A New Method of Subway Tunnel Crack Image Compression Based on ROI and Motion Estimation

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

Abstract. Aiming at the characteristics of the subway tunnel crack images, this paper presents a new method of subway tunnel crack image compression based on region of interest and motion estimation. It contains three key parts: the method of key frame image compression based on Discrete Cosine Transformation, the method of internal frame image compression based on forward predictive coding and motion estimation, the method of lossless image compression based on crack information database and suspected crack regions. The simulation experiment results show that this method can not only enhance the image compression ratio without losing any information of images in the region of interest, but also interface with the existing subway tunnel crack recognition system very well and make good use of the data from the crack recognition system database and the images in the disk array.

Keywords: image compression, ROI, motion estimation, DCT

1 Introduction

In today's world, as an important medium of the multimedia data, images are playing an increasingly important role. With the increase of the social demand and the rapid development of the image technologies, the Image resolution is improving and the data size is larger and larger. Considering the limit of network transmission bandwidth and storage capacity, it is necessary to find new appropriate technologies to compress the image data effectively.

There are many kinds of image compression algorithms. As a general view, they can be mainly divide into two parts: lossy compression and lossless compression. Lossy compression makes use of the feature that people are not sensitive to the images' certain frequency components, so it loses some information that has no use or has little use during the compression process. Although lossy compression can't recover the original data completely, it can bring us dozens of times of the compression ratio. Lossless compression has lower compression ratio, but in many special situations, such as medical image compression, remote sensing image compression, high-precision image analysis, and so on, it is indispensable.

Although there are several methods for compressing the images, there are only a few methods that are suitable for subway tunnel crack image compression. Among several reasons, it is the most important reason that analysts are only interested in the regions of the crack. The size of the pixel region which represents the cracks is much less than the one which represents the background. If only using lossy compression method to compress the whole images, we will lose a lot of important information about the cracks. And the missing part is probably the valuable information that researchers spend a large number of time and money in improving camera resolution to get. If only using lossless compression method to compress the whole images, researchers will get huge data and most of it is the useless data that is represent for background region. Considering that the number of regular tunnel investigations is larger and larger and the whole history data should be stored, the disk arrays have huge storage pressure.

Subway tunnel crack images are different from these ordinary static images. As for ordinary static images, the color makes great changes and the correlation is weak between two pictures. But the correlation between two adjacent pictures among the subway tunnel crack image sequences is strong and the changes of color are not obvious. So we can make good use of the correlation between two adjacent frames in order to improve the coding efficiency.

The proposed method in this paper is on the basis of Beijing Subway Tunnel Crack Recognition System. This crack recognition system can recognize the region which probably exists tunnel cracks easily and fast. This kind of region is called SCR (Suspected Crack Region). This system can also copy the SCR image from original images and store the SCR in the disk arrays for the convenience of retrieving and researching these precious image information in the future. At the same time the system can store the whole information about SCR into the crack information database. These information contains the ID of the SCR, the storage path of the SCR image, the ID of the original image which contains this SCR, the storage path of the original image which contains this SCR, the location where the SCR lies within the original image, and the length and width of this SCR.

This paper presents a new method of subway tunnel crack image compression based on ROI and motion estimation. In this paper, the ROI (Region of Interest) is the same with the SCR (Suspected Crack Region). This method contains three key parts: the method of key frame image compression based on Discrete Cosine Transformation, the method of internal frame image compression based on forward predictive coding and motion estimation, the method of lossless image compression based on crack information database and suspected crack regions. The basic idea for such a method is described below. Firstly, background region images and SCR images should be saved respectively. Secondly, these images are divided into two parts: key frames and internal frames. One group of images contains one key frame and several internal frames. The key frames are compressed via lossy compression method with high compression ratio while the internal ones are compressed via forward predictive compression coding based on motion estimation. Thirdly, the SCR images are compressed via lossless compression method. Finally, the whole images are reconstructed by the combination of information about the cracks, SCR images and background region images. The simulation experiment results show that this method can not only enhance the image compression ratio without losing any information of images in the region of interest, but also interface with the existing subway tunnel crack recognition system very well and make good use of the data from the crack recognition system database and the images in the disk array.

This paper is organized as follows. In Section 2, related work and related technologies will be proposed. Section 3 gives a detailed presentation of this new method. In Section 4, experimental results are reported. Finally, conclusions and some future work are drawn in Section 5.

2 Related Work

Lossy image compression has many technologies, which can be divided into Classical Image Compression and Modern Image Compression Algorithm.

Classical Image Compression contains predictive coding, transform coding, statistics coding and vector quantitation coding. Predictive coding and transform coding are the most commonly used technologies in image coding area. Predictive coding [1] uses adjacent known pixels to predict the values of the present pixels, and then calculates the difference between the present and the predicted to quantize and code the predictive error. DPCM is one of the most important method of predictive coding. The advantages of predictive coding are that its algorithm is very easy, the calculating speed is quick and it's easy to be realized, so it is suitable for the cases of not pursuing imagine quality strictly. The compression coding based on forward predictive coding and motion estimation that we used in this paper is one of the predictive coding. Transform coding [2] converts the given image to frequency domain in order to present a large amount of information using less date. The common used conversion contains discrete Fourier transform (DFT)[3], discrete cosine transform (DCT)[4], discrete wavelet transform(DWT)[5],etc. Among them, DCT and DWT are widely used, which corresponds to JPEG standard and JPEG2000 standard respectively. In recent years, JPEG2000 which is based on DWT [6] has been a research hotspot. Huang Daqing[7]proposed a sub-region image compression algorithm based on the wavelet transform and JPEG2000 for the reconnaissance images of a certain model UAV(Unmanned Aerial Vehicle) · Zhang Leng[8] proposed an integrative optimization algorithm for effective compression display of remote sensing images based on the common JPEG2000 compression frame, and designed preliminarily to the system. It cannot be denied that, the compression performance of JPEG2000 increased 10%—30% compared to JPEG, and JPEG2000 itself supports the region of interest coding. However, Feng Chao[9]pointed out that the algorithm complexity of JPEG2000 is higher than JPEG whose technology is pretty mature, and every model in the system is much more complicated and time-consuming so it is not beneficial to the hardware and software implementation.

Modern Image Compression Algorithm mainly has fractal image coding, model based coding and segmented image coding, etc. Fractal image coding [10] is developed on the basis of fractal geometry. But fractal image has higher code efficiency only to the images with obvious self-similarity or statistical self-similarity, while it has not good effect to the images without these characteristics. The basic idea of model based coding [11] is that in the transmit side, extract compact and necessary description information using image analysis module to get some model parameter with not large amount of data and in the receive side, reconstruct original image and synthesize imagine information using image synthesis module. Model based coding of current research has much distortion [12] and it's not suitable to our research which is about subway tunnel crack image compression. Compressive sensing [13] is an image compression method with hot research, whose core idea is merging compression and sampling. Firstly, gathering the non-adaptive linear projection (measured value) of signal. Then reconstructing original signal in according with the related reconstructing algorithm. However, it is difficult to find suitable sparse matrix and the compressed sensing to equipment needs too much computation [14].

Common lossless compression format has BMP and PNG. BMP uses bit-mapped storage format but compression, so it occupies a large space. PNG uses derived algorithm of LZ77 algorithm to compress, so the result is to get higher compression ratio and don't lose data. Cabrita [15] proposed a PNG optimization algorithm to make the PNG compression format is more suitable to network transmission.

In addition, image transmission can be considered as an important part of image compression system. Chi-Yuan Chen [16] proposed a transaction pattern based anomaly detection algorithm and Liang Zhou [17] presented a joint forensics-scheduling strategy. These two method can improve the safety of the image transmission system. And C.C.Lin [18] put forward an effective algorithm to transmit multimedia data with minimal cost. Besides, wireless technology (IEEE 802.11e) can also be used [19].

Based on the analysis above, this paper will adopt mature and quick JPEG compression method which is based on DCT to compress key background image, use H.261 interframe coding of video coding which is based on forward predictive coding based on motion estimation to compress non-important internal frames, and use PNG which has relatively high compression ratio among lossless compression methods to compress suspected crack region.

3 A New Image Compression Method

Before introducing the image compression method proposed in this paper, this paper make a brief introduction about its application scene. It is used in Beijing Subway Tunnel Crack Recognition System. The structure diagram of this recognition system are shown in Fig.1.

As shown in Fig.1, the system consists of several parts: camera module, laser module, subway tunnel crack recognition system, storage module and image compression module. Subway tunnel crack recognition system consists of several parts: image acquisition, histogram tula stretching, median filtering, top-hat transform, block binarization and noise removal. As for the storage module, suspected crack region images are stored independently in order to retrive the most important information and analyze them fast and conveniently. Meanwhile, it plays an important role in back-uping the most important data. Image compression module is the main content of this paper.

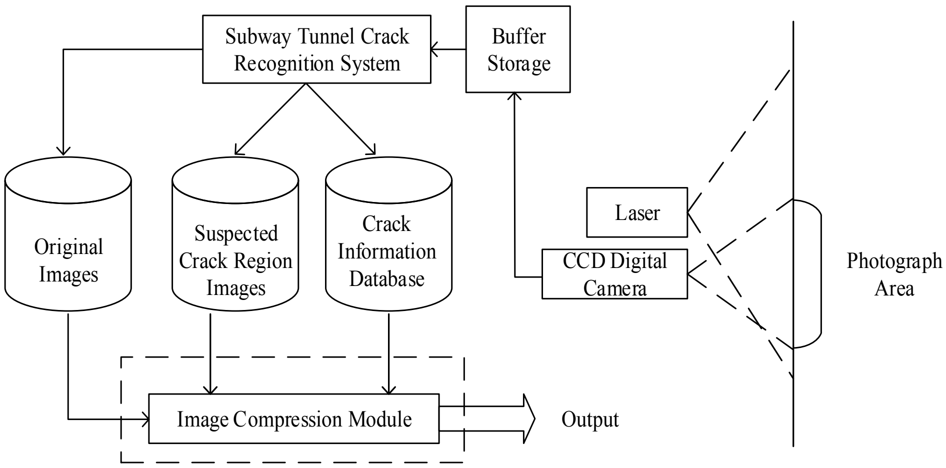


Fig. 1. Structure diagram of subway tunnel crack recognition system

Three sequential subway tunnel images are shown in Fig.2. As shown in Fig.2, the similarity and correlation of adjacent image is very high. So, we can adopt video compression method to compress internal frames.

As shown in Fig.3, background images are divided into two parts: key frame (K-frame) and internal frame (I-frame). K-frame will be compressed based on DCT while I-frames will be compressed via the method of forward predictive coding based on motion estimation. In this system, the speed is about 10m/s when the CCD camera captures images. And every frame represents about 30cm. So, there are approximately 30 frames every one second. After calculation, every 15 images are called one group. Every group has one K-frame and 14 I-frames.

3.1 Key Frame Image Compression Based on Discrete Cosine Transformation

DCT (Discrete Cosine Transform) is an orthogonal transformation method like discrete Fourier transform. Here are some advantages of DCT.

- It converts the 8*8 image data to frequency domain in order to present a large amount of information using less date.
- The coefficients of DCT are easy to be quantized.
- The speed of DCT is high.
- The decoding process is simple. It just uses IDCT.

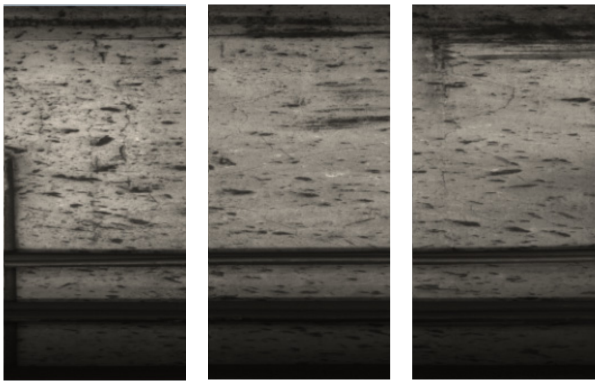


Fig. 2. Image sequence in the subway tunnel

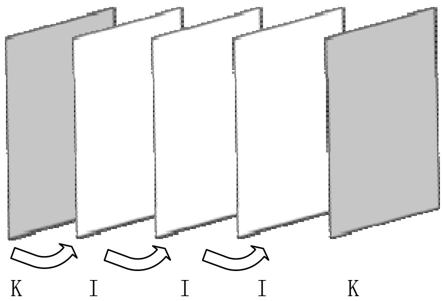


Fig. 3. Structure of K-frames and I-frames in image sequence

In this paper, 2D-DCT is adopted as follows:

$$F(u,v)=\sqrt{\frac{2}{N}}c(v)\sum_{y=0}^{N-1}\sqrt{\frac{2}{M}}c(u)\left[\sum_{x=0}^{M-1}f(x,y)\frac{\cos(2x+1)u\pi}{2M}\frac{\cos(2y+1)v\pi}{2N}\right] \quad \textbf{(1)}$$

where

$$u=0,1,2,\cdots,M-1 \qquad v=0,1,2,\cdots,N-1 \quad \textbf{(2)}$$

$$c(u)=\begin{cases}\frac{\sqrt{2}}{2}, & u=0\\ 1, & u=1,2,\cdots,M-1\end{cases} \qquad c(v)=\begin{cases}\frac{\sqrt{2}}{2}, & v=0\\ 1, & v=1,2,\cdots,N-1\end{cases} \quad \textbf{(3)}$$

f(x,y) stands for the data of M*N pixels and F(u,v) stands for the data after DCT.

2D-IDCT is adopted as follows:

$$f(x,y)=\frac{2}{\sqrt{MN}}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}c(u)c(v)F(u,v)\frac{\cos(2x+1)u\pi}{2M}\frac{\cos(2y+1)v\pi}{2N} \quad \textbf{(4)}$$

Meanwhile, 2D-DCT can be represented as shown below.

$$F(u,v)=\sqrt{\frac{2}{N}}c(v)\sum_{y=0}^{N-1}\sqrt{\frac{2}{M}}c(u)\left[\sum_{x=0}^{M-1}f(x,y)\frac{\cos(2x+1)u\pi}{2M}\frac{\cos(2y+1)v\pi}{2N}\right] \quad \textbf{(5)}$$

If D stands for DCT, 2D-DCT can be represented as shown below.

$$F=DfD^{T} \quad \textbf{(6)}$$

where

$$D_8=\frac{1}{2}\begin{bmatrix}
\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
\cos\frac{\pi}{16} & \cos\frac{3\pi}{16} & \cos\frac{5\pi}{16} & \cos\frac{7\pi}{16} & -\cos\frac{7\pi}{16} & -\cos\frac{5\pi}{16} & -\cos\frac{3\pi}{16} & -\cos\frac{\pi}{16} \\
\cos\frac{2\pi}{16} & \cos\frac{6\pi}{16} & -\cos\frac{6\pi}{16} & -\cos\frac{2\pi}{16} & -\cos\frac{2\pi}{16} & -\cos\frac{6\pi}{16} & \cos\frac{6\pi}{16} & \cos\frac{2\pi}{16} \\
\cos\frac{3\pi}{16} & -\cos\frac{7\pi}{16} & -\cos\frac{\pi}{16} & -\cos\frac{5\pi}{16} & \cos\frac{5\pi}{16} & \cos\frac{\pi}{16} & \cos\frac{7\pi}{16} & -\cos\frac{3\pi}{16} \\
\cos\frac{4\pi}{16} & -\cos\frac{4\pi}{16} & -\cos\frac{4\pi}{16} & \cos\frac{4\pi}{16} & \cos\frac{4\pi}{16} & -\cos\frac{4\pi}{16} & -\cos\frac{4\pi}{16} & \cos\frac{4\pi}{16} \\
\cos\frac{5\pi}{16} & -\cos\frac{\pi}{16} & \cos\frac{7\pi}{16} & \cos\frac{3\pi}{16} & -\cos\frac{3\pi}{16} & -\cos\frac{7\pi}{16} & \cos\frac{\pi}{16} & -\cos\frac{5\pi}{16} \\
\cos\frac{6\pi}{16} & -\cos\frac{2\pi}{16} & \cos\frac{2\pi}{16} & -\cos\frac{6\pi}{16} & -\cos\frac{6\pi}{16} & \cos\frac{2\pi}{16} & -\cos\frac{2\pi}{16} & \cos\frac{6\pi}{16} \\
\cos\frac{7\pi}{16} & -\cos\frac{5\pi}{16} & \cos\frac{3\pi}{16} & -\cos\frac{\pi}{16} & \cos\frac{\pi}{16} & -\cos\frac{3\pi}{16} & \cos\frac{5\pi}{16} & -\cos\frac{7\pi}{16}
\end{bmatrix} \quad \textbf{(7)}$$

JPEG based on DCT is adopted to compress K-frames. The process of JPEG is shown as Fig.4. What should be noticed is that the images captured by CCD camera are 256 gray images and in order to control the compression ratio, a compression parameter should be introduced. This parameter is important. After a large number of experiments, the compression ratio is determined to be 30.After quantized, run length coding and Huffman coding are adopted.

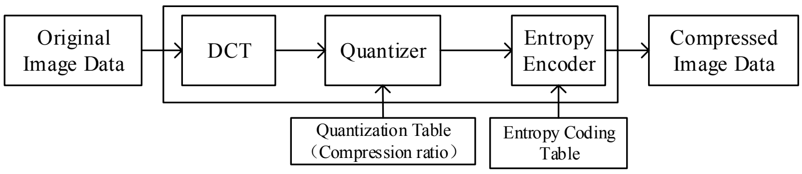


Fig. 4. Procedure of compression coding based on DCT

3.2 Internal Frame Image Compression Based on Forward Predictive Coding and Motion Estimation

Fig.2 shows that in every group of background image sequence, the similarity of adjacent image is very high. So, we can adopt compression method based on forward predictive coding and motion estimation to compress internal frames. As shown in Fig.5 below:

Firstly, when internal frame (I frame) comes to the system, it calls the motion estimation process to get the corresponding motion vector .

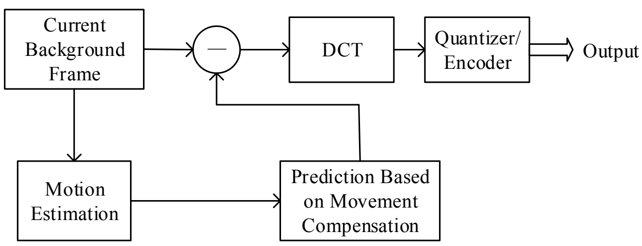


Fig. 5. Subway Tunnel Crack Image Sequence Compression Method Based on Motion Estimation

Then send the estimated motion vector to the motion compensation prediction module. The motion compensation prediction module will give the most appropriated predicted value matched, and the difference between this predicted value and original image is named predictive error.

Finally, run compression algorithm to encode the predictive error. To make fully use of key frame compression method based on DCT, we still use DCT as the predictive error compression method in this part.

Motion estimation uses block matching method in the H.261 standard. The core idea is to divide the image into several non-overlapping sub-blocks. For the first sub-block in the k-th frame, find out the most similar sub-block in the k-1th frame, which we think the position of matching block in the k-1th frame is the position of k-th frame before displacement. And the change of this position is the motion vector that we get. Here, the matching criterion we used is Mean square Error (MSE).

$$MSE(d_x, d_y) = \frac{1}{MN} \sum_{(x_1, y_1) \in B} [f_k(x_1, y_1) - f_{k-1}(x_1 + d_x, y_1 + d_y)]^2 \quad (8)$$

Besides, B represents the M*N subblock. (d_x,d_y) represents the motion vector. f_k and f_{k-1} represent the gray value of the k-th frame and the k-1th frame respectively.

3.3 Lossless Image Compression Based on Crack Information Database and Suspected Crack Regions

Above, compression method of background region images has been discussed. In this part, we will introduce an image compression method in region of interest. Region of interest includes two parts of data: suspected crack area image and crack information. The flowchart of this part is shown as Fig.6 that every piece of suspected crack area image has been compressed losslessly with standard PNG format. Meanwhile, find out all the information of this piece of related crack area images from database and code the crack information using the predefined Huffman coding with fixed format. Information integration module is to integrate the codes of compressed images and codes of crack information and then pack them together in order to transmit them simultaneously. What should be noticed is that the lossy compression coding in background region is transmitted by a group which is a sequence of 15 adjacent images. Therefore, we should find out all the information about the crack region of these 15 images from the database, and then pack the related suspected crack region image with lossless compression as the following graph. Standard PNG lossless compression format and Huffman coding are not explained in this paper.

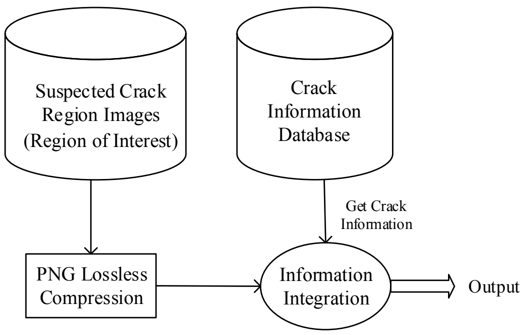


Fig. 6. Structure diagram of lossless compression method based on region of interest

4 Experiments

According to the detailed description in Section III, this paper proposes a new method of subway tunnel crack image compression based on ROI and motion estimation as shown in Fig.7.

In order to measure the performance this method, two groups of sequential gray images (2000 pixels * 2000 pixels) are chosen. Matlab is used to emulate this new method proposed in this paper. After Matlab processing, one of these images is taken as an example.

As shown in Fig.8, (a) is an image from background region image disk array without compression. (b) is a compressed image with the method of key frame image compression based on Discrete Cosine Transformation. (c) is a compressed image with the method of internal frame image compression based on forward predictive coding and motion estimation when this image is after a K-frame. (d) is a reconstruction image using background region image, SCR image and crack information from database. As shown in Fig.9, (a) is a suspected crack region image without compression. (b) is a suspected crack region image with JPEG compression. (c) is a suspected crack region image with the method of internal frame image compression based on forward predictive coding and motion estimation. (d) is a suspected crack region image with PNG lossless compression. (a)(b)(c)(d) in Fig.9 correspond to (a)(b)(c)(d) in Fig.8 respectively.

From the figures below we can find that Fig.8-(b) is a little vague and it has some mosaics. Fig.8-(c) is vaguer than Fig.8-(b). These distortions have a great effect on the crack recognition and analysis but have almost no effect on the observation of background image. So the method of this paper can enhance the image compression ratio without losing any information of images in the region of interest.

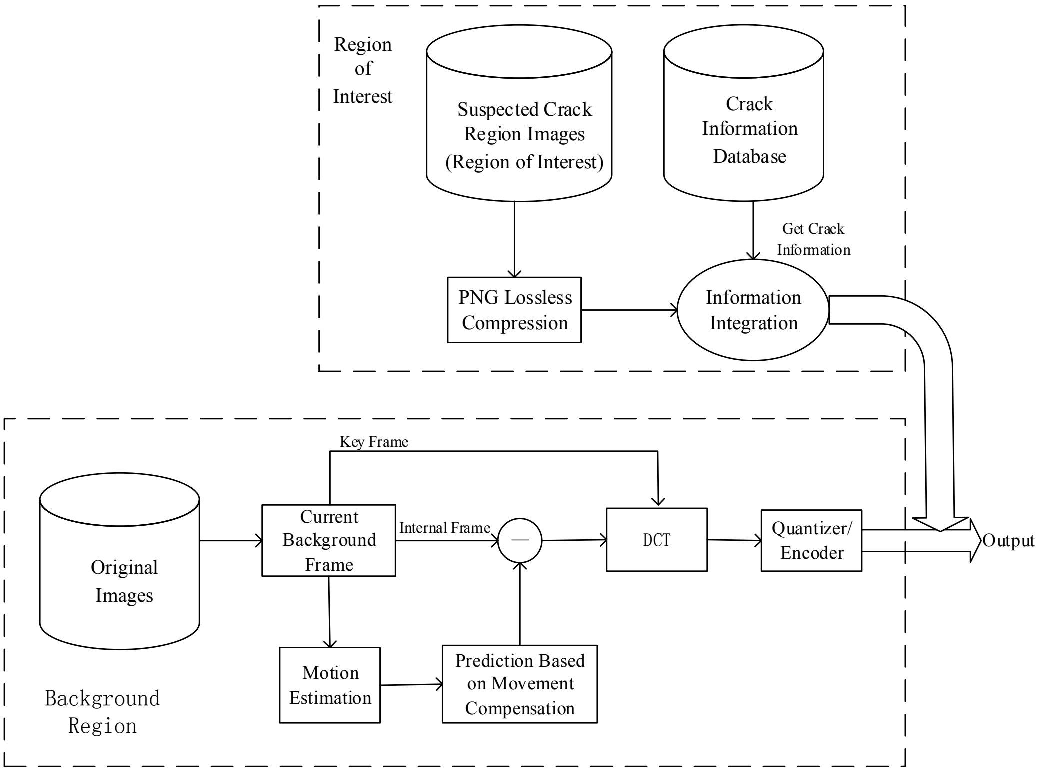


Fig. 7. Structure diagram of the method of subway tunnel crack image compression based on ROI and motion estimation

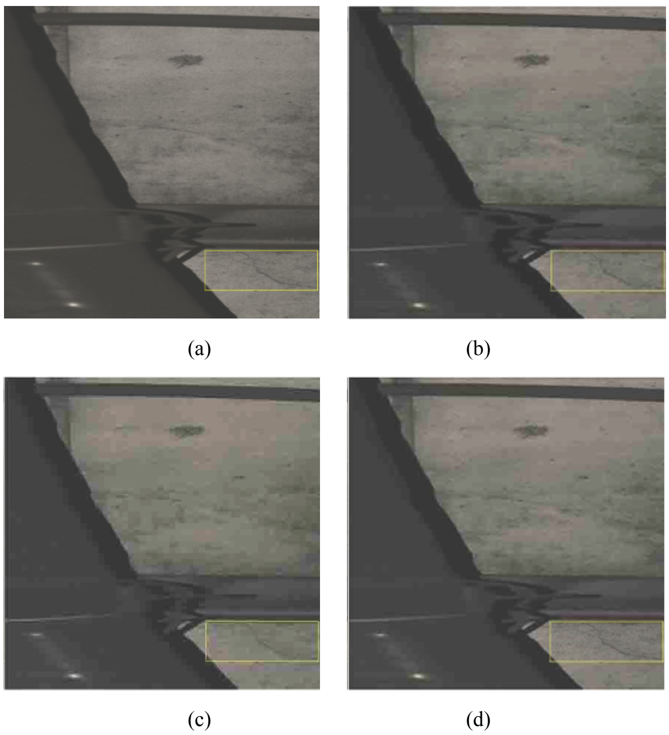
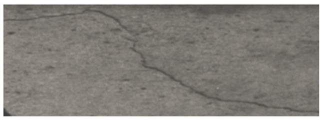


Fig. 8. Visual quality of the images of subway tunnel. (a)Original. (b) Compressed image with the method of key frame image compression. (c) Compressed image with the method of internal frame image compression. (d) Reconstruction image.

(a) (b)

(c) (d)

Fig. 9. Visual quality of the images of suspected crack region. (a)Original. (b) Image with JPEG compression. (c) Image with the method of internal frame image compression. (d) Image with PNG lossless compression.

5 Conclusion

Today, images are playing an increasingly important role. Although there are many kinds of image compression algorithms, only a few methods are suitable for crack image compression in subway tunnel as the image resolution is improving. In this paper, a new method of subway tunnel crack image compression based on ROI and motion estimation has been designed. The process of this method has been introduced in detail. After the simulation experiment, the new method has been proved to be a good method which not only has a relatively high image compression ratio but also doesn't lose any information of suspected crack region images.

In our future work, the following issues can be investigated. First, further improving the computing speed of this method should be considered. Second, the compression ratio needs to be higher.

Acknowledgment

This research is supported by National Natural Science Foundation under Grant 61371071 and Grant 61271308, 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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