# Health Monitoring System for Wire Rope Using Image Processing

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**Abstract.** Rupture of wire ropes is one of the potential severe accidents in a lift system. Before rupture by aging degradation, diameter of wire ropes decreases and surface of wire ropes is rusted. Thus diameters and red rust of wire ropes should be checked in periodic inspections of lift systems in Japan. The diameters are usually measured by using vernier calipers or scales, and red rust is checked with eyes, so there are errors and differences among inspectors. Therefore development of a new monitoring system for diameters and red rust of wire ropes is required in order to maintain the quality of inspection and efficiently manage inspection data. This paper proposes and constructs a health monitoring system for wire rope using image processing. The system consists of a digital camera and a computer. The digital camera takes a photograph of a wire rope and the photograph is analyzed by the computer. The diameter is calculated from the number of pixels of the rope, and red rust is detected by resolving the colour of the photograph into RGB data. Image processing method and examples of inspection are reported in this paper. As a result, the measurement error was less than 1% by adjusting photographing condition.

## 1 INTRODUCTION

There are many kinds of wire ropes such as hoist rope and compensating rope in a lift system. Hoist rope is an especially important component because it suspends a car, so rupture of the rope causes severe accidents. In addition, roping of recent lifts has been complicated. The increase in number of bends of the hoist rope heightens the risk of the rope's vulnerability. Therefore maintaining rope safety is very important.

In 2011, a rupture accident of a hoist rope in a lift system occurred in Tokyo. According to the accident analysis report[1], the cause of the accident was aging degradation of the hoist rope and insufficiency of inspections. Decrease in the diameter of the rope and rust were confirmed in the rope, but detection of rupture was difficult because the rupture had started inside the rope. In consequence of the accident, further investigations regarding safety measures of hoist ropes of lift systems and revisions of inspection methods were implemented. The investigation report described the relationship between decrease in diameters of rope and decrease in strength of rope [2]. In addition, wires in strands may break before rupture of a rope. Therefore detection of wire breakage is also important.

In Japan, the diameter of the rope and red rust are checked in periodic inspection of lift systems. Usually the diameters are measured by using vernier calipers or scales, and red rust is checked with eyes, so there are errors and difference among inspectors. However the inspection should be implemented homogenously and accurately from the viewpoint of above-mentioned accidents.

In order to check conditions of ropes homogenously, accurately and speedily, this paper proposes a new health monitoring system for the diameters and red rust by using image processing. A photograph taken by a digital camera of a rope is used in this system, and the digital image is processed by using a computer. The diameter is calculated from the number of pixels of the rope, and red rust is detected by resolving the colour of the photograph into RGB data. A concept of the health monitoring system of wire rope using image processing, methodology used and results of experiments for verification of the system are reported in this paper.

## 2 CONCEPT OF HEALTH MONITORING SYSTEM USING IMAGE PROCESSING

The health monitoring system of wire rope using image processing proposed in this paper aims at inspection of diameters and red rust of wire ropes. Figure 1 shows a concept diagram of the proposed system. The proposed system consists of a PC and a digital camera, and the camera is able to be set any place near the hoist rope, because the camera is small and is able to be connected with the PC by cable, Wi-Fi and Bluetooth. Digital images taken by the digital camera are transmitted to the PC, and these images are processed using analysis software such as MATLAB. Both the digital camera and the PC are of consumer use, so no special function is equipped. This system will be able to measure diameter of a running rope by using a high-speed video camera instead of the digital still camera.

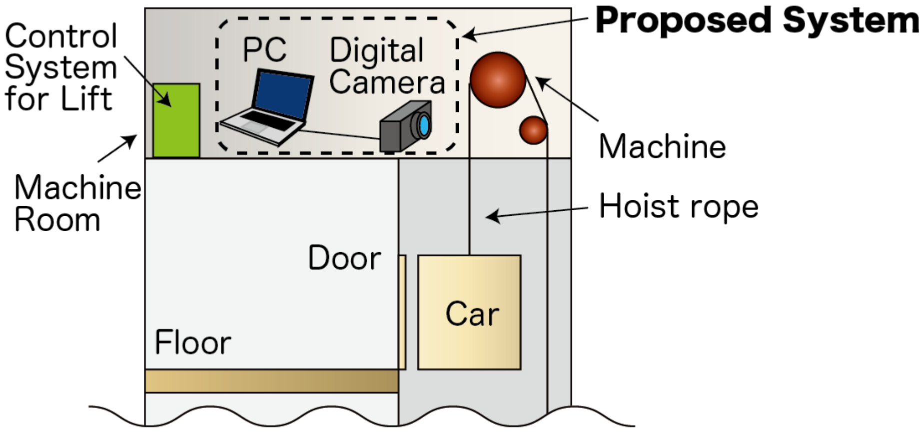



**Figure 1 Concept diagram of health monitoring system**

## 3 METHODOLOGY

### 3.1 Diameter measurement by image processing

This section describes an algorithm of diameter measurement of a rope by using image processing. Figure 2 shows a flowchart of the diameter measurement programme, and Fig. 3 is an example of image processing. The algorithm is as follows:

First of all, a digital image taken by a digital camera is loaded to a computer as shown in Fig. 3 (a).

Next unnecessary part of the image is trimmed, and the image is changed from colour to gray scale as shown in Fig. 3 (b). Generally a colour image consists of three layered two-dimensional arrays that are a red layer, a green layer and a blue layer, and each colour is expressed by 8bit (= 256) data. The gray scale image has only one layer that expresses luminance, and the luminance is also expressed by 8bit (= 256) data. Therefore, the capacity of data of the image is decreased by this process.

Then a low-pass filter is applied as shown in Fig. 3 (c). This process removes noise, dust and unevenness of rope surface, so boundary line will be decreased.

After that, the image is changed from gray scale to monochrome as shown in Fig. 3 (d). A monochrome image is expressed by 1bit (= 2) data. In other words, black is expressed by 0, and white is expressed by 1. In this process, a threshold value that separates gray scale data into black and white is needed, and the threshold value should be adjusted in consideration of photographing condition.

Then boundary lines between white and black are detected as shown in Fig. 3 (e). In this process, value of each pixel is checked, and boundary is judged by comparing it with surrounding pixels. These lines express an outline of the rope.

After that, the Hough transform [3] is applied as shown in Fig. 3 (f). Hough transform is a method that detects linear functions from a digital image. In general, a linear function is expressed by the following equation.

$$y = b_1 + b_2 x \qquad (1)$$

However $\beta_2$ of perpendicular line will be infinity, so this cannot be expressed in computer programmes. Therefore the line is expressed by distance from the origin $\rho$ and an angle between the horizontal axis $\theta$ as shown in Fig. 4. In the Hough transform, candidate values of $\rho$ and $\theta$ of each pixel are calculated, then $\rho$ and $\theta$ are decided by their coincident values. Difference of $\rho$ is distance between two lines.

Finally the diameter of the rope is calculated. Distance derived by the Hough transform was distance in the digital image, so it should be transformed to length in actual scale. The pixel in the digital image is transformed to actual length by using the sensor size and a ratio of the focal length in the digital camera to distance between the camera and rope as shown in Fig. 5.

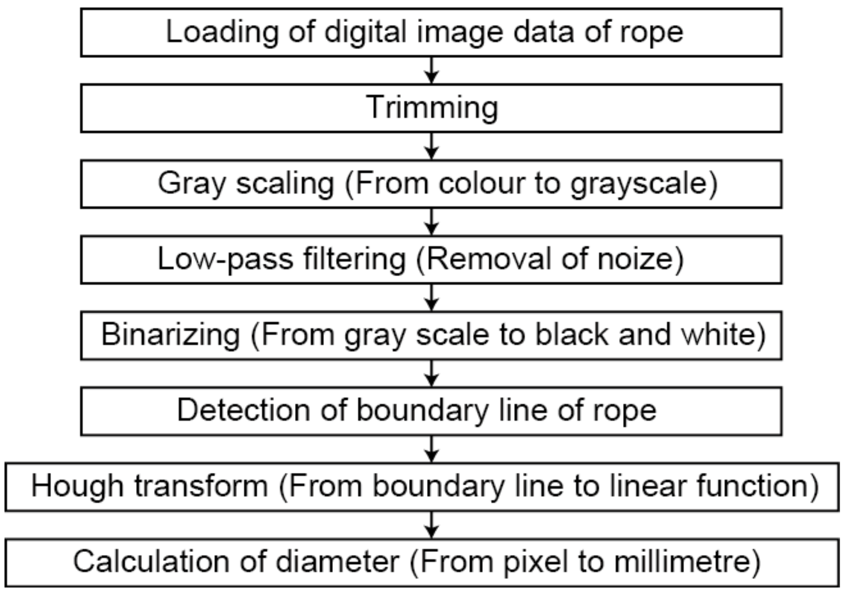
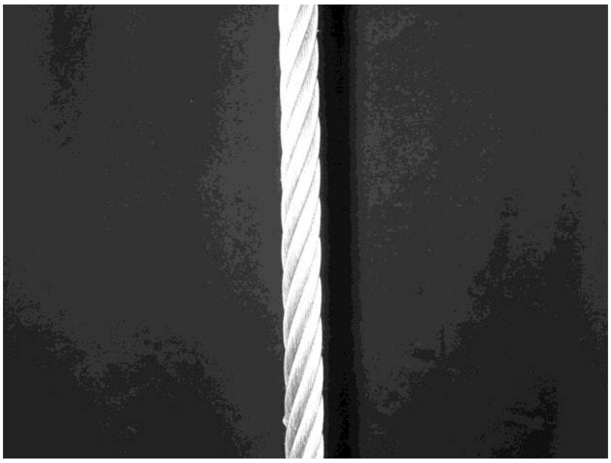
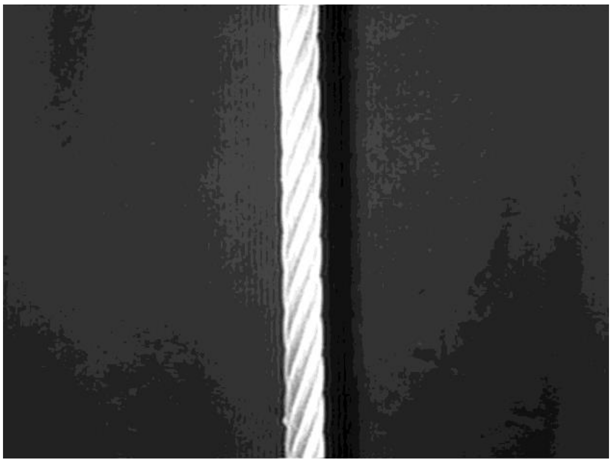



**Figure 2 Flowchart of diameter measurement programme**

(a) Original image

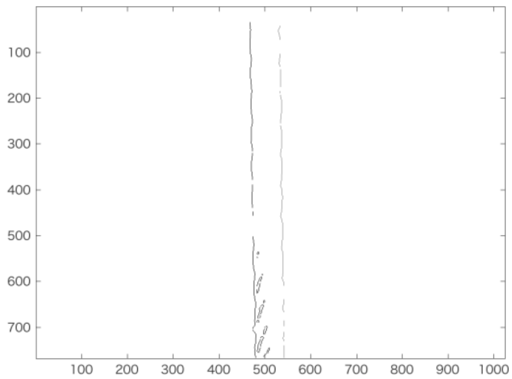


(b) Trimmed and gray scaled image

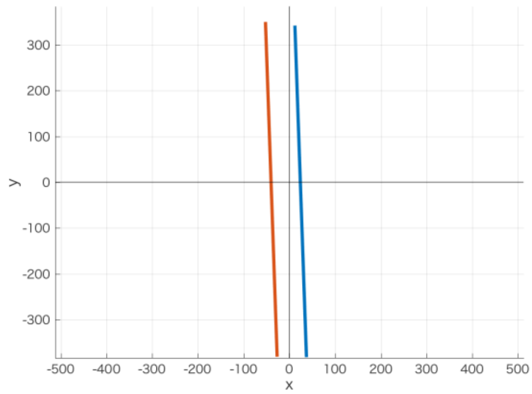


(c) Filtered image

(b) Binarized image




(e) Boundary line image




(f) Linearized image

**Figure 3 Example of process of image processing**

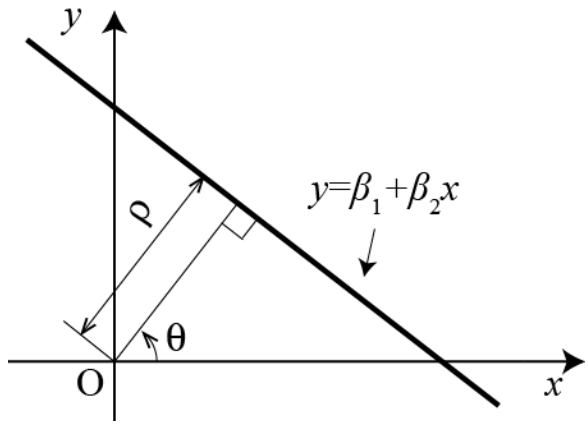



**Figure 4 Linear function**

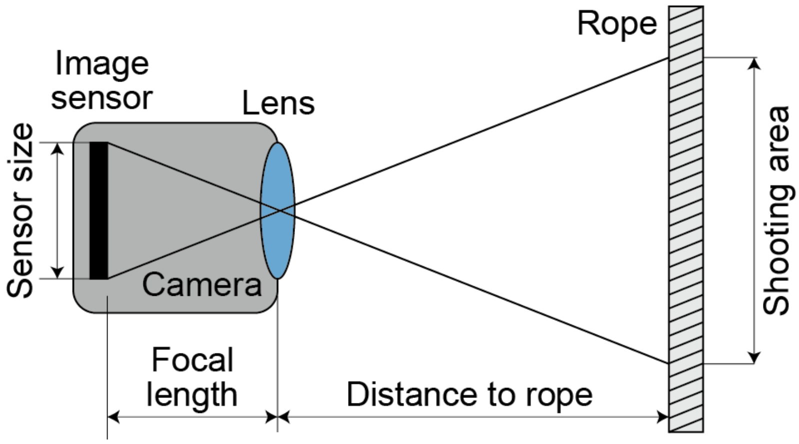



**Figure 5 Calculation of actual size by specification of camera**

### 3.2 Red rust detection by image processing

This section describes an algorithm of red rust detection of a rope by using image processing. Generally a colour image consists of three layered two-dimensional arrays as shown in Fig. 6. Each layer indicates the luminance of red, green and blue, and each luminance is expressed by 8bit (= 256) data. Therefore a colour is identified by combination of luminance of red, green and blue.

This system detects red rust by colour recognition. First, ranges of luminance that correspond with red rust is set, that is to say, the upper and lower limits of luminance of red, green and blue are set. Next, luminance of each pixel is inspected. Finally the pixel is marked if the luminance is in the range of red rust.

Figure 7 shows an example of red rust detection, and (a) shows original image, (b) shows red rust part. The object is a rust oilcan. The ranges of luminance of red rust were set as follows; red is 130 to 255, green and blue are 0 to 80. Although a background of the digital image had similar colour to red rust, red rust on the oilcan was detected well by suitable setting of the ranges of luminance.

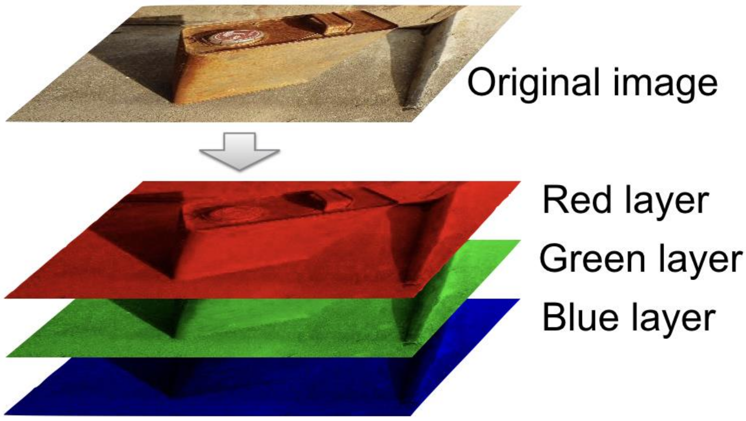
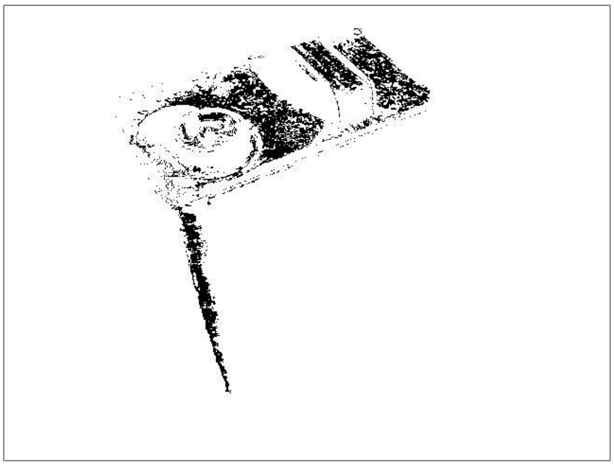



**Figure 6 Resolution of digital image to RGB layer**

(a) Original image



(b) Red rust part

**Figure 7 Example of red rust detection**

## 4 VERIFICATION BY EXPERIMENTS

### 4.1 Diameter measurement

Experiments were carried out in order to verify accuracy of the proposed system and to clarify suitable condition of photography. Influence of diameter of ropes on measurement accuracy, influence of lighting conditions of photography on measurement accuracy and influence of resolution of digital images on measurement accuracy were investigated.

Figure 8 shows an experimental apparatus. The experimental apparatus consists of a wire rope, a weight to tighten the rope, a stepladder that the rope is suspended on and a digital camera. Three wire ropes made of carbon steel were used. Diameters measured by a vernier caliper were 6.00, 9.05 and 15.95mm, respectively. The digital camera had a focal length of 6mm and an 1/1.7-inch CCD image sensor. Distance between the rope and camera was 400mm.

First, influence of a diameter of a rope and lighting conditions of photography were investigated. Resolution of digital images was 1280 x 960pixel. In this condition, one pixel corresponded to about

0.4mm. Figure 9 shows comparison of measurement accuracy on diameters and the lighting condition. It is confirmed from Fig. 9 that the suitable lighting condition for photography is the condition without lighting and with the flash. In this condition, error ratio was less than 0.93% and there was no significant difference between diameters. Therefore proposed system has sufficient measurement accuracy.

Next, influence of resolution of a digital image was investigated. A 15.95-mm-diameter wire rope was used for the experiment. Lighting was turned off, and the flash was turned on. Figure 10 shows comparison of measurement accuracy and processing time on resolution of digital images. The error ratio decreased by increasing resolution, because the number of pixels per mm increased. On the other hand, the processing time increased by increasing resolution, because the number of calculations increased. In addition, error ratio of 1280 x 960pixel is larger than Fig. 9 though same image was used, because different parameters such as the low-pass filter and the threshold value for binarization were applied.

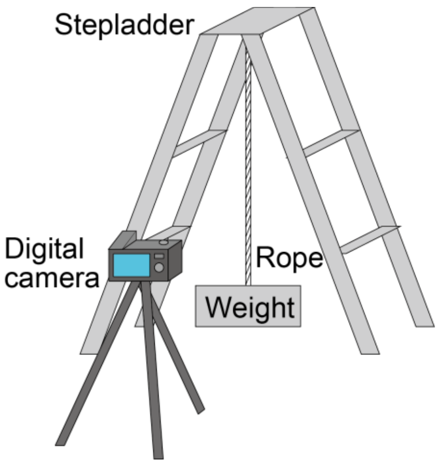



**Figure 8 Experimental apparatus**

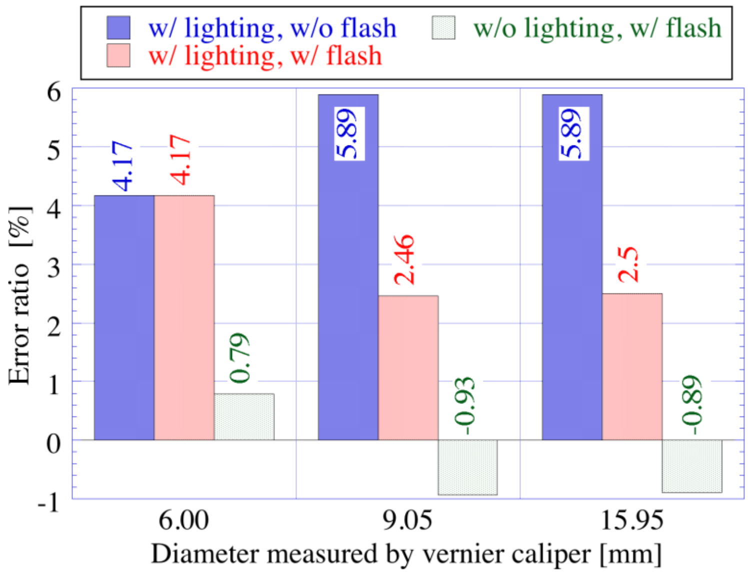



**Figure 9 Influence of diameters and lighting condition**

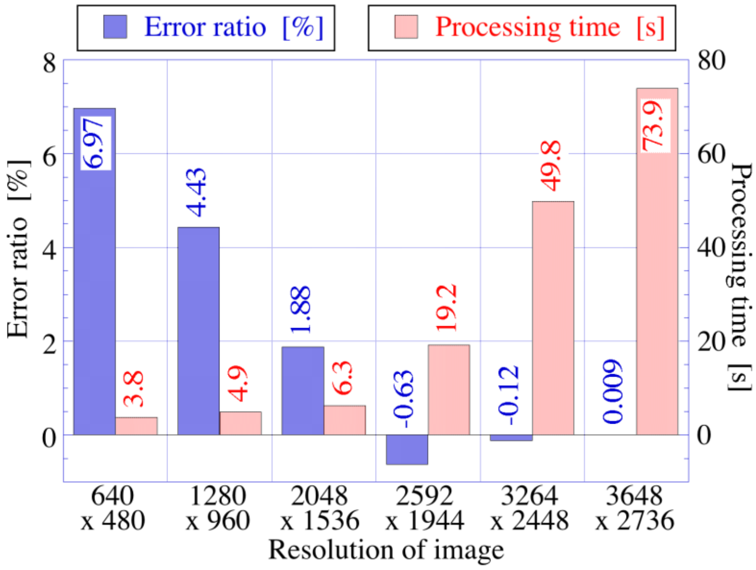
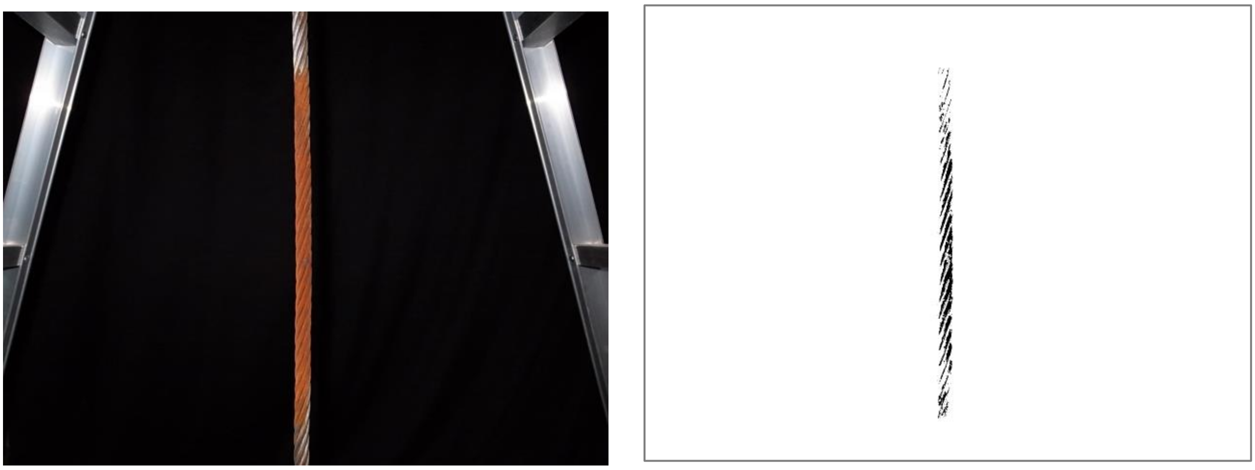



**Figure 10 Influence of resolution of digital images**

## 4.2 Red rust detection

Experiments using a rust wire rope were carried out in order to verify applicability of red rust detection of proposed system. Same experimental apparatus as section 4.1 was applied in the experiments. Distance between the rope and camera was 400mm. Resolution of digital images was 1280 x 960pixel. Lighting was turned off, and the flash was turned on.

Figure 11 shows a result of red rust detection, and (a) shows original image, (b) shows red rust part. The object is a rust rope made of carbon steel and having 12mm diameter. The ranges of luminance of red rust were same as section 3.2, i.e. red is 130 to 255, green and blue are 0 to 80. Red rust on the rope was detected well as shown in Fig. 11 (b). Although red rust was detected well by using parameters that is set in section 3.2, more accurate detection is possible by adjusting these parameters.



(a) Original image (b) Red rust part

**Figure 11 Red rust detection**

## 5 CONCLUSION

This paper focused on decrease of diameter and occurrence of red rust of wire ropes that relate to rupture of wire ropes, and proposed the health monitoring system of wire rope using image processing. The system was built by using MATLAB and the accuracy was verified by experiments.

As a result, proposed system had sufficient accuracy of diameter measurement regardless of diameters, and the photography condition without lighting and with flash was suitable. In addition, proposed system was able to detect red rust on the wire ropes.

In order to improve accuracy and applicability of this system, adjustments of parameters of image processing, consideration for various situations such as a rope covered with grease and development of fast algorithms are required in the future. In addition, detection of wire breakage and counting the number of it by image processing will be also implemented. After this method using a still camera is constructed, a high-speed video camera will be used in order to measure diameter of a running rope.

## REFERENCES

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## BIOGRAPHICAL DETAILS

Prof. Keisuke Minagawa is an associate professor of Saitama institute of technology and is a chair of the Technical Committee of Lifts, Escalators and Amusement Facilities held in JSME (Japan Society of Mechanical Engineers). He has been an evaluator of lift systems and mechanical car parking systems since 2015. He is also an expert of seismic isolation and vibration control.

Prof. Satoshi Fujita, a JSME (Japan Society of Mechanical Engineers) Fellow, has ten years of management experience as a director, a dean of school of engineering and currently a vice-president of Tokyo Denki University. He has been engaged in engineering research and development of seismic isolation systems and vibration control systems for buildings or key industrial facilities for over 35 years at both University of Tokyo and Tokyo Denki University. In recent ten years, he has been a committee member of the Panel on Infrastructure Development of Japanese ministry of land, infrastructure and transport (MILIT), and a chair of the Special Committee on Analysis and Evaluation of Lifts, Escalators and Amusement Facilities Accidents and Failures held in MILIT. In addition, he has been a chair of the ISO TC178 Japanese committee.