An Algorithm to Detect the Crack in the Tunnel Based on the Image Processing

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Received 7 October 2014; Revised 20 October 2014; Accepted 23 October 2014

Abstract. The safety is very important for urban rail transit. So it is the necessary to detect the crack of subway tunnel to keep the secure of the line. In traditional way, relevant staffs are asked to go into the tunnel to detect the crack by naked eye. But this method is too inefficiency to meet the actual demand. In this paper, we propose an algorithm to detect the crack based on the image processing. Compared with other algorithm, this algorithm simplifies the image preprocessing procedure, and use the block binaryzation to replace the traditional method of binaryzation. Then extraneous noisy pixels are removed from the image according to the differences of characteristics between noise and crack. Finally, crack can be detected automatically.

Keywords: crack detection; image processing; noise removal

1 Introduction

In recent years, network of subway in Beijing has been rapidly developed. A large number of infrastructure in the tunnel has been used for a long time, and should be maintained. The crack in the tunnel is related to the stability of tunnel structure, which has huge influence on the safety of the rail transit. So it is extremely important to detect and maintain the crack on the tunnel.

At present, urban rail transition in China is still mainly dominated by artificial checking. But taking the safety of explorers into consideration, the testing work are always in the night. So this method will result in a low efficiency and security. Meanwhile, the line is too long to get the whole status in a short time, so it is apparently that the studies of automatic crack detection technology is especially important.

The image processing is the most common method to detect crack in an automatic way. It is mainly divided into two modules, module of image acquisition and module of crack identification module. Currently the image acquisition techniques have been completed. Linearity CCD camera has a high-frequency data collection. When exposed to a proper light, it can get a clear picture of subway tunnel. But the module of crack identification requires appropriate crack identification algorithm, which is not mature. This article mainly makes an analysis on images of the real subway tunnels taken by CCD cameras. And on the basis of previous studies, we propose an automatic recognition algorithm of the subway tunnel cracks which can be applied to a complex background.

2 Related Work

In China, there are many researches on the crack detection of highway, and some achievements have been made. XU ZH G and ZHAO X M put forward an asphalt pavement crack recognition algorithm based on histogram estimation and shape analysis [1]. YAN M D and BO SH B put forward a method of image detection and analysis for pavement crack based on morphology [2]. ZHANG J, SHA AI M, put forward a pavement crack automatic recognition method based on phase-grouping method [3]. ZHANG L, WU JA, put forward a method for natural fractures identification based on rough sets theory and BP neural network [4]. The studies of crack detection were started early in foreign countries, in which the crack detection of highway systems were developed and put into use. For example, the Komatsu System [5] in Japan, the PAVUE System [6] in England, the Wisecrax System [7] in Canada

The researches on tunnel crack detection in China are still in its initial stage, Liu Xiaorui and Xie Xiong of the Tongji University put forward a detection device of tunnel surface cracks based on image processing [8]. Japan and South Korea are at the leading position in the research of crack detection in tunnel. Researchers in South Korea, propose an automatic monitoring system to detect crack in tunnel based on the platform of mobile robot. In module of crack detection, they used the edge enhancement and graph searching technology to extraction the crack on the image. Researchers in Japan developed a vehicle to detect the crack in highway tunnel. The method they used is also based on image processing [9].

In recent years, for the safety of the subway or other transport facilities, more researchers begin to focus their study on the tunnel crack detection, and many achievements have been made. Zhiwei Liu, Shahrel S A. Suandi proposed an efficient tunnel crack detection and recognition method [10]. This method combines the analysis of crack intensity feature and the application of Support Vector Machine algorithm. Miwa M, Huynh Quang Huy Viet use the scale-space stability of valley line to detect tunnel crack [11]. They use watercourse method to get the valley lines. Since the pixel intensity of the crack is very low compared to its surroundings, its generated valley line does not move when the watercourse method is applied at various scales of the image. By measuring the stability of a valley line, crack can be distinguish from other valley lines. Systems used to detect the crack in the tunnel are also be designed. Lee S Y, Lee S H, y propose an inspection system for the rapid measurement of cracks in tunnel linings and provides an objective method for assessing crack data [12]. The system consists of both image data acquisition and analysis systems. The acquisition system is composed of optical components (line-scan cameras) and mechanical components and includes a data storage device that obtains an image of the inner face of the tunnel wall. The system can be considered as a kind of multimedia system. Many problems should be solved in the transmission and storage. Chi-Yuan proposes an algorithm which can improve the safety of the system [13]. The strategy mentioned in the paper written by Liang Zhou can make full use of network resource [14]. C.C.Lin put forward an effective algorithm to transmit multimedia data with minimal cost [15]. Wireless technology (802.11e) can also be used in the system [16].

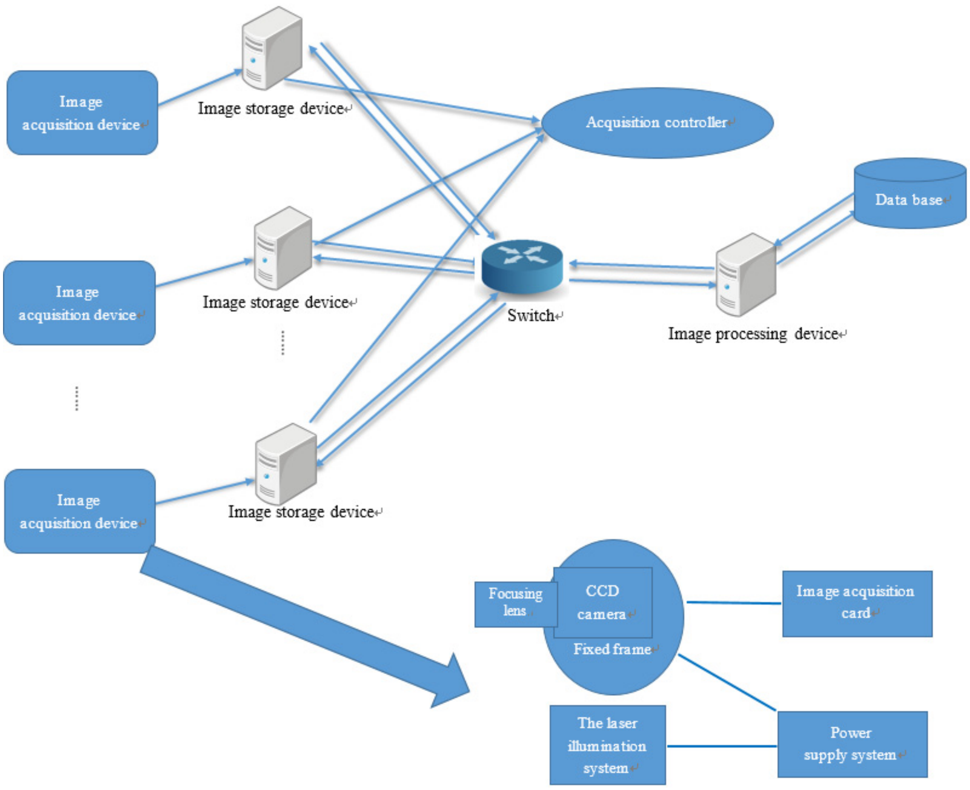

Fig. 1. Image acquisition system

3 The Crack Identification System

According to the actual application requirement, we design a crack identification system which is suit for the tunnel monitoring. This system is combined by three parts—image acquisition system, image storage system and image processing system. All of them are installed on a carriage of a subway train. Fig. 1 shows the structure of this system, and Fig. 2 shows the facilities of this system.

Image acquisition system is used to acquire the tunnel surface image. The most important device in this part is linear CCD camera. As introduced in the Section 1, the linear CCD camera can get distinct image even in high speed. In order to cover the whole surface in the tunnel, nine cameras are used. Each camera is responsible for a part of the surface, and picture that the neighbor camera take has an overlap area. Laser is chose to be the light source because its light has high intensity and low attenuation. We also make a controller to ensure all the camera can start collecting image at the same time. Cameras and laser source are placed on a specially made iron rack. In order to take distinct image, the laser should be in the same line with the area the linear CCD camera take. So the position of cameras and laser source should be fine-tuned. The specially made iron rack can achieve this function.

Image storage system is included by nine server, each of which is equipped with RAID (Redundant Arrays of independent Disks). The resolution of the CCD camera we chose is 12288. The maximum speed of the subway train can reach 30km/h and the minimum speed can be 15km/h. So the amount of data produced per second can reach 400M or more. The write speed of ordinary hard disk is 60M/s to 100M/s. Image date will be discard if ordinary hard disk is used. So the RAID is be applied. One server is in charge of one camera to avoid the loss of data.

Image processing system is included by one server and one switch. The nine storage servers(s-server) are connected with the processing server (p-server) by switch. All the s-server are installed the crack automatic recognition software. P-server can log on remotely to the s-servers to control them to run this software.

(a) (b)

Fig. 2. (a) is the image acquisition system, including laser source and CCD camera. (b) is all the server used in image storage system and image processing system

4. Research on the Algorithm

The crack automatic recognition software is based on the crack recognition algorithm. After testing, we found that most of the algorithm mentioned in section 2 is not suitable for the tunnel image. In order to highlight the feature of crack, they use the combination of various pretreatment methods to wipe off the noise on the image. Then crack can be easily detected. But in the image they provided, there are no pipe, wire and other infrastructure. So if we use their methods to detect the crack in the subway tunnel without improvement, the crack can't be detected because of the interference mentioned before. So after preprocessing, we propose three important features to distinguish the crack from other noise on the tunnel image.

4.1 Difficulties in Crack Detection

By observing the captured image (Figure.3), we can find some features of the subway tunnel images. One, the crack is very thin compare to other objects on the image, so the information of the crack is a small fraction of this image. Second, there are pipes, wire and other infrastructure whose grey level is higher than the crack's, so it is difficult to highlight the crack. Because of the difficulties mentioned above, two important problems should be solved in the process of crack recognition. First, we must highlight the crack and reduce the noise to the greatest extent a in the image preprocessing. Second, we must find obvious characteristics to distinguish the crack and non-crack after image preprocessing.

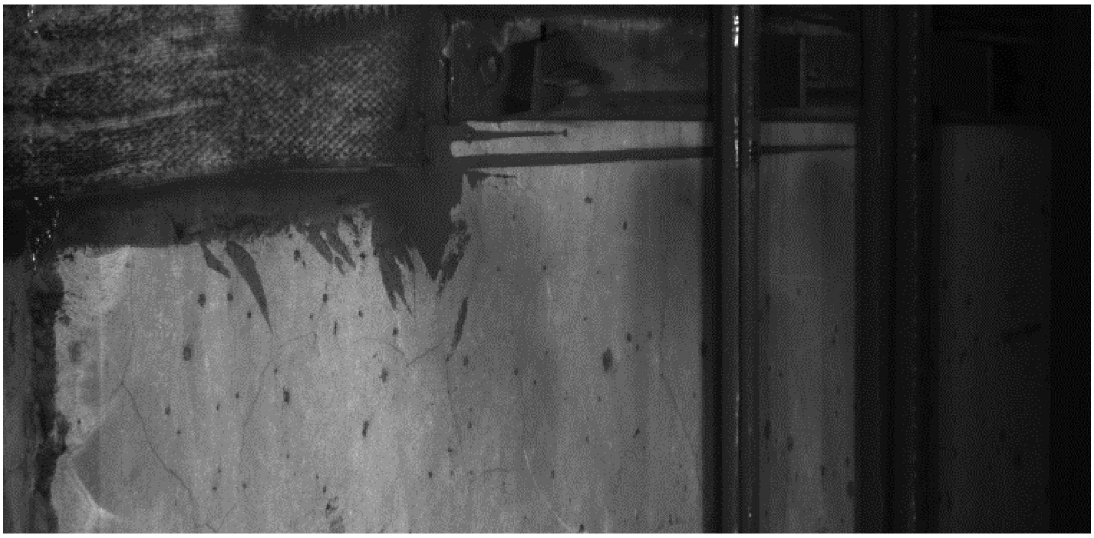

Fig. 3. Original image of the tunnel

4.2 Procedure of the New Algorithm

Fig. 4 is the procedure of the new algorithm. Details of every step will discussed as follow.

Fig. 4. Procedure of the new algorithm

4.3 Image Preprocessing

The image preprocessing procedure is included by three steps. Histogram Tula stretching, median filter and Top-hat. By pretreatment, random noise caused by camera (such as slight jitter) can be removed, and the contrast can be increased.

Histogram Tula stretching method proposed by Liu Xiaorui is used in this algorithm. Formula are as followed:

$$g(x,y)=\begin{cases}0, & f(x,y)<a\\ 255, & f(x,y)>b\\ 255\times\dfrac{f(x,y)-a}{b-a}, & a\le f(x,y)\le b\end{cases} \quad (1)$$

g(x,y) stands for the image after the change. f(x,y) stands for the original image. a, b are the thresholds. The gray value less than a is determined to a black pixel. The gray value great than b is determined to a white pixel. The gray value between them is determined to make equalization.

Fig. 5 is the result after the preprocessing. Compared with the contrast in original image, contrast in the result has been significantly enhanced.

Fig. 5. the image after Histogram Tula stretching

Median filtering is a kind of nonlinear processing technology that can remove salt and pepper noise effectively. Fig. 6 shows the binary images obtained from the image without stretching and filtering and the image with stretching and filtering. Obviously, a lot of useless information on the image is removed after filtering. So it is necessary to use the stretching and median filtering to do the image processing.

Top-hat transform is a kind of morphological operators. In Hands-on Morphological Image Processing written by Dougherty and Lotufo [17], details of the morphological operators can be found. Local minimum gray-levels can be extracted using Top-hat transform. So, dark cracks can be separated from the original image.

$$F = I \bullet s - I \tag{2}$$

F is the final image. *I* stands for the gray-scale image. *s* is the structuring element. ● is the closing operation in morphological.

4.4 Block Binarization

Gray value of crack is lower than a crack gray value of background. So they can be separated by binarization.

Otsu method is a widely used method to make binarization. By calculating the inter-class variance between the background and objectives, we can separate the two areas. However, there are two problems that can't be ignored if this method is used.

- The information of the crack is a small fraction of this image. And some grey values of background are similar to the crack. So, it is difficult to distinguish the crack between the backgrounds.
- The inter-class variance between the background and crack is seriously affected by the barbed wire, pipes and other facilities in the image.

In order to solve these problems, we use the block binarization. First calculate average value f of the M*M adjacent pixels value surrounded with a pixel. Then set a threshold Δ.

$$g(x,y) = \begin{cases} 0, & f(x,y) < f - \Delta \\ 255, & f(x,y) \geq f - \Delta \end{cases} \tag{3}$$

g(x,y) stands for the image after the change. f(x,y) stands for the original image.

The result of block binarization is related to two aspects: the size M of the neighborhood and the threshold Δ. Figure 7 is the result image with different value of M and Δ. In this way, the background and crack are separated effectively and impact of the facility are reduced.

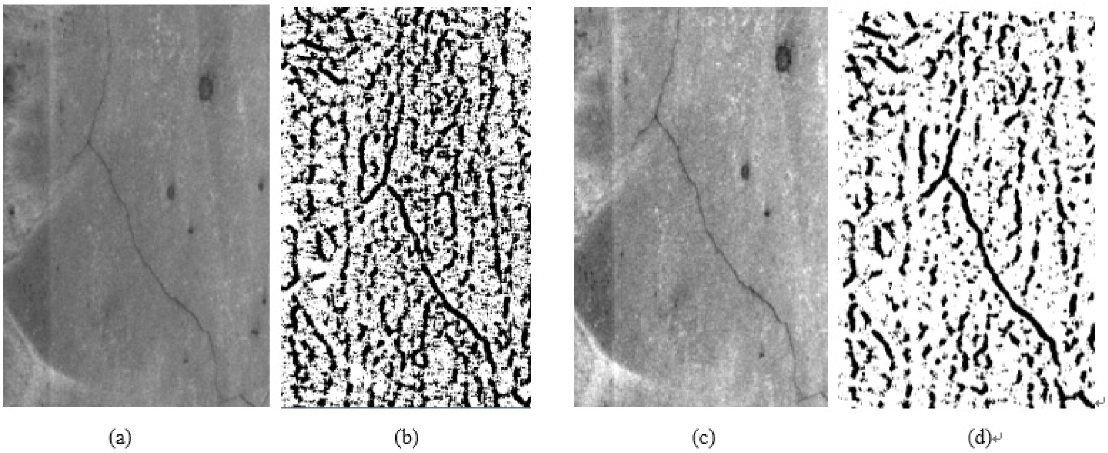

Fig. 6. (a) is the original image. (b) is the binary image obtained from (a). (c) is the image after stretching and filtering. (d) is the binary image obtained from (c)

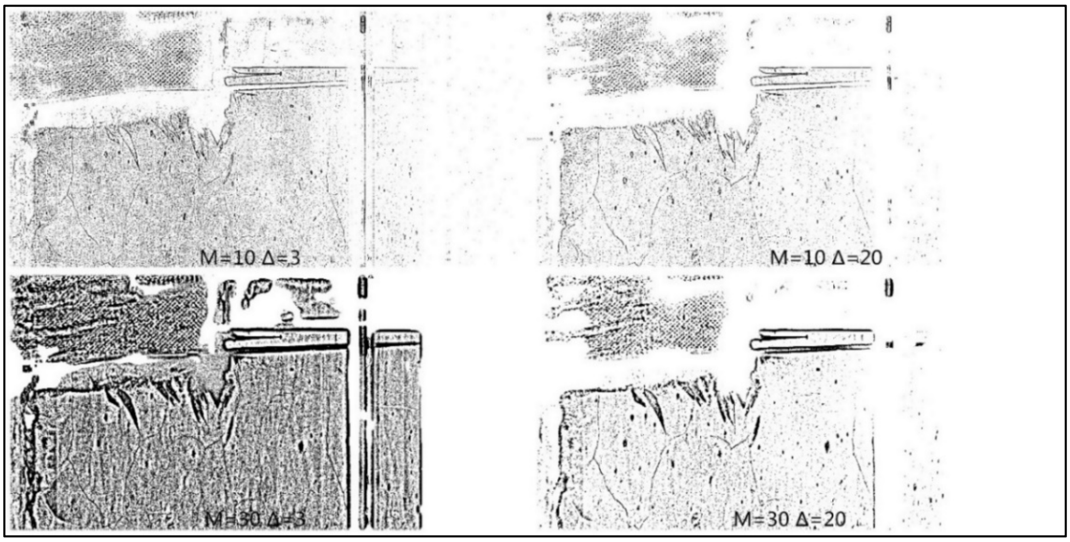

Fig. 7. Image after Block Binarizatiom in different value of M and Δ

4.5 Noise Removal

After block binarization processing, noise in the images can be divided into two categories.

- Speckled noise. Because of the uneven illumination, or the textural features of the tunnel surface, the gray value of some areas is considerably higher than that of crack. These areas often do not have continuity, so after block binarization processing, they become speckled.
- Noise similar to the cracks. The gray value of the pipelines and other facilities is significantly lower than that of the background, and it occupies a much larger proportion than the cracks. After block binarization processing, the disturbance of the internal pixels is removed, and leaves the edge information alone.

The first step of noise removal is looking for connected interval in the image and number them. The connected interval is a collection of black pixels. For the two kinds of disturbance mentioned above, we use different methods to remove.

Compared with the characteristic of cracks, speckled noise is not continuous, and the area and the length-width ratio of the connected interval are relatively small. So this kind of noise is easy to remove. In this article we count the black pixels in the connected interval, name it M, and set the threshold T, when $M<T$, remove the connected interval.

The area of the connected interval in noise similar to the cracks is relatively large. This kind of noise has similar morphology with cracks, so it is difficult to use the features of connected interval to remove it. We have to find other features.

Noise similar to the cracks is generally the edge of the pipelines and other facilities. Gray value of these facilities is low and concentrated. So in this algorithm, noise is removed according to this features. Turn the original image to binary image using a thread Δ, and then the gray values of the facilities are turned into zero. The width of the crack generally do not exceed a certain threshold Δw. The connected interval is located in a black area whose width w. If $w > \Delta w$ remove this connected interval.

In order to make the search for the area of the connected interval easier, the image after block binarization is thinned (Fig. 8). Fig. 9 is the final image after removing the useless connected interval.

Fig. 8. Image been thinned

Fig. 9. Final Image

5 Implementation of the Algorithm

According to the algorithm, we wrote a subway tunnel crack identification system (Fig. 10), which includes image demonstration and crack identification. Because there were still some errors in automatic identification in the system, we added artificial determination function, then the false and missing crack images can be modified manually.

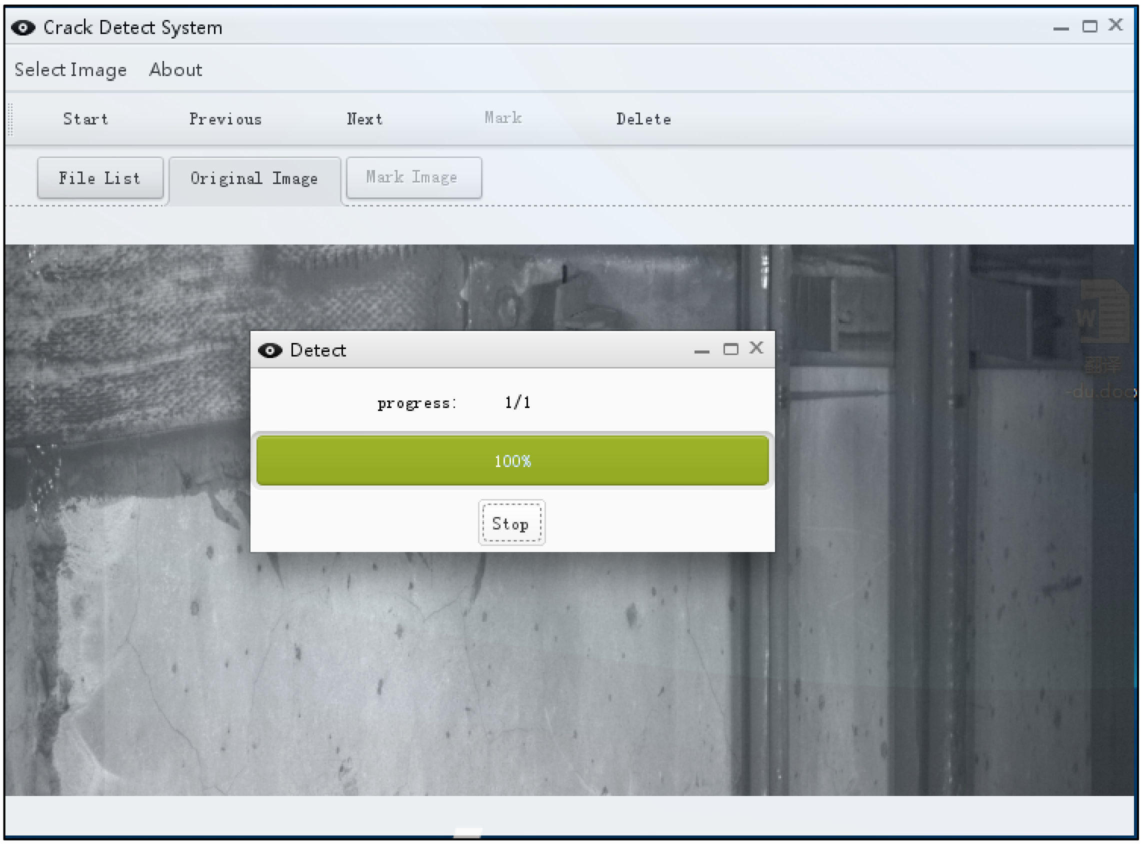

Fig. 10. Crack Detect System

6 Conclusions and future work

This article aim at proposing an automatic recognition algorithm based on image processing in complex tunnel environment. While simplifying the preprocessing of images, the algorithm takes advantages of the binarization thinking, and processes images by the local features, so the cracks can be effectively isolated from the noise. For the two kinds of noise appeared after binarization processing, we have two different approaches to eliminate. To the speckle noise, we can refer to the area of the connected interval, and to the ones similar to the cracks, we can compare them whit the original images. Finally, the crack information can be obtained by the usage of morphological expansion corrosion.

This algorithm is simple, easy to implement, and also have good effect on recognition of cracks.in complex environment of subway tunnels. However, there are still something to be improved in it. For example, the threshold appeared in the processing of binarization and noise removal must be tested for many times, and the algorithm cannot select the threshold by itself according to the characteristics of images.

In the following studies, we can classify the characteristics of images by means of machine learning to achieve the purpose of selecting threshold automatically.

Acknowledgment

This research is supported by National Natural Science Foundation under Grant 61371071, Beijing Natural Science Foundation under Grant 4132057, Beijing Science and Technology Program under Grant Z121100007612003, Academic Discipline and Postgraduate Education Project of Beijing Municipal Commission of Education.

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