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Automatic Thickness Measuring System by Image Processing for Brake Shoes of Traveling Rolling Stock*


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1 Introduction

The inspection and maintenance work on railroad equipment is carried out in various fields. For example, the wear of rails and trolley wires, the condition of insulators and poles that support the trolley wires, signals and automatic train stopping devices installed on the tracks, obstruction by trees and other obstacles along the railroad line, functional devices in rolling stock, and the wear of consumables such as pantographs and brake shoes are regularly inspected and the necessary maintenance done.

This inspection and maintenance work is carried out at prescribed intervals or, for rolling stock, after a specific mileage. Inspectors in the field conduct visual inspection before maintenance work. In addition, this work is usually conducted during normal commercial operation hours or during the period from midnight to early morning when there is no operation.

Therefore, inspection and maintenance workers are constrained by time and exposed to some danger. The development of techniques for improving the working environment and efficiency for inspection and maintenance is required for railroads.[1]

Image processing techniques applied to these visual inspection tasks can provide many advantages such as automatic measurement, quantitative determination, and a data base of measured information.[2,3] Kawasaki Steel was entrusted with the development of a system for measuring the thickness of brake shoes on operating rolling stock by East Japan Railway Company.

As a result, Kawasaki Steel has developed an automatic thickness measuring system for brake shoes for the Series 205 electric cars of the JR Yamanote Line. This was made possible by using Kawasaki Steel's image processor, Dr. Image, and by developing algorithms for the recognition of brake shoe dimensions and boundary conditions.

This report describes the equipment configuration and algorithms for this system.

2 Technical Problems in Image Processing for Brake Shoes

The brake shoes of the Series 205 electric cars of the JR Yamanote Line are mounted on the bogie as shown in **Photo 1**, and apply the braking force directly to the wheel tread (the face in contact with the rail). Inspection has been periodically conducted visually and brake shoes replaced every three to six months. There are

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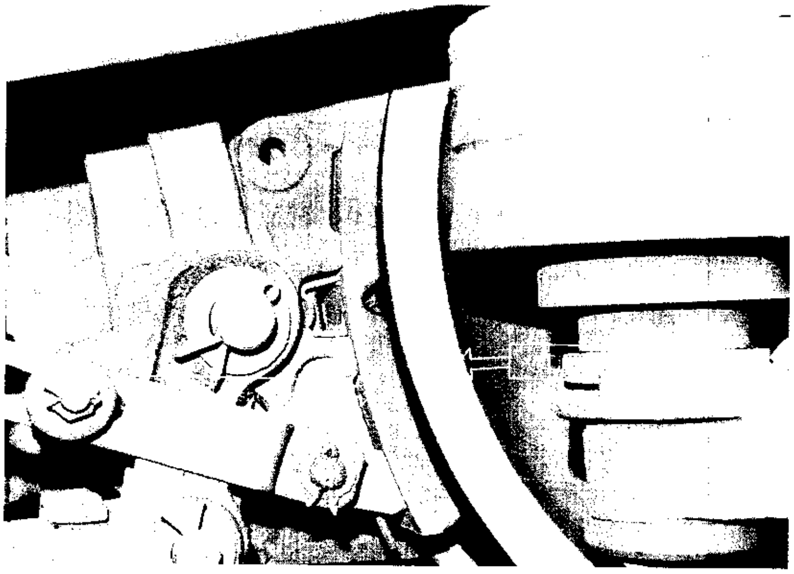


Photo 1 Brake shoe

variations in the degree of wear of brake shoes; consequently, the work load is too heavy for inspectors to measure the wear on every brake shoe and a visual inspection is much depended upon. For this reason, it has been difficult to quantitatively assess wear on all brake shoes and to manage spares stocks according to plan.

To automate this procedure, it was necessary to satisfy the following requirements:

(1) Measurements must be possible while rolling stock is moving.
To obtain the images of brake shoes, it is necessary to take photographs of the brake shoes on electric cars while they are moving toward the electric car shed, using a camera installed somewhere between the operating line and the electric car shed. Although the traveling speed of the electric cars is less than 20 km/h at this point, it is necessary to capture each moving brake shoe as a still image.

(2) The camera must be capable of operating beside the track outdoors, so that environmental protection against rain, wind, sunlight, etc. needs to be taken.

(3) Measurement must be possible during the day and night.
Although there is sufficient light during the daytime, there is little illumination at night. The same image quality needs to be provided by day and night.

(4) Remote measurement must be possible.
An appropriate means of communication and remote control are required because the distance between the camera installed outdoors and the computer installed indoors is about 500 m.

(5) High-speed processing must be possible.
Although about 18 trains are measured a day, many trains move to the electric car shed at the end of the day, and they sometimes come in at intervals of about 10 min. An adequate processing speed needs to be provided by the communication and image processing methods.

(6) Operation must be easy.
The system needs to be capable of being operated by someone with minimal knowledge of computers.

(7) A network must be capable of being constructed easily.
The system needs to be capable of exchanging and sharing data with other systems.

(8) High detection performance must be provided.
An automated system for measuring the thickness of brake shoes needs high resolution to extract only the image of the brake shoe.

3 Equipment Configuration

A hardware configuration that satisfies the requirements in the preceding section is shown in **Fig. 1**. This system is composed of two sections, one for image input and the other for image processing. In the former section, the brake shoes on moving rolling stock are photographed by a television camera and their images are recorded and stored. In the latter section, the data stored in the image input section is subjected to image processing, the brake shoe thickness is measured and the results are output. The next paragraphs describe how the requirements are met.

3.1 Image Input Section

In image processing, the quality of input images has a great effect on how well they can be processed. For this reason, it is necessary to obtain stable images under the adverse conditions already described. In this section, the following measures were taken:

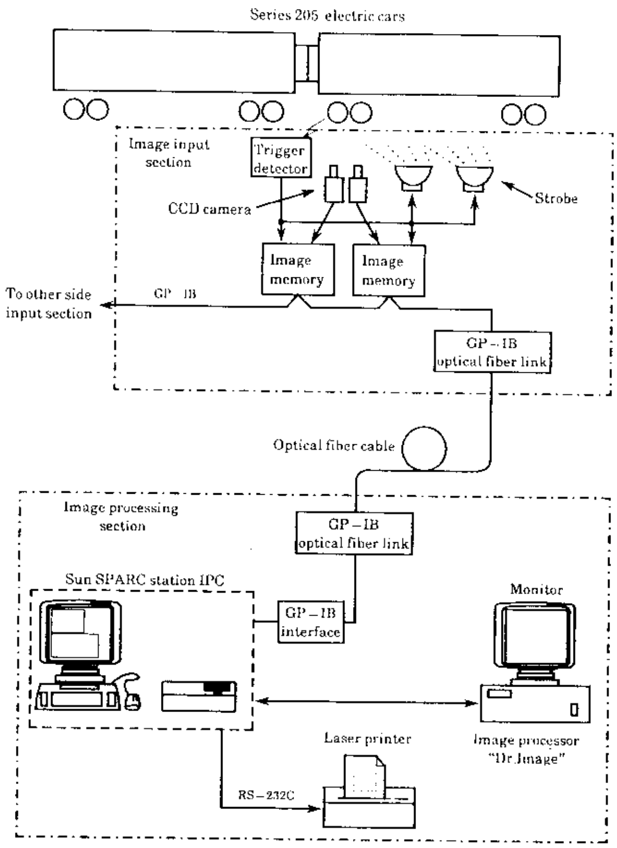


Fig. 1 Configuration of hardware

(1) Photographing Moving Rolling Stock by a Strobe Method
It is very difficult in terms of processing time to process the image of a brake shoe on moving rolling stock while the image is moving. In ordinary television cameras, video signals are obtained by exposing images to an imaging device for a constant time (1/30 s/frame for the NTSC method) and, therefore, blurring occurs when a moving object is photographed, which makes it difficult to process the image. To solve this problem, the strobe and triggered shutter methods are used together.
The strobe method takes a photograph of moving objects as a still image by utilizing a short flash time (5 to 50 μs) as used in multistrobe photography, etc. This method is suitable for photographing moving objects at high speed.
The triggered shutter method was achieved by using a television camera fitted with charge coupled device (CCD) in the imaging element and an electronically controlled shutter. Many electronic shutter cameras have shutter speeds of 1/125 to 1/10 000 s or so. The camera used with this system has the triggered shutter function so that the shutter operates from trigger signals.
These two methods allow the brake shoes of moving rolling stock to be captured as still images.
(2) Obtaining Uniform Images Day and Night
The image input section is installed outdoors beside the tracks, so that illumination conditions can change greatly. The difference between the lighting during the daytime and nighttime is especially large, and to obtain stable images, it is necessary to reduce this variation in natural lighting.
In addition, the brake shoes are installed under the body in the shade of the bogie, where there is little light. For this reason, a strobe was used even during the day time. Although the brake shoes are photographed as still images, the parts that protrude outside the bogie such as axle springs create blurring due to the more intense natural light, and this blurring also affects the image of the brake shoes. This problem was solved by using a high-speed triggered shutter camera. The shutter speed was 1/2 200 s, the maximum speed of the camera used. As a result, it was possible to consistently obtain the required image quality.
(3) Protective Measures for Outdoor Installation

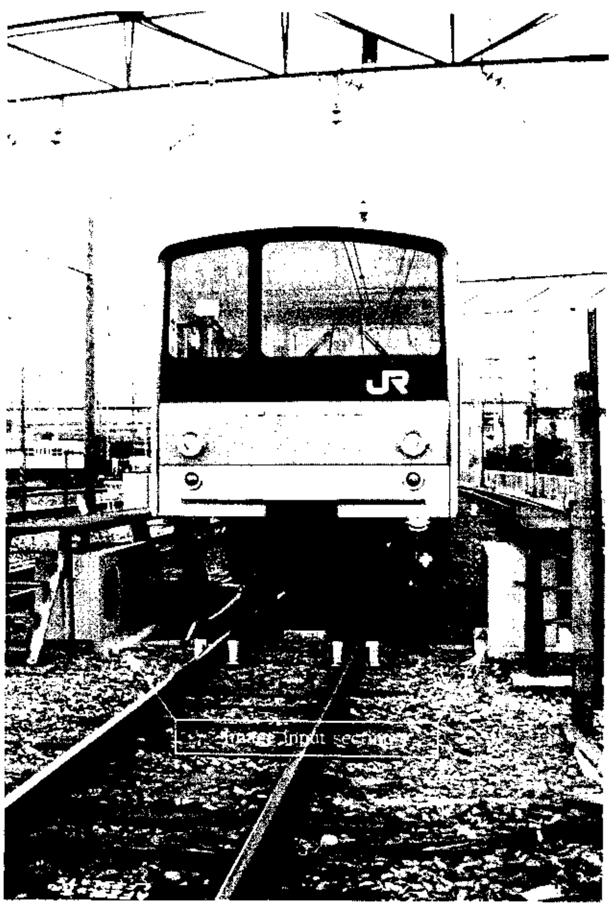


Photo 2 External view of image input section

The image input section is installed outdoors beside the tracks (**Photo 2**), and the measurement devices are protected in a housing, with a fan and a heater provided to keep the temperature range in the housing constant.

(4) Remote Operation through Optical Cables

The image input section is installed in a place about 500 m from the image processing section, and it needs to be operated by remote control from the computer of the image processing section. The image recording device is equipped with a GP-IB interface to permit suitable control and image data transmission. GP-IB is particularly useful for transmitting large amounts of information such as image data at high speed.

Data transmission by optical fiber cables was used because the transmission line that connects the image input section and the image processing section is 700 m in length and liable to be affected by external noise.

The equipment configuration of the image input section is next described. The Series 205 electric cars are each suported on two bogies, and there are four brake shoes on each bogie, two on the left and two on the right. Therefore, in a train composed of ten cars, there are 80 brake shoes. These brake shoes are photographed for each bogie. Therefore, as shown in Fig. 1, four CCD cameras and four image memory units were used. One image memory unit can record 20 images maximum and the CCD cameras connected to the image memory units have the triggered-shutter function. The strobe lighting ensures sufficient illumination intensity by flashing each brake shoe.

The passing wheels are sensed by a trigger detector, shutter timing is given, and the brake shoes of one bogie are photographed at the same time.

3.2 Image Processing Section

The important functions of the image processing section are its high-speed and automatic recognition of the image of a brake shoe in the picture. Furthermore, the operation capability of the man-machine interface also was regarded as important and it needs to be capable of connecting easily to a network, for the purpose of exchanging and sharing data with other measurement systems, etc.

For this reason, Kawasaki Steel's Dr. IMAGE[4] general-purpose image processing system was used. This system has the many image processing functions that are needed to develop an algorithm for high-speed processing and extraction of brake-shoe data. Furthermore, Dr. Image works on a UNIX work station so that a man-machine interface using GUI was possible and connection to Ethernet was easy.

4 Software Configuration

The most important software of this system is the image processing algorithm for extracting the brake-shoe data. The effectiveness for evaluating the condition of brake shoes is greatly influenced by whether this algorithm is good or not. As well as the image processing software, software for the control of the image input section, communication software for image transmission, and software for the man-machine interface were necessary. This section describes the software configuration and operation, and explains the algorithm for the extracting the brake-shoe data.

4.1 Software Configuration and Operation

The software configuration of this system is shown in **Fig. 2**. It is basically composed of three programs: the communication program for communicating with the image input section, the image processing program for evaluating the brake shoes, and the man-machine interface program to link with the users. Each program is operated in multitask form by UNIX.

When the images for one train (80 images) have been stored in the image memory unit, an interruption request is sent through GP-IB to the work station of

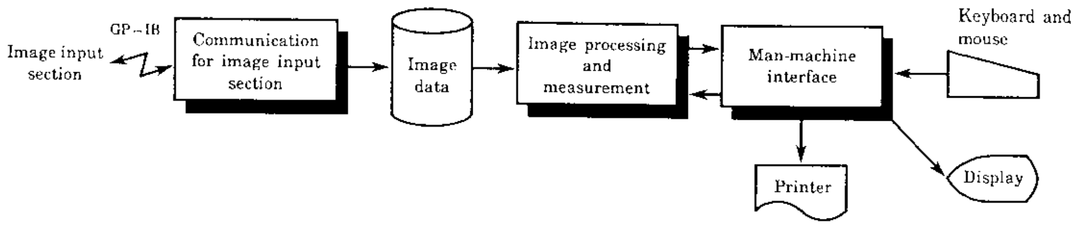


Fig. 2 Configuration of software

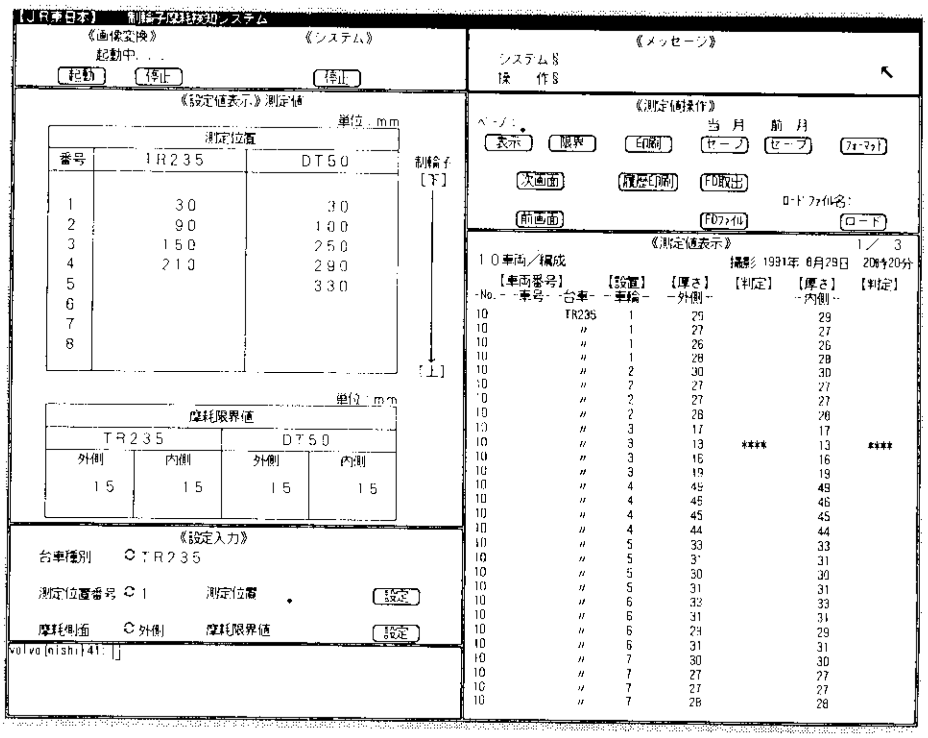


Fig. 3 Example of operation menu displayed on Sun workstation monitor

the image processing section, and the completion of storage is made known. Upon receiving the interruption request, the communication program sequentially reads the image data for one train from the image memory unit and stores the data on a hard disk.

After ascertaining that the image data exist on the disk, the image processing program starts to operate, transfers the measured results to the man-machine interface program, and the results are displayed and printed out. Settings for the measuring positions on the brake shoes, the allowable wear limits, and the storage of measured results on floppy disks are also controlled.

Among these operations, communication and image processing must operate in a multi-task manner. This is because it takes about 30 min to process all the images for one train, while trains come in at intervals of 10 min minimum, with the result that it is necessary to feed in new image data while processing previous image data.

The man-machine interface is a menu system using windows as shown in **Fig. 3**, and its operation is very easy. The measured results are displayed in the lower right window, and the asterisk mark * is indicated in the judgment column when the amount of wear is more than the wear limit. The results are printed out in the same format on the printer.

4.2 Algorithm for Extracting the Brake Shoe Image

One of the most important operations in image processing is the development of an algorithm for extracting a particular object from an image. In the case of a brake shoe image, there are many other components in close proximity such as the wheel, axle spring, metal parts supporting the brake shoe, and the bogie frame, besides the brake shoe itself, as shown in Photo 1. To extract only the brake shoe from this image and to measure the remaining thickness of the brake shoe is the purpose of this system.

The features and conditions that were applied to develop an image processing algorithm for a brake shoe are as follow:

(1) The brake shoe has a crescent-shaped external form.
(2) Due to the photographing method, the brake shoe position can change by several centimeters vertically and laterally in the picture. Therefore, it is first necessary to extract the position of the brake shoe.
(3) The curvature of the side of the brake shoe in contact with the wheel changes due to wear. However, the other side of the brake shoe on which it is mounted has a constant curvature, and this part is used as the reference line for wear measurement.
(4) Because the longitudinal dimension of the brake shoe changes little due to wear, this is used to recognize the type of brake shoe.
(5) Because gray level of the brake shoe and its surrounding parts varies due to dirt and illumination level, it is necessary to adjust the gray level.
(6) Although the external profile of the brake shoe can be recognized, parts that are unclear due to dirt exist and it is necessary to employ a method for estimating these parts as arcs with a certain curvature.

The algorithm was developed to suit these features and conditions, and the flow chart is shown in **Fig. 4**.

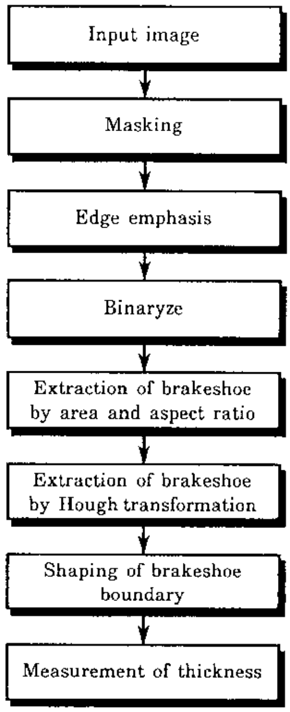


Fig. 4 Flow chart for extracting brakeshoe shape and measuring its thickness

The input image is masked and the region near the brake shoe is cut out. The extracted image is then processed by a special filter to emphasize the edges and lines, and the processed image is superimposed upon the original image. The edges and lines of the original image are emphasized by this process so that thresholding in the next process can be easily conducted.

After thresholding, the image of the brake shoe is extracted from the binary image by area and aspect ratio. The outline of the back of the brake shoe where it is attached is detected by Hough transformation,[5] and the final shape bounded by that outline is judged to be the brake shoe.

The extracted brake shoe may have a few irregularities formed in its external shape in the course of processing or holes due to noise. Therefore, the true shape is restored by an expansion and contraction process. Special processing is also conducted to correct curves broken by dirt, etc.

The thickness of the brake shoe is found by measuring the average horizontal intercept length at the measurement positions on the brake shoe and converting each value into the thickness in the normal direction.

Kawasaki Steel's unique application of the Hough transformation for high-speed processing allows figures capable of being expressed by equations (straight lines, circles, ellipses, parabolas, etc.) to correspond to points in space composed of parameters of the equations, and detects figures by the clustering of this space. The Hough transformation used for the brake shoe detects a circle by utilizing the property that the profile of the back of the brake shoe on which it is attached is a circular arc with a constant curvature.

Figure 5 shows a case of detecting a circular arc with radius r_0 by utilizing the Hough transformation. Here,

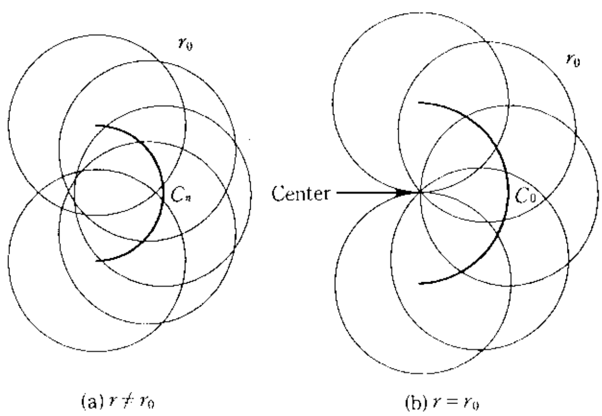
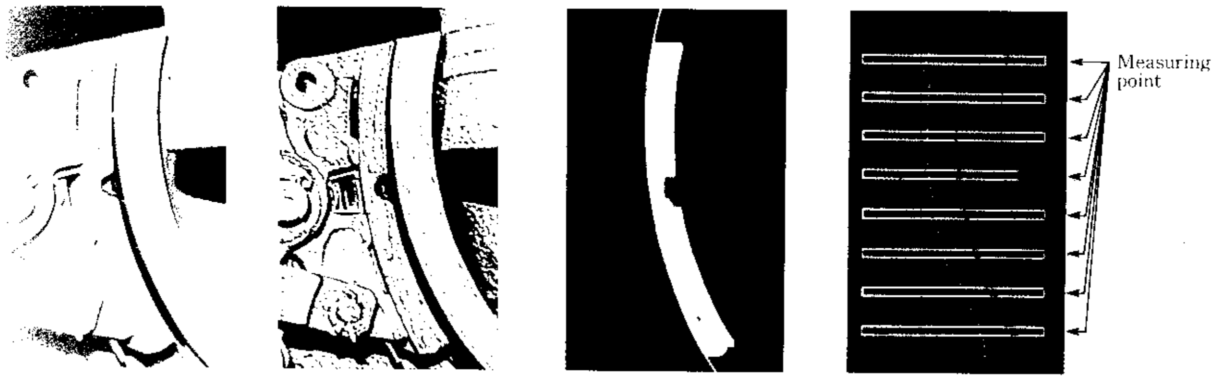


Fig. 5 Extraction of a circular arc with a definite radius r_0



(a) Original image (b) Binary image (c) Extracted brakeshoe (d) Measurement of thickness

Photo 3 Progress of image processing

(a) shows a case for radius r of circular arc C_n being different from r_0. In this case, when many circles with radius r_0 are described with their centers on circular arc C_n, the coordinates at which the loci of these circles intersect with each other are distributed. Therefore, the value that is obtained by adding up the frequency of intersection with each intersecting coordinate is low. And (b) shows a case for radius r of circular arc C_0 being equal to r_0. In this case, a peak occurs for the added values in one place among the intersecting coordinates. A circular arc with a defined radius can be obtained in this manner, and based on this circular arc, a brake shoe having a circular arc with the prescribed radius can be extracted.

The series of images processed by the algorithm given in Fig. 4 is shown in **Photo 3**: (a) is the original image, (b) is the binary image, (c) is the image of the extracted brake shoe, and (d) shows the extracted brake shoe with the thickness measuring points (eight points each enclosed with in a rectangle) superimposed upon the original image.

It is apparent from the processed images that the brake shoe has been accurately extracted, demonstrating the effectiveness of the algorithm.

As a result of this processing method, brake shoes of 60 mm in thickness can be measured with a resolution of 1 mm and a measuring accuracy of ± 3 mm.

5 Conclusions

At the request of East Japan Railway Company, Kawasaki Steel developed a system for automatically measuring the remaining thickness of brake shoes on moving rolling stock by image processing. The results are summarized as follows:

(1) Still images of 80 brake shoes on the bogies of a train moving at 20 km/h can be stably captured without blurring outdoors and under changing illumination during day and night.

(2) The brake shoe in a picture is detected by applying a Hough transformation for the constant curvature of the back of the brake shoe.

(3) The remaining thickness of the brake shoe can be measured automatically with the required accuracy by restoring a partially broken outline.

(4) The measured data on the remaining thickness of all brake shoes, together with identification data obtained by a car number reading device, are incorporated in the system data base. This permits quantitative spare-parts control, for example, by the predicting the replacement time.

This system contributes to the maintenance and quality control of rolling stock and replaces the dangerous and time-cousuming manual inspection. The authors intend to apply this system, which combines image measurement and an image data base, not only to rolling stock, but also for the inspection and maintenance control of external facilities such as railroad power transmission equipment, power equipment and roads.

The authors would like to express sincere thanks to the staff of the Transportation Vehicle Inspection Section and Yamanote Electric Car Section of East Japan Railway Company for their guidance and advice provided in the development of this system.

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