this paper divides the bridge cracks into three categories: small cracks, large cracks, serious cracks, using MATLAB to enhance the image, denoising, and segmentation, and then using convolution neural network model to classify the types of fractures.

1) IMAGE PREPROCESSING

a: IMAGE ENHANCEMENT

Image enhancement can be divided into two main categories: frequency domain method and space domain method.The former regards the image as a two-dimensional signal, and carries on the signal enhancement based on the two-dimensional Fourier transform.The use of Low-pass filtering (that is, only low-frequency signal through) method, can remove the noise in the diagram, using high pass filtering method, can enhance the edge and other high-frequency signals, so that blurred picture becomes clear. The representative algorithm in the latter space domain method has the local average value method and median filter (the median pixel value in the local neighborhood) method, etc., which can be used to remove or weaken the noise.

The method of image enhancement is to attach some information to the original image or transform the data by some means, selectively highlight the features of interest in the image or suppress (conceal) some unwanted features in the image, so that the image and the visual response characteristics match.In the process of image enhancement, it is not necessary to analyze the reason of image quality reduction, and the processed image does not necessarily approximate the original image. The image enhancement technology can be divided into two kinds, which are based on spatial domain and the algorithm based on frequency field, according to the different space of the enhanced processing process.Based on the spatial algorithm processing, the image gray level is directly calculated, and the algorithm based on frequency domain is a kind of indirect enhancement algorithm, which modifies the image transformation coefficient in some transformation domain of the image.

This paper uses piecewise linear function to increase the contrast of picture:

$$f(x,y)=\begin{cases}\dfrac{g(x,y)}{k}, & g(x,y)<x_1;\\ k\left[g(x,y)-x_1\right]+\dfrac{x_1}{k}, & x_1\le g(x,y)\le x_2;\\ \dfrac{g(x,y)+225(k-1)}{k}, & g(x,y)>x_2.\end{cases} \tag{11}$$

In the formula: *f(x,y)* is the gray value of the output point, *g (x,y)* is the gray value of the input point, and the *x1,x2* is the turning point of the 2 horizontal axis; k value determines the slope of the interval function of several sections of transformation.

Using MATLAB2016a system to gray image processing results as shown.

b: WAVELET IMAGE DENOISING

Image denoising refers to the process of reducing noise in digital images called Image denoising.Digital image in the digital and transmission process is often affected by imaging equipment and external environmental noise interference, called noisy image or noise image. This method preserves most of the wavelet coefficients which contain the signal,

FIGURE 7. The original image of the crack.

FIGURE 8. Gray image.

so it can maintain the image details better by using wavelet denoising.

There are 3 steps for image denoising in wavelet analysis: wavelet decomposition of image signals, quantification of the high frequency coefficients after layered decomposition, and the use of two-dimensional wavelet reconstruction image signal noise is an important cause of image jamming. There may be a wide range of noise in the actual application of a picture, which may occur in the transmission or in the process of quantification.

The denoising process in this paper is divided into the following steps:

STEP1: Wavelet transform

A real value function is scaled on a scale and the physical translation on the time axis is obtained, which can be used to identify an effective signal in each frequency by means of a wavelet transform [10].

The basic wavelet satisfies the condition that the integral is 0, namely

$$\int_{-\infty}^{+\infty} \Psi(t)dt = 0 \tag{12}$$

Its spectrum satisfies the condition

$$C_\Psi = \int_{-\infty}^{+\infty} \frac{|\Psi(s)|^2}{s} ds < 0 \tag{13}$$

That is, the basic wavelet decreases continuously in frequency domain.

STEP2: Basic function of one-dimensional continuous wavelets

The basic wavelet constructs the wavelet base function by the scale factor and the displacement factor, namely

$$\Psi_{a,b}(x) = \frac{1}{\sqrt{a}} \Psi_{a,b}\left(\frac{x-b}{a}\right) \tag{14}$$

Where $\Psi(x)$ is called Basic wavelet, a is a parameter, b is the displacement parameter.

STEP3: One-dimensional continuous wavelet transform

One-dimensional continuous wavelet transform, also known as Integral Wavelets, is

$$\begin{aligned} w_f(a,b) &= \left(f, \Psi_{a,b}(x)\right) = \int_{-\infty}^{+\infty} f(x)\Psi_{a,b}(x)\,dt \\ &= \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(x)\Psi_{a,b}\left(\frac{x-b}{a}\right) dx \end{aligned} \tag{15}$$

When a is larger, the lower the frequency of the analysis, the more likely it is to observe the smooth part of the image, whereas the more likely the details of the image are observed.

STEP4: Two-dimensional continuous wavelet basic function

$$\Psi_{a,b_x,b_y}(x,y) = \frac{1}{|a|}\Psi\left(\frac{x-b}{a}, \frac{y-b}{b}\right) \tag{16}$$

STEP5: Two-dimensional continuous wavelet transform

$$W_f\left(a,b_x,b_y\right) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)\Psi_{a,b_x,b_y}(x,y)\,dxdy \tag{17}$$

Wavelet transform can be regarded as a kind of filter, when the first layer of filter is finished, the output of each filter can be filtered again, and through the appropriate telescopic transformation will be combined together to form a small wave transformation filter family, namely

$$\begin{aligned} f(x) &= \frac{1}{C_\Psi}\int_0^{+\infty}\int_0^{+\infty}\left(f^*\tilde{\Psi}_a\right)(b)\,\Psi_a(b-x)\frac{da}{a^2} \\ &= \frac{1}{C_\Psi}\int_0^{+\infty}\left(f^*\tilde{\Psi}_a\Psi_a\right)(x)\frac{da}{a^2} \end{aligned} \tag{18}$$

FIG. 9 depicts the analysis of a wavelet transform filter family [14] for a signal.

The results of wavelet denoising for the original fracture image are shown by using MATLAB2016a system.

c: IMAGE SEGMENTATION

Image segmentation is the technology and process of dividing the image into several specific areas with unique characteristics and making interesting targets.It is a key step from image processing to image analysis.The existing image segmentation methods are mainly divided into the following categories: Thresholding based segmentation, region based segmentation, Edge based segmentation and segmentation based on specific theory.Image segmentation is an important

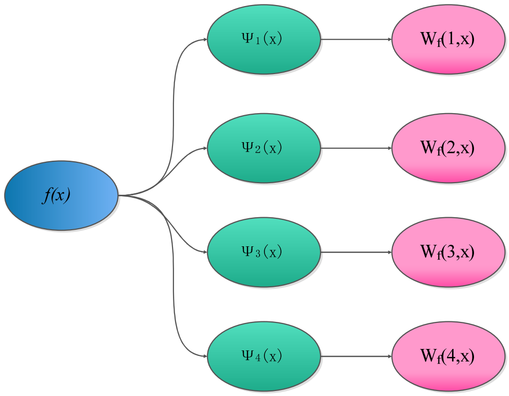

FIGURE 9. Wavelet transform filter family analysis diagram of signal.

FIGURE 10. Denoising figure.

preprocessing of image recognition and computer vision. Without proper segmentation, it is impossible to identify correctly. However, the only basis for segmentation is the brightness and color of pixels in the image, when the computer automatically processing segmentation, will encounter various difficulties. For example, the uneven illumination, the influence of noise, the unclear parts in the image, and the shadow, etc., often occur segmentation errors.

Gray threshold Segmentation is one of the most commonly used parallel region techniques, which is the most widely used in image segmentation. The threshold segmentation method is actually the following transformation of the input image f to the output image g:

where T is the threshold value for the object's image Element $g(i,j) = 1$, for the background of the image element $g(i,j) = 0$.

This shows that the key to the threshold segmentation algorithm is to determine the threshold value, if you can determine a suitable threshold can be accurately separated image. After the threshold is determined, the threshold is compared with the gray value of pixel, and the pixel segmentation can be carried out in parallel to each pixel, and the result of segmentation is given directly to the image region.

The advantage of threshold segmentation is simple calculation, high operation efficiency and fast speed. It is widely used in applications where the efficiency of operation is emphasized, such as for hardware implementation.

The selection of thresholds needs to be determined according to specific problems, which are generally determined by experiments. For a given image, the best threshold can be determined by analyzing the histogram, for example, when the histogram is apparent Shuangfeng, the midpoint of two peaks can be chosen as the optimal threshold value.

In this paper, the threshold value of the two-value processing of bridge crack image is OTSU algorithm, and the image has an L-gray level. The number of pixels with the gray value of I is n, the frequency of each gray pixel is p, and the image is divided into 2 parts by the threshold T (foreground a and background b), the frequency of which appears is P_a and P_b respectively, then the Gray mean of the former and background is

$$W_a = \sum_{i=0}^{T_1} ip_i/p_a \tag{19}$$

$$W_a = \sum_{i=T_i+1}^{L-1} ip_i/p_b \tag{20}$$

The gray mean of the image is

$$W_0 = P_a W_a + P_b W_b = \sum_{i=0}^{L-1} ip_i \tag{21}$$

The variance between the classes of foreground and background is

$$\delta^2 = P_a (W_a - W_0)^2 + P_b (W_b - W_0)^2 \tag{22}$$

$$T_1^* = \arg\max \left[P_a (W_a - W_0)^2 + P_b (W_b - W_0)^2 \right] \tag{23}$$

The results of the segmentation of the original fracture image are shown by using the MATLAB2016a system.

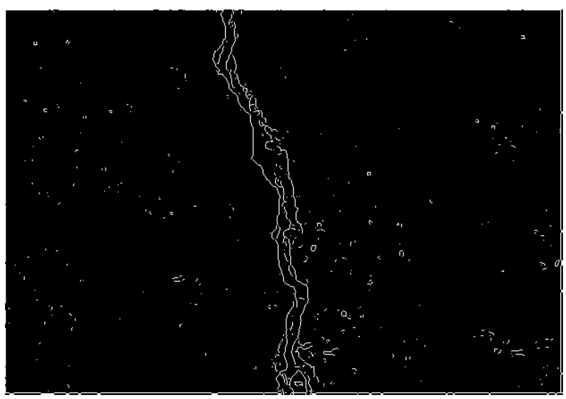

FIGURE 11. Segmented image.

2) THE ESTABLISHMENT OF CONVOLUTION NEURAL NETWORK MODEL

The establishment of the convolution neural network model is as follows:

STEP1: Image preprocessing;

STEP2: Set up convolution neural network model;

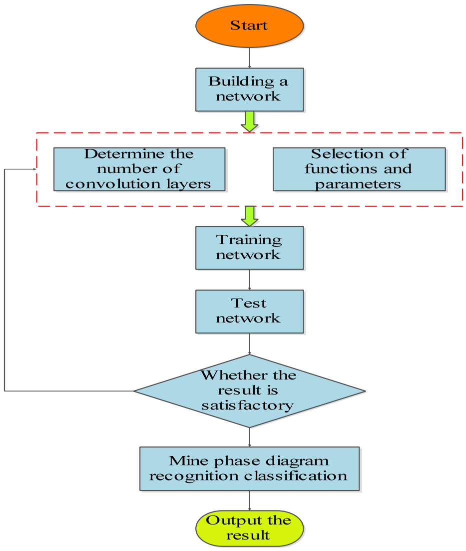

FIGURE 12. Mine phase diagram recognition classification model.

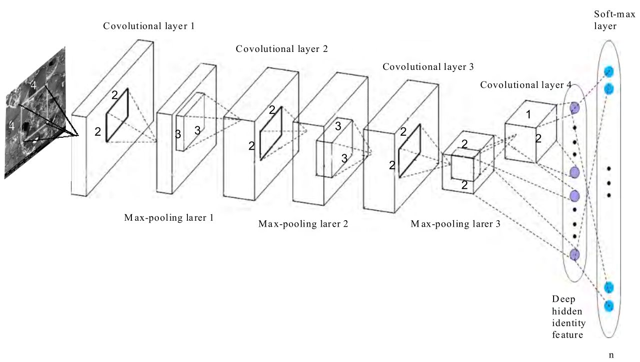

FIGURE 13. CNN network structure diagram.

STEP3: Select the convolution kernel function and convolution parameter according to the size of the input picture, and determine the convolution layer;

STEP4: 200 groups of input networks were randomly selected from three types of images for training;

STEP5: The remaining 100 groups of pictures in each type of image input network to identify the classification of mine facies map. If the test results are satisfactory continue to STEP6. otherwise return STEP3, modify parameters;

STEP6: Output classification Results.

The convolution layer of the network structure contains 3 feature graphs, and the convolution kernel size is 5*5. The output result is 3 classes.

Before training the sample, you need to adjust the processed fracture picture to 32*32 pixel size and convert it to a two-dimensional matrix. Its structure is shown in the figure.

3) EXAMPLE ANALYSIS

According to the bridge cracks, the image samples are divided into three categories: small cracks, large cracks and severe cracks, each of which has 300 images.200 images were randomly selected as input layers after image preprocessing. The above convolution neural network model was used for training. The pixel was 32*32*3, and the convolution kernel was 5*5*3. Using the remaining 100 images as test samples, the system updates the weights every 30 samples. Through repeated tests, it is found that when the average time of a single iteration is 7 s and 200 iterations, the mean square error is less than 0.1, as shown in the FIG. 14. At this point, the accuracy of model classification is more than 90%, and the training results are better.

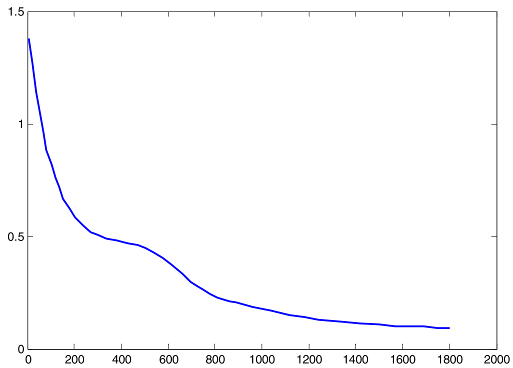

FIGURE 14. Graph of the relationship between the number of iterations and the mean square error.

The simulation results show that the overall correct rate is greater than 90%, and the experimental results are shown in table 1.

TABLE 1. Statistical table of fracture classification.

Type of fracture	Small cracks	Larger cracks	Serious cracks
Total number	100	100	100
Correct classificat	92	95	90
Correct rate/%	92%	95%	90%

V. CONCLUSION

Based on the characteristics of the structure of the Internet of Things and the structural characteristics of the bridge engineering, this paper analyzed the practical application value of the Internet of Things technology in the crack identification of bridge structures, and established a crack classification application system for bridge structures based on the Internet of Things technology. Aiming at the current situation that the bridge crack detection mainly relied on artificial visual inspection and the risk factor was extremely backward, a digital and intelligent detection method was studied to improve the efficiency of bridge safety diagnosis and reduced the risk factor. Firstly, image enhancement, wavelet denoising, image segmentation and other pretreatments were performed on the collected bridge crack images. Then a classification model of the bridge crack convolution neural network was established. The model of the processed image was modeled using MATLAB 2016a, and the classification of bridge cracks was obtained. According to the actual detection, the mean square error of the model was less than 0.1, and the overall accuracy rate was greater than 90%. This verifies the feasibility and effectiveness of the scheme. This method could effectively solve the problems of low fracture diagnosis efficiency and high risk factor in domestic fractures. Bridge safety inspections are moving toward automation and intelligence.

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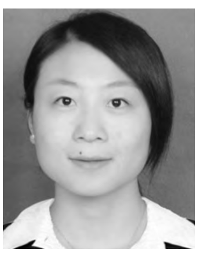

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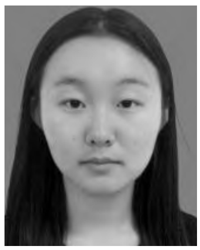

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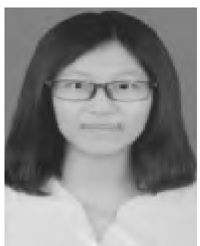

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