Development of Image Processing Technique for Detection of Tunnel Wall Deformation Using Continuously Scanned Image

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It is now practical to use continuously scanned images (CSI), taken by a line sensor camera, for inspection of railway facilities. Such inspection system has been under development since 1995. Railway facilities are so extensive that this system will provide an effective tool of taking those images. In this paper, we report the result of its application as an inspection system of tunnel wall deformation. Especially, we focus on the image processing technique to extract those deformations. We completed an original image processing database system and a graphical user interface for convenient and easy operation. This system enables us to diagnose the soundness and durability of tunnel wall at a higher accuracy level.

**Keywords**: Inspection system, tunnel wall deformation, image processing, line sensor camera

1. Introduction

The structural soundness of railway tunnels is currently inspected and maintained through visual monitoring of deformations such as cracking on the wall. In actuality, however, the working environment is so bad and the monitoring area is so extensive that it is very difficult to follow all deformations that develop on the wall. Modernization of maintenance and inspection is now an urgent subject theme in view of the shortage of work force and aging of maintenance workers. We need to establish a movable inspection system which enables us to inspect long facilities such as tunnel wall surfaces, which are now patrolled on foot and investigated with the naked eye.

In the existing method shown in Fig.1, which uses a photograph and laser, there is a problem with complexity, inspection speed, accuracy and data processing. To realize the aforementioned goal, an automatic inspection and diagnosis system to use pictures will be an efficient non-contact inspection method. We developed the tunnel inspection system shown in Fig.2 which comprises a one-dimensional line sensor camera as the main device, and an image processing database system which has diagnosing capability by image processing.

2. Outline of Continuously Scanned Image (CSI) System

The purpose of this system is to obtain proper and efficient images to monitor deformations, and diagnose tunnel conditions. This system consists of two major units, one to take tunnel wall images, and the other to detect wall deformations by image recognition and store inspected results in a database. In order to obtain high-resolution images shown in Fig.3, we developed a 5,000 pixels per line camera synchronized with 40MHz clocks and a real-time data recorder of huge capacity.

Because tunnel wall images are obtained in a large quantity, it is required to develop a system for the person...
in charge to apply the image processing method with a computer, which can automate processing to some degree in addition to the so-called subjective inspection to observe images on the display. We are developing an automatic image processing algorithm, to extract deformations like cracks, as the first step for this purpose. It can automatically extract cracks on standard tunnel walls as a result. Furthermore, we worked out an algorithm based on the deformation profiles by using a powerful image processor and a workstation.

We applied various techniques to this algorithm. One is to distinguish cracks from the CSI of the tunnel wall. Actually there are several noise elements in the obtained image. We must separate actual cracks from noises. The other is to measure various dimensions such as the length or width of cracks. These data can rank the deformations, and get a prognosis of their growth accordingly.

3. Automatic extraction of crack by image processing

3.1 Basic examination

Major causes of tunnel wall deformation are cracks, water leakage, separation, and joint cutting. We are developing an image processing algorithm in order to automatically detect these deformations through tunnel wall images taken by a line sensor camera. This section discusses the detection of a typical example of deformation or cracks.

First, the procedure of general image processing carries out image quality improvement of noise removal etc., then binarizes and implements particle analysis by the characteristic quantity and extracts the intended object. The image quality improvement processing that eliminates particles and also improves the contrast of indistinct images is necessary to obtain optimal binary images. Because several dark pixels such as spiked form noise are seen, which are darker than the surroundings pixels, I adopted an effective median filter to remove the noise.

As tunnel walls have curved surfaces, it is difficult to light the walls evenly. I understand that there are a number of blurs in the tunnel wall brightness level, when the density histogram of its image is taken. Thus, lighting inconsistencies are inevitable in the images taken. It is necessary to revise these lighting inconsistencies and the luminance differences of the tunnel wall surface itself. In the revised method, we perform a dynamic binarization which changes the threshold level in linkage with partial area features. Because a number of isolation points remained in the images after binarization, I removed these small points by eliminating particles.

3.2 Comparison of the diagram characteristic quantity of crack and noise

Cracks are slender in form. On the other hand, the noise is random in form. We measured the following eight kinds of characteristic quantities shown in Fig.4 that seemingly reflect the characteristics of the form of crack and noise.

<table>
<thead>
<tr>
<th>Area</th>
<th>Maximum Pythagoras length</th>
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</thead>
<tbody>
<tr>
<td>Feret's occupancy rate</td>
<td>Maximum occupancy rate</td>
</tr>
<tr>
<td>Complicated degree</td>
<td>Maximum vertical width</td>
</tr>
<tr>
<td>Maximum occupancy rate</td>
<td>Minimum diagram width</td>
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Fig. 3 Continuously scanned image

Fig. 4 Characteristic quantities

(The height of the image is decided with the effective picture prime number of the line sensor. The width be infinite theoretically.)
Fig. 5 shows the result of measurements. There is a clear difference in the trend of the radar chart in cracks and noises. As for cracks, Feret’s occupancy rate and maximum occupancy rate are a small value, while conversely the value of complicated degree are large. We found that the Feret’s occupancy rate and the complicated degree and the maximum occupancy rate are effective characteristic quantities to separate cracks and noise. It was impossible to completely remove noise only with these characteristic quantities, presumably because:

1. Cracks were discontinuous and severed to small line segments.
2. Cracks and noise were fused to make a complicated form.
3. Large noise discontinued by chance made a form similar to that of a crack.

This is caused by the fact that the continuous cracks become discontinuous basically in the process where particles and isolation points are eliminated to make a bisect image. After dynamic binarization, it is effective to apply a filter to remove noise and improve the above phenomenon. However, I devised a method to avoid making cracks discontinuous by applying a filter. It is effective to apply such a filter to remove noise on one hand, and make it difficult for cracks to become discontinuous on the other hand to detect crack element.

3.3 Practical crack extraction method

Tunnel wall images are extremely large in scale. Thus, processing is done by dividing each image into multiple areas. However, due to the occurrence of an opening, there
is the possibility of losing information on the crack continuation among the images. Rather than saving the adjoining information by numerical data on the position and checking the continuation, we consider that handling it as an image and getting adjoining information would be more reliable and easier to perform. Thus, we decided to look at the overlapped images from the beginning.

By considering the possible workstation indication size with no reduction or shifting, the smallest block was set as 864 x 864 pixels. By composing crack images taken from each block after processing, long cracks on the tunnel wall surface will be processed.

Fig.6 indicates the general calculation time and Fig.7 shows the resultant images. This consists of processing in dynamic binarization, dilating and eroding for crack junction, eliminating particles after the crack junction, and analyzing particles for a crack prospective sampling. Regarding the particle analysis, we measure the lengths in the directions X, and Y, and Feret's occupancy rate. Each process has a different parameter, and we have tried various parameters through test programs and decided the best value by examining situations for juncture, and crack and noise sampling.

### 3.4 Improvement measures for detection rate improvement

As a result of checking the detection method for concrete joints, cables, shadows of cable, a distinction with
Fig. 9 Characteristic quantities

- Horizontal joints (4~6 pixels)
- Vertical joints 6 pixels
- Joint width 6 pixels
- Cables
- 6 pixels
- 8 pixels
- 9 pixels
- Crack width
- Crack & Joint width
- Crack (3~6 pixels)
- Cracks (3~7 pixels)
- Cracks (5~6 pixels)
cracks was not sufficiently produced. The substantial improvement of the detection rate of cracks can be expected if we are able to remove and distinguish this joint by some method because, especially, the concrete joints shown in Fig.8 exist in most of the wall images. If the width and straightness in the longitudinal direction is taken into account, distinction is possible as shown in Fig.9.

In order to improve the detection rate, we investigated ways of distinguishing joints from cracks on concrete walls. Promoting the detection of cracks with restraint on horizontal joints was made possible by utilizing the spatial frequency filters to separate the widths of horizontal joints and cracks, and considering the characteristic that the position changes in the direction in which the cracks grow larger than that in the joint construction direction. Furthermore, by applying a spatial frequency filter with multiple directions and bandwidths, we found that accelerated cracks could be sampled at stages as shown in Fig.10.
Nevertheless, there is a chance of picking up horizontal joints with similar widths as cracks. In actuality, it is difficult to 100% automatically pick up cracks alone. Taking this fact into consideration, we consider preparing a system, in addition to the examining program of the present report, by which corrections can be made in sampling results through interaction.

4. Conclusions

We discussed the basic detection algorithm, and the wide use and the improvement of detection rate for cracks by image processing. The width of concrete joint is about three or four pixels and the level or vertical component is a going straight target fundamentally. We can distinguish it from the knowledge that the interval of vertical direction length is almost regular. Also the application of the spatial frequency filter of $15 \times 15$ size was effective at the time of horizontal joints. Candidates of cracks were able to be extracted at stages, by using a spatial frequency filter that has plural directivities. As the width of representative cable is about 8 pixels, it is possible to remove it by the filter.

In view of the CSI that needs a special formation as well as the tremendous volumes of image data, there remains a large amount of innovation in this technology. Especially, the enormous volumes of data must be coped with by solving numerous problems in such areas as image storage, image data compression, display and print-out of elongated images with high resolution, or appropriate normalization of the unique geometry of object.

We verified the possibility of detecting typical cracks by using the algorithm proposed above. Among others, comparison in time series, including old and new images, is so significant for inspection of facilities that we have been developing such a function. But there remain several problems to be solved in this algorithm. It is necessary to upgrade the capability of detection, shorten the processing time on the workstation, cope with a wider variety of uses and develop a method to measure crack sizes. Such various deformations should finally be printed out on a special spread-sheet which is now drawn by hand. CSI is bound to constitute an integral part of image technology in railways. Our wish is to positively push the development and, proceed to its actual application while overcoming all difficulties.

References