Detection System of Faulty Ground Wires from Aerial Video of Transmission Lines with Consideration of Influence of Devices on Ground Wires

Ryuichi Ishino
System Engineering Research Laboratory
Central Research Institution of Electric Power Industry
2-11-1, Iwado-Kita, Komae-shi, Tokyo
JAPAN

Abstract: - We have developed a detection system of faulty ground wires from an aerial video of transmission lines. These days, there are many devices installed on the ground wires to reduce the influence of snow and wind, such as antisnow wrapping wires and dampers. Our new system considers such devices. The detection performance of faulty wires is 7% higher than the original detection system that does not take these devices into account.

Key-Words: - Fault Detection, Image Processing, Image Recognition, Ground Wire Inspection, Antisnow Wrapping Wire, Optical-fiber Cable

1 Introduction

Utilities use helicopters to check transmission lines on mountains. When there are lightening strikes on transmission lines, companies take an aerial video of transmission lines to try to identify the faulty wires and restore them quickly [1]. Ground wires are particularly checked, because they are hit by lightening more often than power lines.

To identify a faulty wire using a video, an inspector plays the video at a very slow speed and checks them carefully. Checking videos is a considerable amount of time consuming and is tedious work. To avoid missing the faulty wires, two inspectors may check the same video. In short, checking the videos results in a heavy workload.

To reduce the workload and improve the efficiency of the checking task, we developed a reduction system of video data obtained from the aerial inspection of wires [2]. In this paper, this system is defined as the original system. The original system checks the aerial video of transmission lines and identifies faulty wires. Identifying faulty wires means checking for cut wires and arc marks.

These days, transmission lines have devices attached to reduce the influence of snow and wind, such as antisnow wrapping wires and dampers. The automatic detection system of faulty wires has not considered those devices until now [3]. In particular, antisnow wrapping wires [4, 5] would be judged by the original system to be arc marks. Therefore, a system that is able to take into accounts such devices on ground wires is required.

2 Reduction System of Video Data Obtained from Aerial Inspection of Wires

Figure 1 shows the concept of our original system. The system mainly deals with ground wires, because ground wires are hit by lightening more often than power lines. This original system stores images of faulty wires from the aerial video of transmissions. However, the original system cannot judge the faulty wires clearly, because it cannot distinguish arc marks from dust. Thus, inspectors check the images stored in the original system to determine whether the image includes a faulty wire or not. This means the original system cannot detect faults correctly.

Figure 2 shows the procedure of the original system. The procedure consists of the following 5 steps: (A) store the video of transmission lines, (B) input the position of a ground wire, (C) search and extract the ground wire, (D) detect a cut wire or an arc mark, (E) store the image of the faulty wire. These steps are explained as follows.

First, to process the video, it is stored in a computer (A). The original system can also process images while the video is being taken, but the computation load is too high to simultaneously store the images in the computer. Thus, before checking ground wires, the original system stores the video. At step (B), the actual check of the ground wires starts. Since the original system does not know where the ground wires are, an inspector inputs their location and diameter using one image at the beginning of the video. Subsequently, the original system checks the ground wires automatically until the end of the video.

Step (C) is explained in Fig. 3. Fig.3 (a) is an original image that is checked by the original system. (C) is the step of calculating the contour of a ground wire [6]. As shown in Fig.3 (b), the extracted line of the ground wire includes errors. The original system removes these errors and recalculates the line of the ground wire by the least-squares method [7] under the assumption that a ground wire is a straight line. The recalculated line is defined as the ideal shape of the wire. If the wire is not cut, the ground wire is also a straight line. This means the ground wire is not faulty. Figure 3(c) shows only the ground wire with other objects removed. This ideal shape is used in step (D).

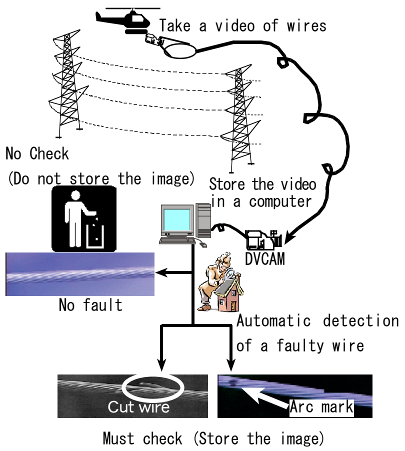


Fig. 1 Concept of the original system

Before explaining the step (D), let us define some terms. The bottom left-hand side of an image is defined as the origin. x is defined as the horizontal pixel number. y is defined as the vertical pixel number. Point (x,y) in the image has brightness br(x,y). The brightness is from 0 to 255. Br(x) is the average brightness of the ground wire at x (Fig. 4). n is the number of pixels of the ground wire in the vertical direction at x. The average brightness of the ground wire in an image is μ, and the standard deviation of the brightness is σ. Formulate for μ and σ are shown in Fig. 5. M is the number of pixels of a ground wire in the horizontal direction in the image.

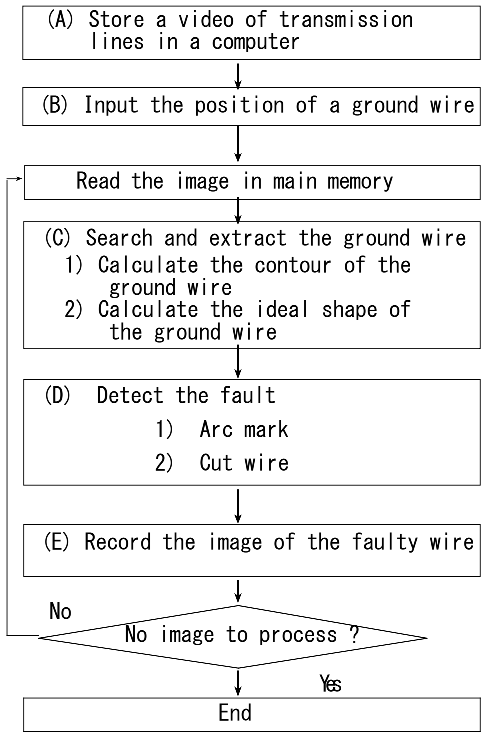
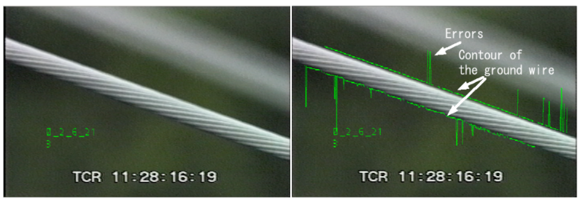
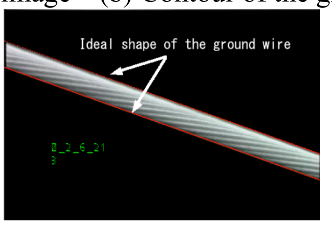


Fig. 2 Process of system



(a) Original image (b) Contour of the ground wire



(c) Ideal shape of the ground wire

Fig. 3 Example of extraction of the ground wire

Detection of a faulty wire consists of the detection of abnormalities of brightness and shape (E).

(1) Detection of abnormal brightness

If Br(x), which is the average brightness of the ground wire at x, is within the range [$\mu - \alpha\sigma$, $\mu + \alpha\sigma$], the ground wire at x is undamaged. If it is out of the range, the ground wire at x is faulty. Here, α is an arbitrary coefficient. [$\mu - \alpha\sigma$, $\mu + \alpha\sigma$] is the range of the brightness of the ground wire in the image. If the ground wire has an arc mark, the brightness is out of the range.

(2) Detection of abnormal shape

The original system compares the actual contour of the ground wire, which is calculated in the step shown in Fig. 2(C)-1, with the ideal contour of the ground wire, which is calculated in the step shown in Fig. 2(C)-2. The original system compares them by subtracting y-position of the actual contour of the ground wire from the position of the ideal contour of the ground wire for each x. If the absolute value of the subtraction is more than the threshold of shape abnormality, the original system judges that the ground wire is cut. The original system then stores the image of the ground wire (E). α and the threshold of shape abnormality are determined under the condition that the original system does not fail to detect a faulty wire on sample videos. We explain the determination of these parameters in Section 4.

After the original system checks the video and stores images, an inspector checks the images that the original system has judged to include faults on the ground wires. Reducing the workload of checking the video is equivalent to reducing the number of images that the inspector must check. A reduction in the number of images that the original system stores means an improved performance of the fault detection of the system. In short, a good detection system reduces the number of images that do not include faulty wires. Thus, we use the reduction in the number of stored images to assess the system performance. Without our original system, the inspector must check all the images on the video. If the original system has a good performance, the inspector checks very few images, and the task of checking the images is no longer labor intensive.

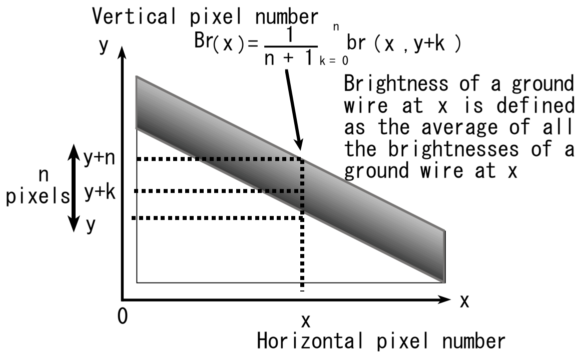
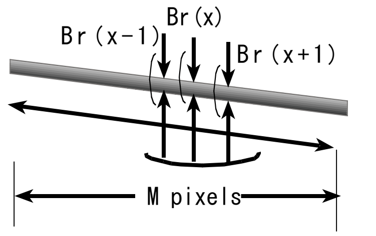


Fig. 4 Brightness Br(x) of the ground wire



$$\mu = \frac{1}{M}\sum_{x=0}^{M-1} Br(x)$$

$$\sigma = \sqrt{\frac{1}{M}\sum_{x=0}^{M-1}(Br(x)-\mu)^2}$$

Fig. 5 Mean and standard deviation

3 Consideration of devices on ground wires

Up to now, the original system we have developed has not considered devices installed on ground wires, such as antisnow wrapping wires and dampers. If these are not attached to ground wires, the original system stores about 20% of images. This means 80% fewer images that the inspector must check. However, if the devices are attached to the ground wires, the reduction rate of the number of images decreases to 70%. The reason is why the original system has judged the attached devices to be faults. In particular, when the original system deals with antisnow wrapping wires and optical-fiber cables that are wound around a ground wire, the reduction rate is very low. Antisnow devices and optical-fiber cables on the ground wires are black. The original system judges these as arc marks, which is why the reduction rate of the number of stored images decreases.

In this section, we present how to judge antisnow devices and optical-fiber cables as not being faults. And we define the system, which can judge antisnow devices and optical ⌇fiber cables as not being faults, as the new system.

3.1 Detection of antisnow devices

When antisnow devices are attached to ground wires, Br(x) is very low (Fig. 6). Likewise, when there is an arc mark on ground wires, Br(x) is again low (Fig.7). An antisnow device covers the ground wire in the vertical direction, whereas an arc mark occurs on part of the surface of a ground wire. This means the brightness of an antisnow device is lower than the brightness of an arc mark. The brightness of all of the antisnow devices on one span of the ground wire is less than μ-3σ. The brightness of an arc mark is less than μ -2 σ. Using this difference in the brightness, the new system can recognize antisnow devices. When there are antisnow devices on a ground wire, before the detection of faults, the new system first judges whether or not the ground wire is covered with antisnow devices. Then, the new system checks for faulty wires.

The vicinity of an area where Br(x) is less than μ - 3 σ is judged to be an antisnow device. Br(x) in some areas is less than $\mu - \alpha\ \sigma$, where α is less than 1, or larger than μ -3 σ. These areas are included in the two shaded boxes in Fig. 8. Thus, as in shown in Fig. 8, at the right-hand-side edge and the left-hand-side edge of an area that is judged to be an antisnow device, the area 20 pixels from each edge, which is shown as the shaded box in Fig. 8, is judged to include the antisnow device.

Figure 9 shows an example. When the new system detects faults, it draws a rectangle on the image. When it detects brightness abnormality, the rectangle is green. When it detects shape abnormality, the rectangle is red. Figure 9 shows that a faulty wire is detected but an antisnow device is not detected as a fault.

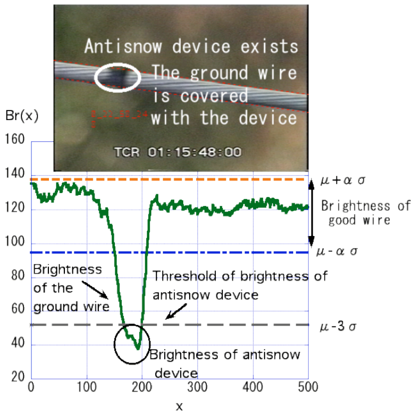


Fig. 6 Brightness of the ground wire with antisnow device

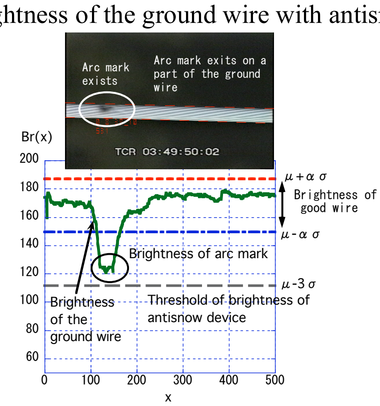
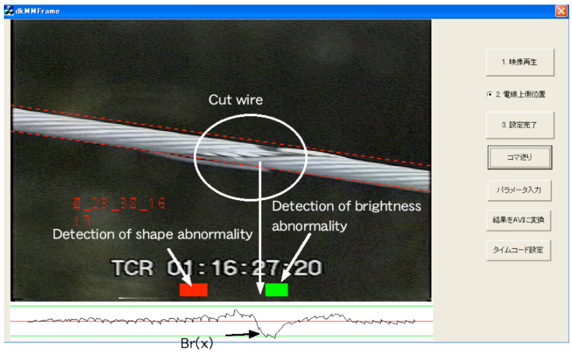
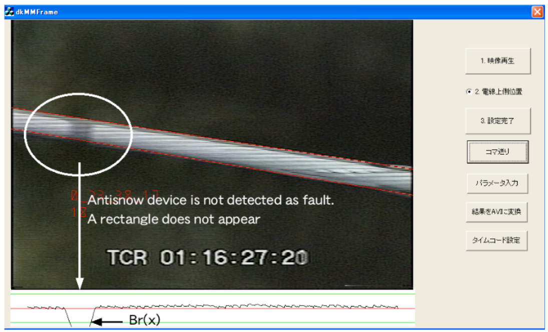


Fig. 7 Brightness of the ground wire with arc mark



(a) Detection of fault



(b) Judgment of antisnow device as non fault

Fig. 9 Example of detection of faulty wire and antisnow device

3.2 Checking of ground wire with wound optical-fiber cable

The wrapping of optical-fiber cables is black [8-10]. The original system would judge optical-fiber cables as arc marks. Thus, before checking the ground wires, as with antisnow wrapping ground wires, the system must identify optical-fiber cables.

3.2.1 Extraction of optical-fiber cables

When there is an optical-fiber cable on the ground wire, the brightness of the ground wire Br(x) is low, similar to that of an antisnow device. We assume there are both an optical-fiber cable and an antisnow device on a ground wire at the same time. Under this assumption, if the brightness of the ground wire Br(x) is less than μ -3 σ, then the new system judges that there is an optical-fiber cable at around x. Figure 10 shows the extraction process of optical-fiber cables on the ground wire. (1) The new system searches for the position where the brightness Br(x) is minimum. The position is defined as x_{min} as on Fig. 10. (2) To the left and right of x_{min}, the new system searches for the first position where the brightness Br(x) is equal to the average brightness of the ground wire μ. Those points are defined as x_{left} and x_{right} respectively. At x_{left} and x_{right}, the middle points of the ground wire in the vertical direction are defined as p_{tmpl} and p_{tmpr}, respectively. (3) The new system forms a line joining p_{tmpl} and p_{tmpr} and obtains two crossings between the line and the ground wire. These crossings are at the ends of the optical-fiber cable on the ground wire. Figure 11 shows an example of the extraction of an optical-fiber cable using this process.

3.2.2 Detection of fault near optical-fiber cables

If there is no optical-fiber cable on the ground wire, the new system checks the wire using the method shown in Fig. 2(D). Here, we explain how to detect a fault that is near the optical-fiber cable. As shown in Fig. 12, if there is no fault on the cable, Br(x) monotonically increases or monotonically decreases either side of x_{min}. However, if there is a fault near the optical-fiber cable on the ground wire, Br(x) does not change monotonically, as shown in Fig. 12. In short, to detect a fault on the ground wire, the new system finds a point where the sign of the gradient of Br(x) changes. The process of finding this point is shown in Fig. 13. The point that is checked is defined as $x_{checked}$. The new system sums Br(x) from x__checked-5 to x_checked+5 and the sum is defined as Br_sum1.

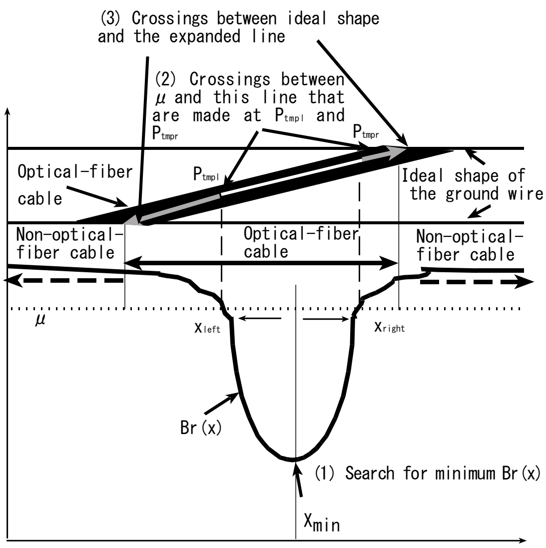


Fig. 10 Recognition of optical-fiber cable

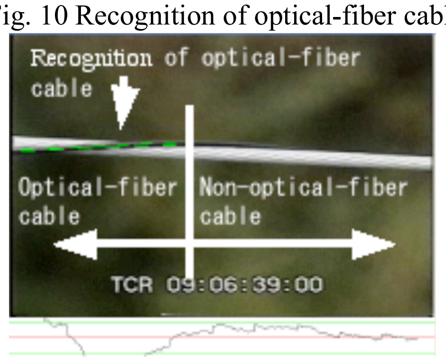


Fig. 11 Example of recognition of optical-fiber cable

Summing Br(x) for these 11 points is equivalent to removing the effect of noise. Next, at new checked point $x_{checked}$ +15, the system sums Br(x) from x__checked+10 to x_checked+20 and the sum is defined as Br_sum2. If the difference between Br_sum2 and Br_sum1 is positive on the left-hand side of x_{min}, the new system judges that there is a fault on the ground wire. If the difference between Br_sum2 and Br_sum1 is negative on the right-hand side of x_{min}, the new system judges there is a fault on the ground wire.

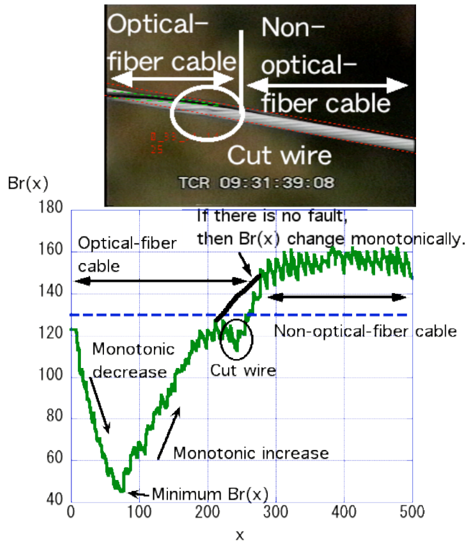


Fig. 12 Example of faulty wire near optical-fiber cable

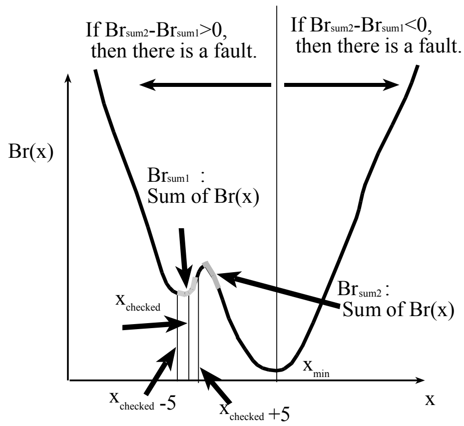


Fig. 13 Detection of faulty wire near optical-fiber cable

Figure 14 shows an example of a cut wire that is detected but the optical-fiber cable nearby is not judged to be a fault.

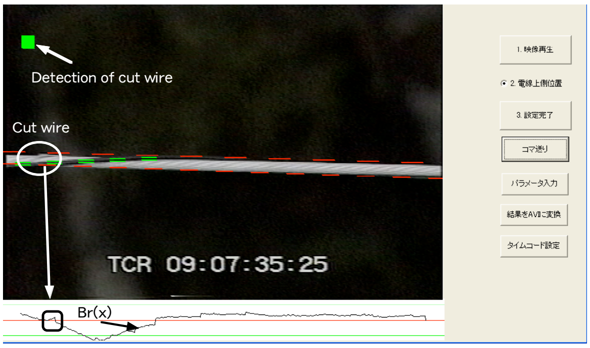


Fig. 14 Example of faulty wire near optical-fiber cable

3.3 Other devices on the ground wire

There are other devices on ground wires, such as dampers and sleeves. It is desirable to recognize all the devices on the ground wires. However, devices other than antisnow devices and wound optical-fiber cables are fewer per span. Thus, we consider that other devices are recognized as objects that the system must check. In fact, if these devices are on the ground wires, the system cannot calculate the ideal shape of the ground wire correctly. Then, the system also stores the images of ground wires whose ideal shapes cannot be calculated correctly. An example of this is shown in Fig. 15. Thus, the inspector must also check the images that include other devices.

We present a summary of measures to deal with devices on the ground wires in Table 1.

Table 1 Measures to deal with devices on ground wires

Device	Measure to deal with devices
Antisnow device	When brightness is less than $\mu - 3\sigma$, that point is not checked
Optical-fiber cable	・Recognition of optical fiber cable ・Judge point of change of sign of gradient of brightness as fault
Others (Damper・Sleeve)	Store the image for manual check

4 Experimental results

4.1 Parameter for detection of faults

The parameter for detecting brightness abnormalities is α. We determined a suitable value of α using 20 faults. Figure 16 shows the results of detection for varying α. The new system must detect all the faults, and we determined α to be 0.9.

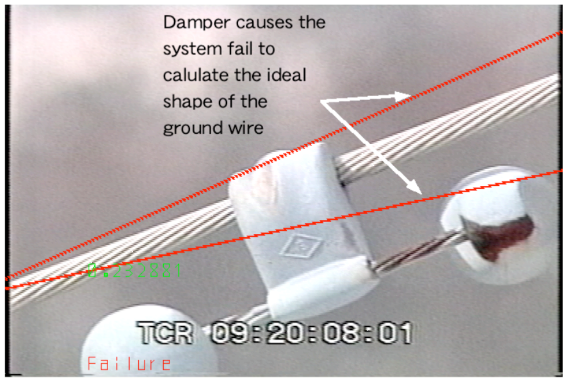


Fig. 15 Failure to calculate ideal shape of the ground wire with damper

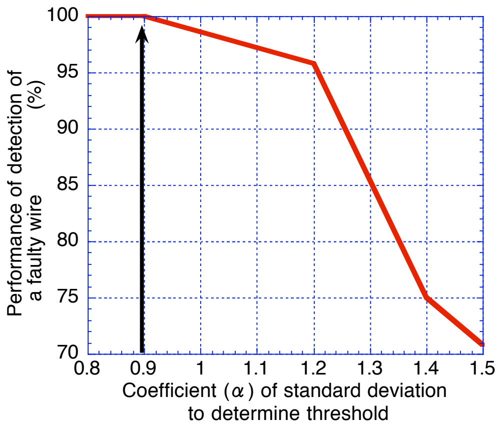


Fig.16 Determination of α using 20 faults

The parameter for detecting shape abnormalities is the difference between the contour of the ground wire and the ideal shape of the ground wire. We determined the parameter for detecting shape abnormalities using 5 examples of a cut wire. When the parameter for detecting shape abnormalities is 5, all the faults are detected. Thus, this parameter is set to be 5.

4.2 System performance using reduction rate of images

The system is evaluated using 39 spans of video (a total of 116,027 images). Table 2 shows the results. All the faults are detected. Without considering devices on the ground wires, which is used the original system, the reduction rate is 70%. With the method that we have developed, which is used the new system, the reduction rate is 77%. Because the new system correctly disregarded antisnow devices and optical-fiber cables, the reduction rate improves.

5 Conclusion

We present a method for the improved detection of faulty ground wires with attached devices. We have developed recognition method for antisnow devices and optical-fiber cables. The recognition prevents the new system from judging these devices to be arc marks. Using the recognition method, the detection performance of faults rises from 70% to 77%. We have confirmed that our fault detection method is effective.

Table 2 Reduction rates of images with and without consideration of devices

Consideration of devices	Reduction rates of checked images(%)
Yes	77
No	70

References:

[1] EPRI, *EPRI Aerial Inspection System All Set forTakeoff, http://www.epri.com/corporate/ discover_epri/news/2001releases/011017_aerial.html*

[2] R. Ishino et al., *Detection System of Damaged Cables Using Video Obtained from an Aerial Inspection of Transmission Lines, Proc. of IEEE Conf. on PES General Meeting, 2004*

[3] H. Tono'oka et al., *Image Processing Technology for Automatic Power Line Inspection, Mitsubishi Denki Giho, Vol. 66, No. 11, pp. 52-56, 1992 (in Japanese)*

[4] Nara K et al., *Application of an expert system to decisions on countermeasures against snow accretion on transmission lines, IEEE transactions on power systems , Vol. 3, No. 3, pp. 1052-1058, 1988*

[5] T.Nagano et al., *Collapse of Towers Due to snow Accumulation and Its Preservation by Making Conductor Snow-Resistant, CIGRE, SC22, 1974*

[6] FORSYTH et al., *Computer Vision A MODERN APPROACH, Prentice Hall, pp. 175-187, 2003*

[7] William H. Presset al., *NUMERICAL RECIPES in C, CAMBRIDGE, pp. 610-611, 1992*

[8] IERE, *New Trials in the Operation and Maintenance of Optical Fiber Cable, http://www-iere.dcc.co.jp/NonMembers/RD_Current_Topics/ CEPCOjp/Topic6.html*

[9] Chubu Electric Power Co., Inc, Development of a Multicore Ground Wire Wound Optical Fiber Cable*, http://www.chuden.co.jp/torikumi/study/ library/news/pdf/list079/N07915.pd (in Japanese)f*

[10] Chubu Electric Power Co., Inc, *Development of a Ground Wire Wrapped Optical Fiber Cable Repair Method, http://www.chuden.co.jp/torikumi/study/ library/news/pdf/list118/N11815.pdf (in Japanese)*