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Development of inspection system of railway facilities using continuous scan image

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Abstract

Inspection system of railway facilities under development since 1991 using continuous scan image (CSI) to be taken by a linear sensor camera, has reached a practical application stage. Many railway facilities are so extensive that this system will provide an effective tool of taking those images. We report especially on the tunnel inspection system in this paper.

The structural soundness of a railway tunnel is currently inspected and maintained via the visual monitoring of deformations such as a cracking on the wall. Actually, however, work environment is so bad and monitoring area so extensive that it is very difficult to follow all deformations developing on the wall to the last crack.

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 the tunnel wall more accurately than previously.

1 Introduction

In Japanese railways, modernization of maintenance and inspection is now an urgent business for reasons of shortage of work force and aging of maintenance workers. We need to establish a movable inspection system which enables us to inspect the long facility such as the wall surface of tunnels and tracks while moving which are now inspected and patrolled on foot with naked eyes for the reason of delayed modernization in inspection technology.

An automatic inspection and diagnosis system by a picture will be efficient as a non-contact inspection method to realize this goal. Table 1 shows the outlines of new tunnel inspection methods. However, the existing video method finds it hard to deal with picture data in view of higher resolution. In Japan, Railway Technical Research Institute is developing a facility inspection system using a continuous scanned image which can take distinct and precise pictures while moving fast.

Facility inspection system by continuous scanned image comprises a camera equipment with one-dimension line sensor camera as a main device, and an image processing database system which has a diagnosis capability by image processing.

Table 1: Outlines of New Tunnel Inspection Methods

Method	Principle	Strong Points	Evaluations
Slit Camera	A special camera that synchronizes with the film feed speed (slit camera) is used to form a continuous image of the lining surface.	- Photography can be done while moving. - The recording medium (film) is easy to handle. - It is possible to obtain color images.	It is useful to efficiently determine the state of deformation. The system is relatively simple and extremely useful in a wide range of applications.
Laser Beams	The lining surface is irradiated with a rapidly rotating laser beam, and the reflected laser light undergoes image processing to produce an expanded photograph of the entire area surrounding the camera location.	- Photography can be done while moving. - The entire surface of the lining can be photographed at one time. - Illumination is unnecessary during the process.	It is useful to efficiently determine the state of deformation. This method can automatically diagnose deformation by means of image processing.
Continuous Scanned Image	A high resolution primary line sensor camera performs continuous photography of the lining surface in the sectional direction.	- Photography can be done while moving. - It is possible to make quantitative assessments so that the photographic image can be stored in a data base.	It is useful to efficiently determine the state of deformation. This method can automatically diagnose deformation by means of image processing.

2 Outline of CSI system

Purpose of this system is to get proper and efficient pictures to monitor deformations, and to diagnose the tunnel condition. This system consists of two major units, one to take tunnel wall images, and the other to detect wall flaws by image recognition and store inspected results in a database. In order to get high-resolution image we developed a 5,000 pixels per line camera synchronized with 40MHz clocks and a real-time data recorder of huge capacity, and furthermore we worked out an algorithm based on the profiles of flaws using a powerful image processor and a workstation.

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

2.1 Problems in the current image technology and the effectiveness of CSI

The present technology for picking up an image of the elongated objects such as track and vehicles; storing, retrieving and diagnosing the collected data is based on the standard rectangular image with a resolution of about 500 × 500. In treating these objects by the present image system, it is necessary to put together separate images. Thereby, in addition to insufficiency of resolution, we encounter additional troubles of "overlap" and "lack of continuity" as shown in Fig.1.

The CSI image proposed here is free from the troubles of "overlap" and "lack of continuity", as indicated by Fig. 2. As for the resolution, 1000～5000 pixels per line in the scanning direction are easily obtainable, while in the longitudinal direction an arbitrary length and resolution can be obtained.

2.2 Camera equipment

Picture of the surface of tunnel walls and tracks can be taken, while moving on the tracks, by a line sensor camera which is carried on the cars. In order to utilize the picture for the diagnosis, a higher resolution is needed. Resolution for the scanning direction depends upon the number of pixels, and resolution for moving direction depends upon the running speed of the cars and the scanning cycle of the camera as shown in Fig. 3. Even if the speed changes, it is necessary to keep the resolution constant. Therefore this scanning cycle is controllable so as to correspond with the changes of the speed. One of the goals of this system is to take pictures by resolution of 1mm × 1mm a pixel, and additionally to adjust various speeds of taking pictures.

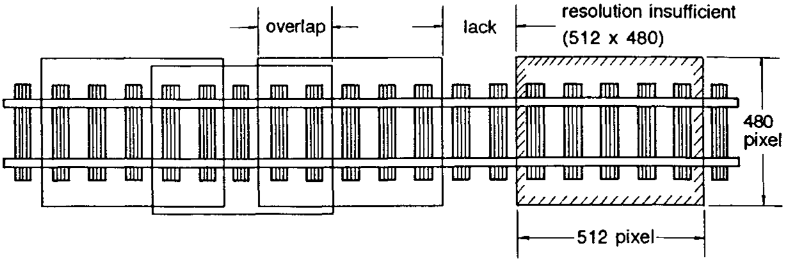

Figure 1: Problems in the current standard rectangular image

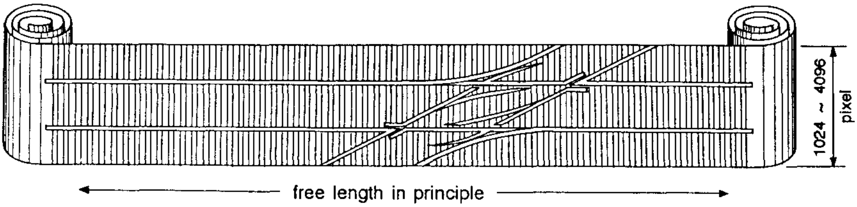

Figure 2: CSI image pattern

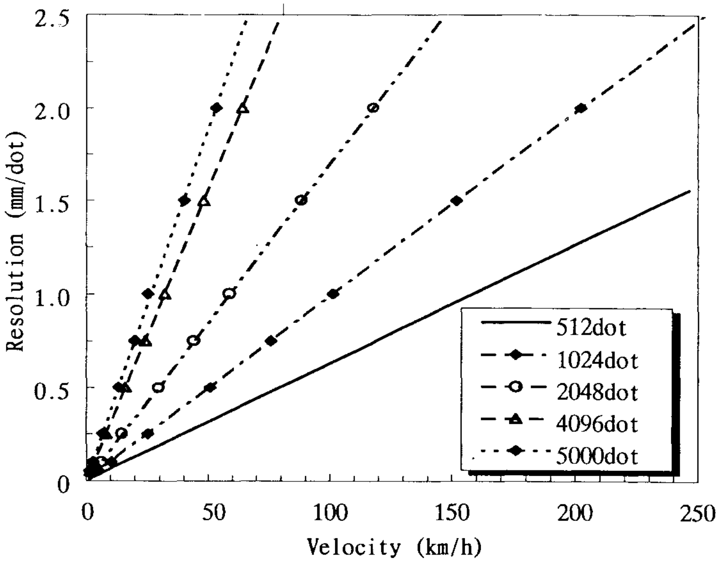

Figure 3: Resolution for moving direction vs. the running speed of the car

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2.3 Data recorder equipment

Image processing database unit into which huge amount of picture data go swiftly comprises a data recorder which keep these data without omission, a workstation which is the center of man-machine interface, and an image processing unit which processes images, and extracts cracks.

Data recorders which can store up to 120GB images are mounted on the cars together with camera equipment. Based upon the image data which are stored in the data recorder, the position and size of the cracks are analyzed by the image processing unit on the ground.

2.4 Characteristics of the system

(1) Because the higher resolution pictures can be seen on the display without going to the field, we can save the labor and time and can do inspection and diagnosis anytime we want.

(2) Accumulating the inspection data enables us to grasp the time series condition of the facilities and to plan and perform efficient maintenance and reformation.

(3) With the image processing make easy, a comprehensive analysis of various data including design data and maintenance history becomes available.

(4) Inspection becomes quick, efficient, and precise using the automatic diagnosis program to which the image processing method is applied.

(5) By exchanging information with each terminal which is located in each maintenance section, maintenance becomes quick and efficient.

3 Tunnel image database system

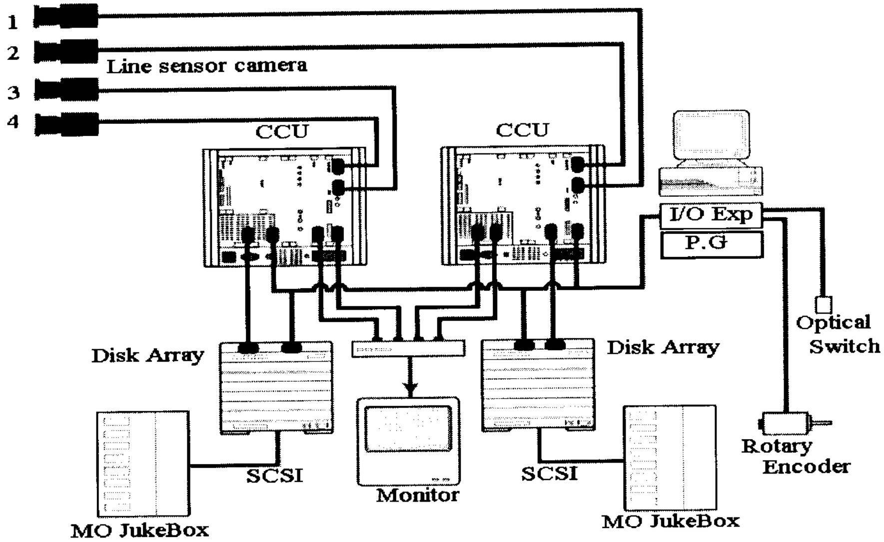

Figure 4: Construction of CSI system

3.1 Taking tunnel image into data recorder

Fig.4 shows the construction of CSI system. A line sensor camera covers one-fourth the area of cross section of tunnels as shown in Fig.5, so four divided cross section images are recorded. As scanning cycle is able to be controlled by an external trigger which is made by encoder pulse signal, this cycle is synchronized with the running speed. Therefore the resolution for moving direction is regularized automatically. In order to search a required position effectively from among the long image, we encode the distance pulse as a part of tunnel image. Furthermore the date of record or number of pixels per line are encoded as file information.

3.2 Geometrical correction and connection of adjoining image

Cross section of tunnel is such a complicated figure that the image taken by camera is distorted geometrically in the direction of cross section. Geometrical correction shown by Fig.6 is a necessary pre-process for measurement of crack size using those images. Border regions of four adjoining divided images overlap each other. By indicating the corresponding points at first, the relative shift value of pixels can be calculated. When a request for displaying four cross sections simultaneously occurs, connected images without overlap can be displayed (Fig.7).

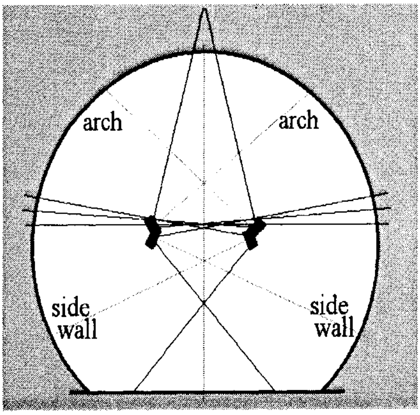

Figure 5: Four line sensor cameras cover cross section of tunnels

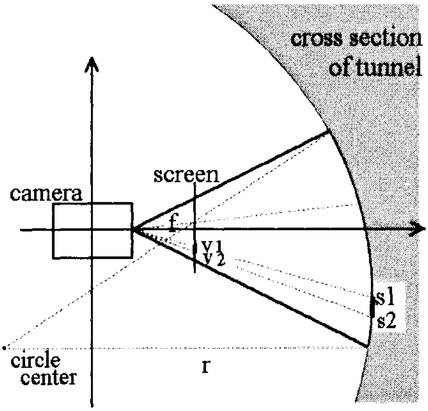

Figure 6: Geometrical correction

3.3 Image viewer

We developed a tool, called in image viewer shown by Fig. 8, which can handle a huge image. The region we want to see can be searched for by line number from the top of file or kilo-pulse encoded in the file header. Display size of tunnel image is variable from one-sixteenth to original scale. If a maximum (original) scale is chosen, the area which can be seen on the display monitor is just a part of image, and it takes a long time for the image to emerge. Though

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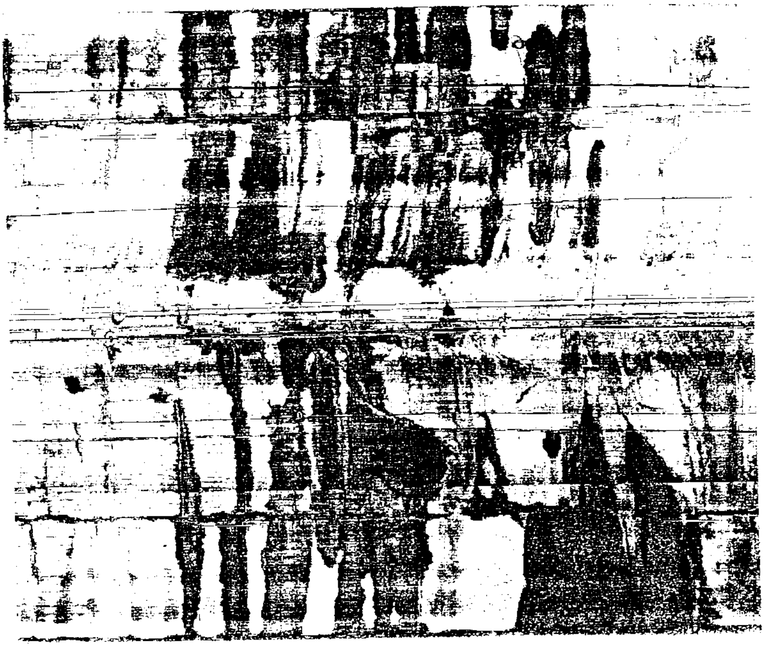
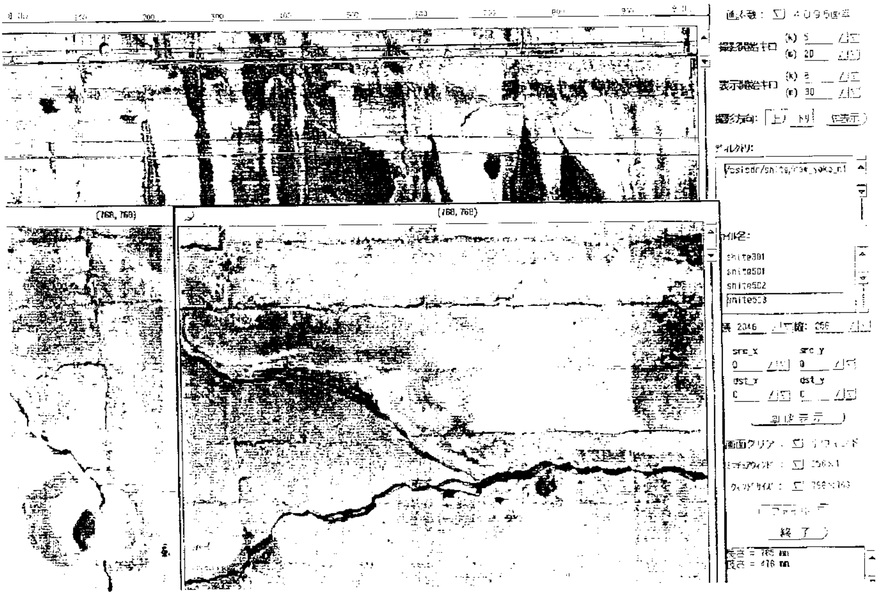


Figure 7: Connected tunnel image without overlap



撮影開始キロ (k) 5 (m) 20

表示開始キロ (k) 5 (m) 30

shite301
shite501
shite502
shite503

src_x 0 src_y 0
dst_x 0 dst_y 0

長さ = 785 mm
長さ = 476 mm

Figure 8: Image viewer using graphical user interface

by using a "scroll" function the whole image can be seen vertically and horizontally, usually a one-sixteenth scaled miniature image is displayed for the purpose of taking a wide view of tunnel. If necessary, image can be revised any size we want. Furthermore these images can be stored in the database together with several pieces of tunnel information. Various kinds of parameters mentioned above can be changed easily and interactively in this tool.

3.4 Examining tunnel wall surface deformation through image processing

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

As tunnel walls have curved surfaces, it is difficult to light the walls evenly. 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 revising method, we perform a dynamic binarization which changes the threshold level in linkage with partial area features. When using dynamic binarization which decides the binarization level, for example, through a moving average of 16 × 16 pixels, the 8-pixels around the image become irregular, and a 16-pixel opening occurs vertically or horizontally. Tunnel wall images are extremely large scaled. Thus, processing is done by dividing an image into multiple areas. However, due to the occurrence of the opening, there is a possibility of losing information showing a crack continuation among the images. Rather than saving the adjoining information by numerical data on position and checking the continuation, we consider, handling it as an image and getting an adjoining information would be more reliable and easier to take measures. Thus we decided to look at the overlapped images from the beginning.

Considering the possible workstation indication size with no reduction or shifting, the smallest block was set as 864 × 864 pixels. By composing crack images taken from each block after processing, the long crack in the tunnel wall surface will be processed. As the size of the tunnel wall image to be processed is large--16,000 × 5,000,000 pixels-- we are working for improving the processing speed and for making adjoining information processing smoother.

Fig.9 indicates the general calculation time and Fig.10 shows the result 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 length of direction X, direction Y, and Feret's occupancy rate. Each process has a different parameter, and we have tried

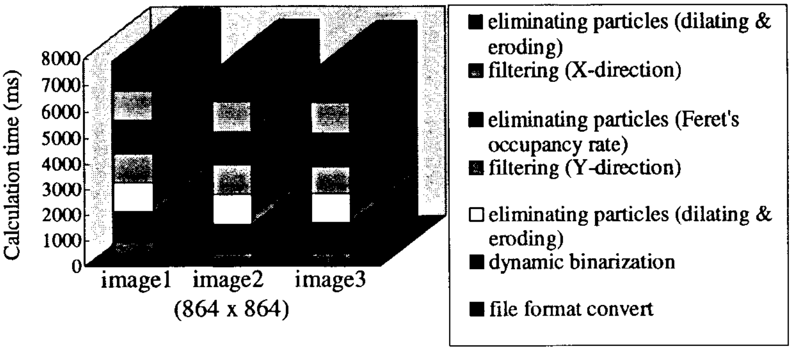
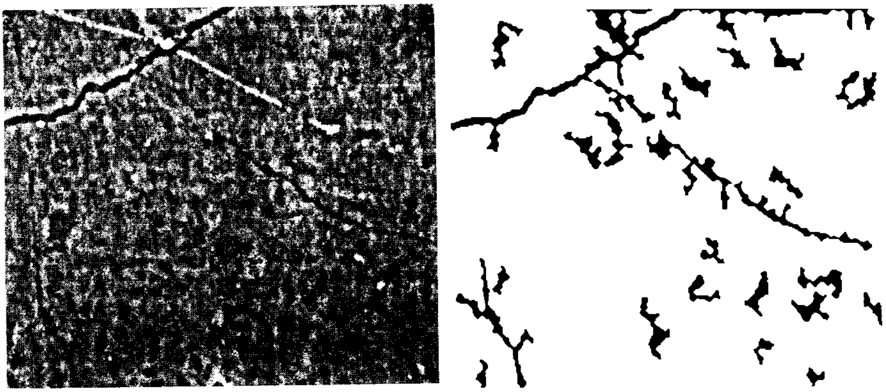
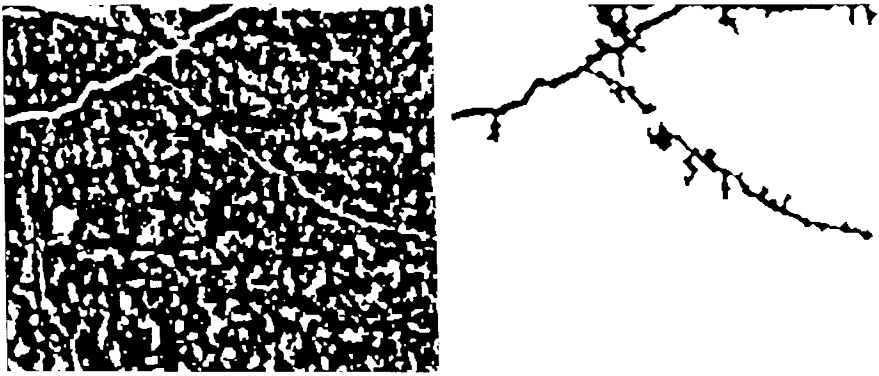


Figure 9: Calculation time of image processing



shading correction eliminating particles



dynamic binarization extraction of cracks

Figure 10: Image processing result

various parameters through test programs and decided the best value by examining situations for juncture, and crack and noise sampling.
In order to improve the detecting 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 following: spatial frequency filters which separate the widths of horizontal joints and cracks, and 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 prospective cracks could be sampled in stages. 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 people can make corrections in sampling results through interaction.

4 Conclusions

In view of CSI needing a special formation as well as tremendous volumes of image data, there is great room left for innovations in the technology. Especially the enormous volumes of data must be coped with by solving numerous problems in areas such as image storage, image data compression, display and printout of elongated images with high resolution, or appropriate normalization for unique geometry of object.
We verified the possibility of detecting typical cracks by using the proposed algorithm mentioned above. Especially comparison in time series, including old and new images, is so significant for inspection of facilities that we have been developing such function. But there remain several problems in this algorithm to be solved. It is necessary to upgrade the ability of detection, shorten the processing time on the workstation, cope with a wider variety of uses and develop a measuring method of crack size. Such various other deformations finally should be printed out to a special spread-sheet which is now drawn by hand. CSI is bound to constitute an integral part of image technology in the railway. Our wish is to positively push the development and, overcoming all the difficulties, to proceed to its actual application.

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