Paper

Detection of Faulty Power Apparatuses Using Distance Information and Temperature Information

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When an apparatus which should be diagnosed is near a neighboring heat source, it is difficult to distinguish the apparatus from the other heat source from only a thermal image, because there is no distance information. Therefore, we added distance information obtained with a stereo camera to temperature information obtained with an infrared camera, and developed a method of detecting a faulty apparatus on distribution poles using the infrared and stereo cameras. This method has four subcomponents: (1) generation of distance information with a stereo camera, (2) projection of distance information space onto temperature information space and integration of distance information and temperature information, (3) extraction of apparatuses on a thermal image, which is a visualization of temperature information, using distance information, and (4) detection of a faulty apparatus based on the local temperature gradient. We verified this method experimentally. The experimental result of using the new method indicated that by integrating distance information and temperature information, the effect of neighboring heat sources was removed and the faulty apparatus could be correctly detected.

Keywords: diagnosis of apparatus, thermal image, depth map, conic

1. Introduction

In power utilities, research has been conducted on methods of diagnosing the high-frequency noise generated by a malfunctioning apparatus and the temperature with an infrared camera, to enable rapid and reliable detection of power distribution apparatus failure (1) (2). A device that moves on an overhead ground wire has been developed to check whether or not a power distribution apparatus is malfunctioning (3).

When an apparatus malfunctions, an infrared camera is used to detect whether the temperature of the apparatus is higher than usual (4). Inspection of composite insulators on live lines has also been used (5). In those cases, inspectors diagnose apparatuses using an infrared camera. For automatic diagnosis, the importance of thermal image analysis has been pointed out. Database development for thermal image analysis has also been reported (6).

We have developed an automatic faulty apparatus detection method that utilizes thermal images. The method is incorporated into an automatic inspection device for power distribution apparatuses. The proposed method automatically identifies a pin insulator, a strain insulator, and a switch gear from a thermal image and detects the malfunctioning apparatus by comparing the temperature among apparatuses of the same type on a pole (7).

In this method, only two dimensional information is used. As a result, in a district where there are many heat sources around a pole, particularly a commercial district, there is a major problem in that the distance between distribution power apparatuses and other apparatuses is too small to distinguish one from the other. Therefore, in addition to temperature information, we used distance information to solve this problem.

In this paper, first, the problem of extracting the target apparatus using only a thermal image is presented. Next, as a solution, a method of extracting a power distribution apparatus by integrating distance information and temperature information is presented. Finally, the experimental results obtained using the proposed method are described.

2. Problem of Extracting the Target Apparatus using Only a Thermal Image

The distance between two poles is sometimes small in an urban district. One example of this is shown in Fig. 1, where there is a middle pin insulator in front of another pole. Figure 2 shows an example of the temperature distribution for the arrangement in Fig. 1. Temperature is expressed in a thermal image as brightness. Therefore, the y-axis of Fig. 2 gives the brightness instead of temperature. The brightness at each point is defined as the average brightness in a square with a side length of eleven pixels. The pin insulator on the left-hand side was cracked and leakage current flowed on its surface. Consequently, the brightness on the faulty pin insulator is the highest.

The brightness of another pole caused the middle pin insulator to show higher brightness than the right-hand-side pin insulator. This means that the use of two dimensional information may cause the detection system to incorrectly judge the middle pin insulator to be a faulty apparatus.

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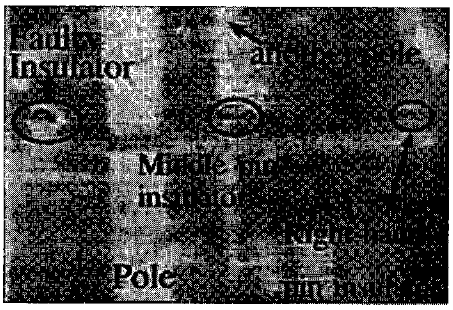


Fig. 1. Thermal image from overhead ground wire

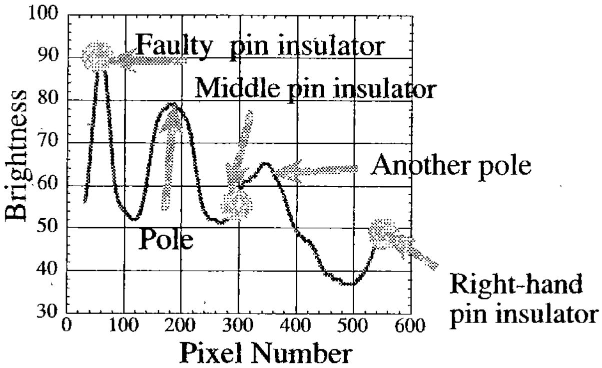


Fig. 2. Brightness in the direction of the arm

3. Integration of Distance Information and Temperature Information

In order to solve the problem arising in the extraction of the target apparatus using only a thermal image, which was described in section 2, distance information obtained with a stereo camera is used. Irrelevant heat sources, such as the rubber cover of a strain insulator on a neighboring pole, are removed based on this information. In this section, the method of integrating the thermal image and a depth map, which is the visualization of distance information, is presented. While the thermal image expresses temperature information, the depth map displays distance information. Superposition of the images from the two cameras is accomplished by Homography, in which corresponding feature points in the two images are defined [8]. Feature points are defined as the points which have special meanings such as a corner of an object or the center of a circle.

Figure 3 shows the Homography process. When an object X in a plane π is projected to X_1 on the screen of camera I, the relationship between X_1 and X is expressed as $X_1 = H_{1\pi}X_\pi$. Similarly, the relationship between X_2 and X_π is $X_2 = H_{2\pi}X_\pi$. Then $X_2 = H_{2\pi}/H_{1\pi}X_1 = HX_1$. The composite of the two perspectives is called a Homography and is expressed as H $(= H_{2\pi}/H_{1\pi})$. In fact, this equation can be rewritten as equation (1). H is a 3×3 matrix, which is generated from more than 8 pairs of corresponding feature points in the two images.

$$\begin{pmatrix} x_2/f_2 \\ y_2/f_2 \\ 1 \end{pmatrix} = \begin{pmatrix} A & B & C/f_1 \\ D & E & F/f_1 \\ P & Q & R/f_1 \end{pmatrix} \begin{pmatrix} x_1/f_1 \\ y_1/f_1 \\ 1 \end{pmatrix} \cdots\cdots\cdots (1)$$

X1 is the point (x_1, y_1) on the plane of camera I, X_2

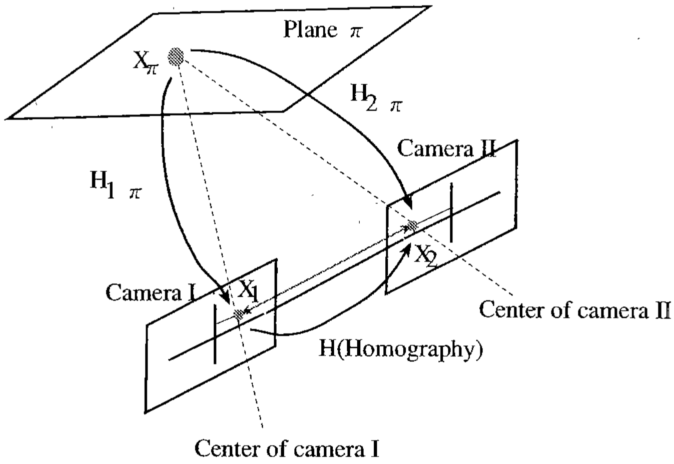


Fig. 3. Homography induced on a plane

is the point (x_2, y_2) on the plane of camera II, and f_1 and f_2 are the focal lengths of camera I and camera II, respectively.

Feature points are precisely extracted using a Gaussian filter [9]. First, feature points such as centers of circles and focal points of ellipses are corresponded to each other. Then, the remaining feature points are corresponded [10]. The reason why the centers and focal points are corresponded first is that objects in a thermal image are blurred and the corner feature points of objects cannot be extracted as precisely as the centers and focal points.

Centers and focal points are extracted through the calculation of conics [11]. A conic is defined as a second-degree equation, which is equation (2), in the plane. There are three types of conics in Euclidean geometry: hyperbola, ellipse, and parabola.

$$ax^2 + 2bxy + cy^2 + 2(dx + ey) + f = 0 \cdots\cdots\cdots (2)$$

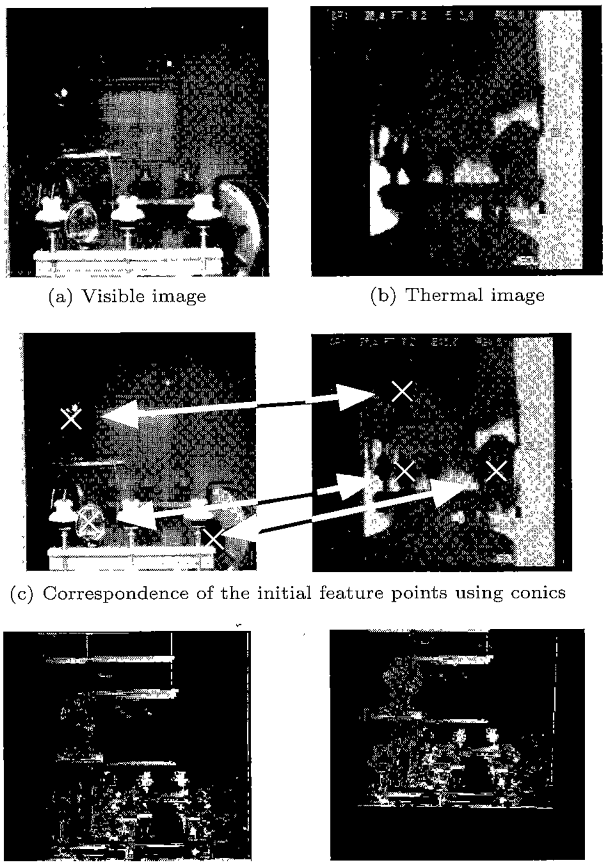
The integration method of distance information and temperature information is as follows.

(1) Initial feature points which are centers of circles are extracted and corresponded (Fig. 4-c).
(2) Calculation of Homography using all feature points.
(3) Calculation of a depth map (Fig. 4-d).
(4) Projection of the depth map onto a thermal image (Fig. 4-b) using Homography (Fig. 4-e).

4. Faulty Apparatus Detection using Thermal Image

During detection of a faulty apparatus on a pole, the problem in which the thermal pattern of the pole is misidentified as a faulty apparatus must be solved [7]. Thermal patterns of poles are wider than those of the apparatus and are nearly constant. Therefore, the thermal patterns of poles are uniform. As the pole absorbs heat from the sun, its high-temperature area becomes wider than that of the faulty apparatus.

The high-temperature distribution in the faulty apparatus is local and appears in the direction perpendicular to the arm. If the temperature gradient in the direction



(a) Visible image (b) Thermal image

(c) Correspondence of the initial feature points using conics

(d) Depth map (e) Projection of depth map onto the thermal image using Homography

Fig. 4. Example of projection of depth map on the thermal image

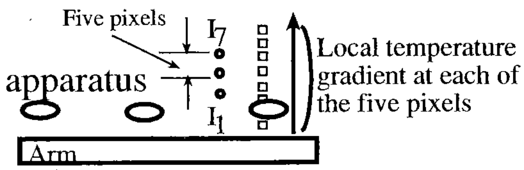


Fig. 5. Calculation of average temperature in vertical direction of the arm

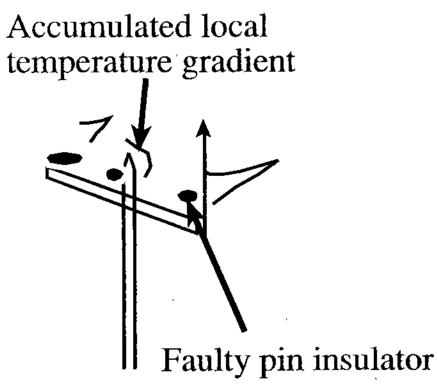


Fig. 6. Faulty apparatus detection using the sum of local temperature gradients in the vertical direction of the arm

perpendicular to the arm is calculated, even if the surface of the pole is warm, the effect of the pole is removed and the detection of an area with a local temperature gradient is realized. This method improves the precision of the detection of the faulty apparatus. The local temperature gradient is expressed as described.

First, as shown in Fig. 5, the average temperature of a square at each of the five pixels is calculated. In this case, the starting point of calculation is the arm and the end point is 30 pixels from the arm. Next, the absolute value of the difference between neighboring points is calculated. As shown in equation (3), in order to enhance the change of the gradient, all of the absolute values of the differences are summed. This is an evaluation measure and is called the accumulated local temperature gradient. Figure 6 expresses this concept.

$$\begin{array}{l}\text{Accumulated local}\\ \text{temperature gradient}\end{array} = \sum_{n=2}^{7} |I_n - I_{n-1}| \cdots\cdots \quad (3)$$

I_n is the temperature at the n-th point.

5. Validation of Extraction Method by Integration of Thermal Image and Depth Map and Distance Resolution of this Method

5.1 Validation of the Proposed Method

Our proposed method is presented in Fig. 7. In this section, the validation of our new method is described.

The experimental setup for the validation of the method is shown in Fig. 8. There are two arms, each with three pin insulators. Each arm has one pin insulator with a higher temperature than the others. On the front arm it is the middle one of the three, and this pin insulator is assumed to be the faulty pin insulator. On the other arm it is on the right-hand side, and this pin insulator is assumed to be nonfaulty. The distance between the arms is 1.5 m.

The process of extraction by integration of the thermal image and depth map is as follows.

(1) Generation of a depth map from a visible image (Fig. 9).
(2) Overlay the depth map and a thermal image (Fig. 10).
(3) Extraction of apparatus from thermal image using the overlay image (Fig. 11).
(4) Detection of faulty apparatus by summing local temperature gradients of apparatus.

As shown in Fig. 12, in the case of using only a thermal image, there are two peaks of the local temperature gradient. In contrast, as can be seen in Fig. 13, integration of the depth map and the thermal image enables the detection of only the faulty pin insulator.

5.2 Distance Resolution of this Method

Distance resolution depends on a number of factors. The factors are focal length, camera resolution, accuracy of calculation of distance from stereo camera images, distance between two cameras and distance between stereo cameras and a target object. Therefore, the stereo camera system must be designed in each situation.

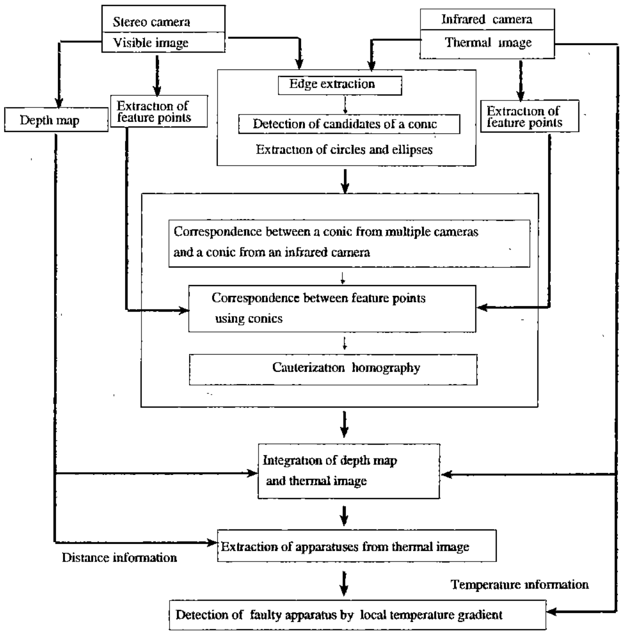


Fig. 7. Flowchart of method of detection by integration of thermal image and depth map

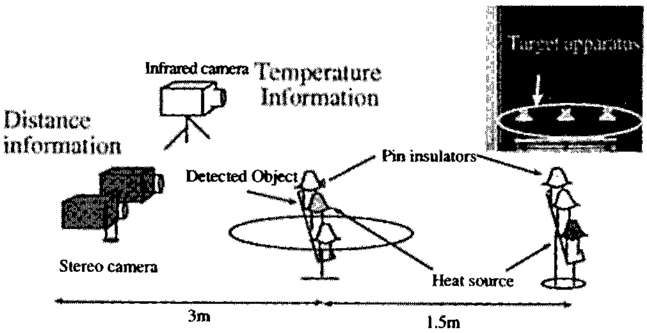
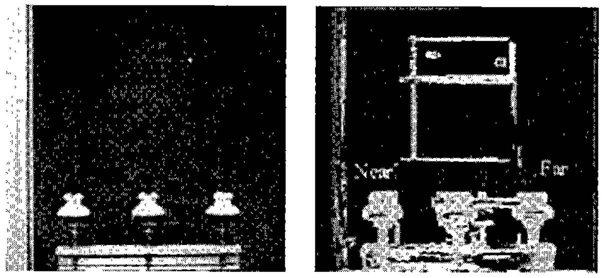


Fig. 8. Configuration for validation of the proposed method



(a) Visible image (b) Depth map

Fig. 9. Generation of depth map

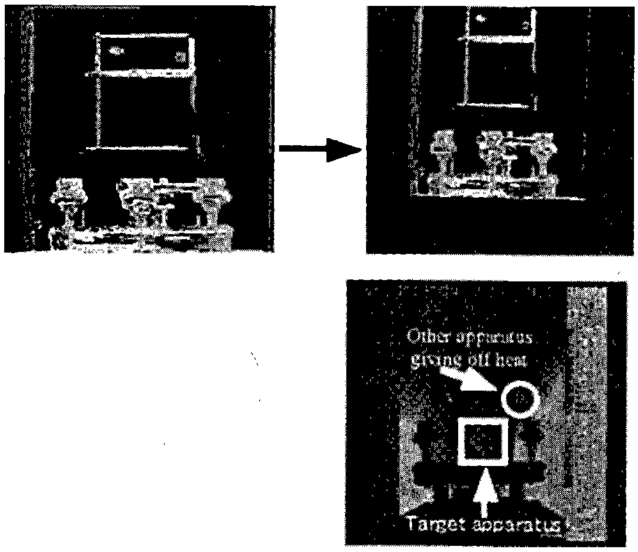


Fig. 10. Overlay the depth map and a thermal image

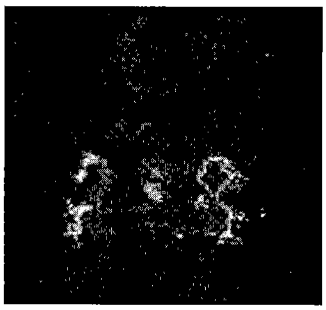


Fig. 11. Extraction of apparatus from thermal image using the overlay image

Because of this, generalized discussion of distance resolution is difficult. Therefore, in this section, the distance resolution of this system is presented.

The specifications of the stereo camera system are as follows.

(1) focal length : ∞
(2) camera resolution : 512×512 pixels
(3) distance between two cameras : 10 cm

As shown in Fig. 14, the distance between stereo cameras and a target object determines distance resolution. In this experiment, distance resolution is about 10 cm/pixel. If the accuracy of calculation of the distance from stereo camera images is 100%, the distance resolution of this method is 10 cm.

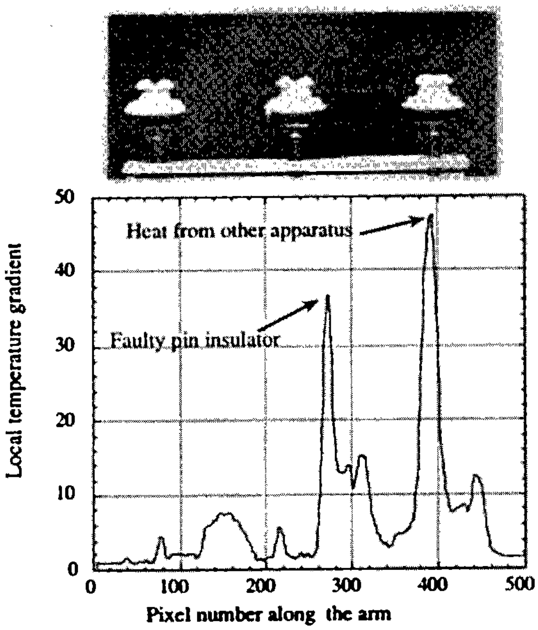


Fig. 12. Temperature information only

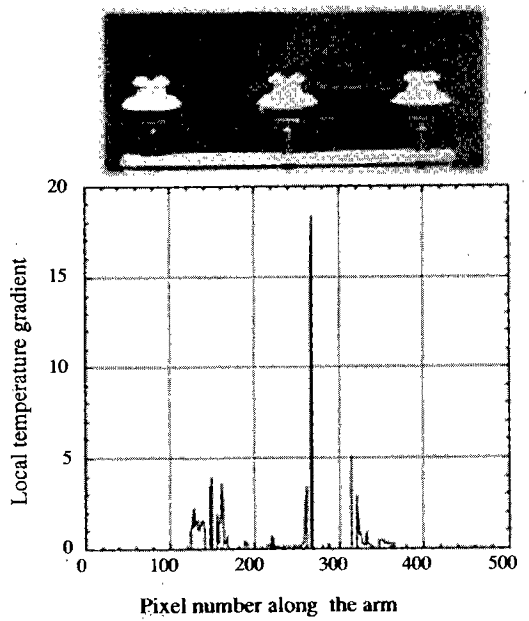


Fig. 13. Integration of distance information and temperature information

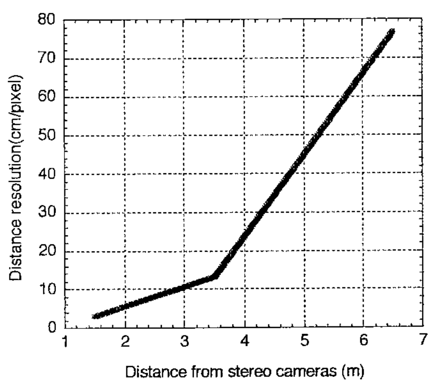


Fig. 14. Distance resolution of this system

6. Conclusions

In this paper, we described the method of detecting a faulty apparatus by integration of temperature information and distance information and the local temperature gradient. It was difficult in our previous method, which uses only temperature information, to eliminate the effect of neighboring heat sources, because only two dimensional information was used. In order to solve this problem, three dimensional information is also used in the proposed method. The experimental result of using the new method indicated that by integrating distance information and temperature information, the effect of neighboring heat sources was eliminated and the faulty apparatus could be correctly detected. The effectiveness of our proposed method was confirmed.

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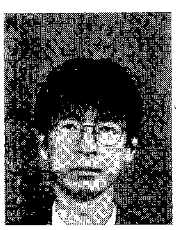

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