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Matching of Thermal and Color Images with Application to Power Distribution Line Fault Detection

Ha-Hyoung Jung[1], Joon Lyou[2*]

[1] Department of Electrical Engineering, Chungnam National University, Daejeon, 305-764, Korea (junghh7@cnu.ac.kr)

[2] Department of Electrical Engineering, Chungnam National University, Daejeon, 305-764, Korea (jlyou@cnu.ac.kr)

Abstract: In this study, we developed a diagnostic system for power distribution lines based on a thermal imaging camera and a color camera. We propose a camera calibration method that shows two images, one from the color camera and the other from the thermal imaging camera with different FOVs, on the screen at the same time. We used the stereo camera calibration method to account for the different characteristics of the two cameras. The cameras were calibrated with the camera calibration tool. From our experiments, the performance and utilization of the proposed distribution line diagnostic system can be evaluated by transforming the thermal images through the intrinsic matrix and the extrinsic matrix.

Keywords: thermal image, color image, stereo calibration, power distribution line, fault detection.

1. INTRODUCTION

Distribution lines among power infrastructure are extensively installed in residential areas and streets [1]. Equipment failures in distribution lines such as switchboards and insulators are caused by high temperature phenomenon of the equipment and by ultrasonic phenomenon caused by disturbances in the surrounding air molecules.

The distribution line diagnostic system is a complex sensor system that incorporates a thermal image camera, a color camera and other sensors. The distribution line diagnostic system improves the performance of fault diagnoses by providing clear information to the user unlike a conventional method in which a person is checking with a single sensor.

Recently, interest in camera calibration research between different camera such as depth camera and thermal image camera has been on the increase [2-5]. Zalud tried to make image fusion for military robots by matching the TOF camera, thermal imager and color camera [2]. And Vidas et al. used an RGB-D camera and a single additional thermal-infrared camera to check the non-destructive temperature monitoring of building interiors for energy efficiency assessment. [3].

In this paper, we used a color camera and a thermal imaging camera with different FOVs and resolutions so the results are more convenient and easier to analyze by the user. The IR camera shows the temperature distribution to determine the degree of equipment degradation. With the thermal image alone, it is not easy to determine the degree of equipment degradation. This, the equipment can be diagnosed by combining the thermal imaging camera and the color camera.

The two cameras are calibrated with captured images from a chessboard which is the reference image for the two cameras [6-8]. We could not use an existing chessboard calibration tool because the color camera can only detect color differences and the thermal imaging camera only the temperature distribution. Therefore, to solve these problems, we developed a calibration tool to show circle patterns in a thermal and color image at the same time. Also, as inspectors observe the overlapped color and thermal image as presented in this study, the visibility would increase much more than depending only on thermal image camera.

The remainder of this paper is structured as follows. The stereo calibration method for thermal and color image calibration are described in Section 2, and the experimental results are presented in Section 3. Finally, the conclusion is presented in Section 4.

2. STEREO CALIBRATION METHOD FOR THERMAL IMAGE AND COLOR IMAGE CALIBRATION

In this paper, the thermal image camera and color camera were placed similarly as a stereo camera system. When two cameras are calibrated, accurate parameters and the geometric relationship between the two cameras should be defined. The method to estimate the parameters of a camera is called the stereo camera calibration method. A variable of a pinhole camera model is the intrinsic parameter of a 3x3 matrix defined as the focal lengths in the direction of the X and Y axes and the principal points in the center of the image. The extrinsic parameter defined as the geometric relationship between the cameras is comprised of the rotation matrix (3x3 matrix) and the translation vector (3x1 matrix).

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$[R|t] = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \quad (2)$$

Where (fx , fy) are the focal lengths in the direction of the X and Y axes, and (cx , cy) indicate the principal points in the center of the image. Additionally, $[R\ /\ t]$ represents the rotation and translation relationship between the cameras [6].

To estimate the camera parameter in Zhang's camera calibration algorithm, we used an image captured from the chessboard of the two cameras' references. We could not detect a general chessboard from the thermal image camera. Thus, we made a calibration tool which recognizes circle patterns in the color camera image, and distinguishes between the temperature difference of a front panel and a cooling back plate by cutting circle patterns at regular intervals [7, 8]. Figure 1 shows the thermal and color images captured by the developed calibration tool. The center points of the circle patterns are needed to use the stereo calibration in the image [9, 10]. The Hough circle algorithm is used to extract the center points. By limiting the regional view of the calibration tool to those extracted feature points, the center points are extracted from the pattern image.

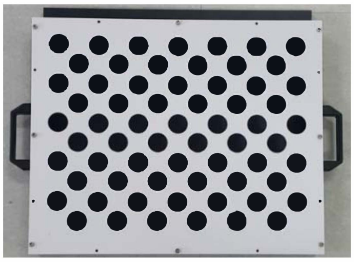

Fig. 1. Calibration tool of circle pattern.

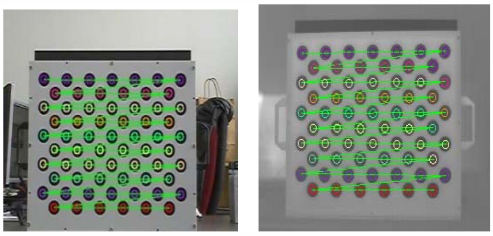

Fig. 2. Extracted point sets of the two cameras

Figure 2 shows the extracted center point sets of the two cameras. We obtained the intrinsic matrix parameter with Zhang's camera calibration method using the center point sets of each image. By calculating the correlation of the two center point sets for the color and thermal camera images, we can estimate the extrinsic parameter (R, t) of the geometric relationship between the two cameras. Next, Table 1 is an intrinsic matrix of a color camera and a thermal image camera. Here, we confirm that a focal length between two cameras with different FOV is dissimilar. Table 2 means the geometric relationship between the cameras, and the base line of two cameras has a gap about 7 cm from Z-Axis direction.

By matching a process of two cameras using an intrinsic matrix and an extrinsic matrix, a transformed thermal image of size and position was displaying. Due to the different FOV, some parts of the thermal image region cannot be checked in a color image.

TABLE I. COMPARISON OF THE FOCAL LENGTH

	Color Camera	Thermal Camera
f_x	652.9	1585.59
f_y	650.36	1582.76

TABLE II. THE TRANSLATION VECTOR OF COLOR CAMERA

(mm)	X	Y	Z
Position of color camera	0.3363	7.4888	68.3971

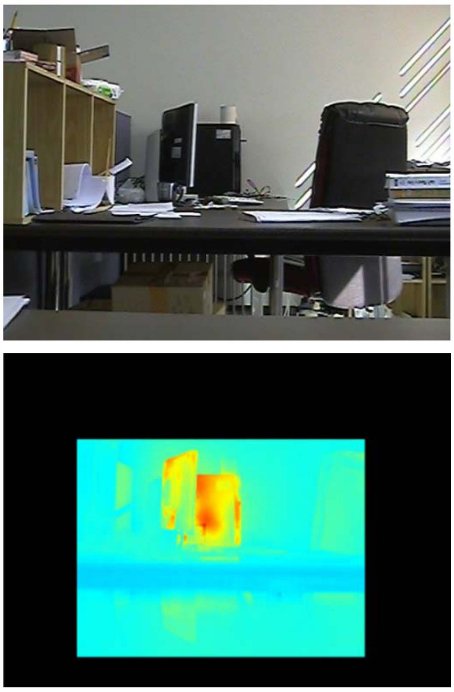

Fig. 3. Conversion images of a color and a thermal image.

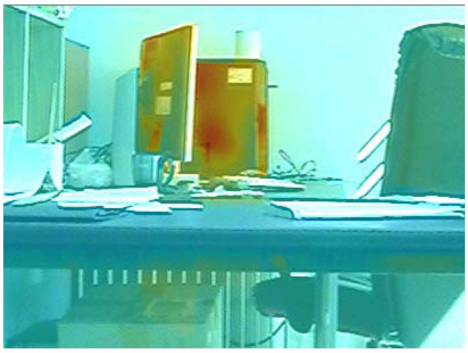

Fig. 4. A fusing image of a color and a thermal image.

So the result corresponds to a cutting image that crops an overlapped image between a colorization of a thermal image and a color image, as illustrated in Fig. 4

It is possible to distinguish objects from the resultant image, and to visualize the temperature distribution of the objects.

3. EXPERIMENTAL RESULT

Our image based distribution line diagnostic system consists of a thermal image camera, a color camera. Figure 5 shows the system dataflow, and Figure 6 shows the hardware sensor configuration.

The image sensor module contains a color camera, a COX CX-320u camera (thermal image camera which has a resolution of 320x240 pixels and FOV 22.6 degree angle, 20 mm lens. This module is tightly fixed by an aluminum case to provide shock protection and movement availability. The color camera and the thermal image camera provide a 30 FPS video steam. The proposed system accepts one or more images or video sequences. The system software is written in the C++ language and made with the OpenCV libraries. It is intended that this can form the basis for further development of a tool for the benefit of the research community.

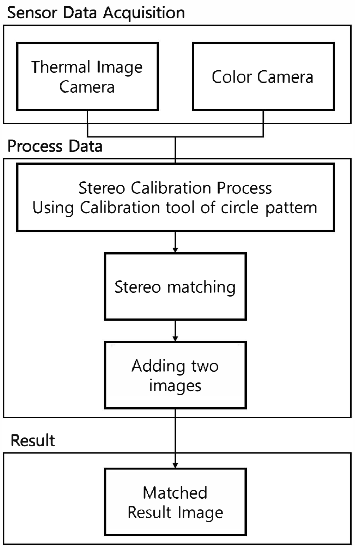

Fig. 5. Diagnostic System dataflow.

Fig. 6. Distribution line diagnostic system.

In order to evaluate the performance, first we experimented with a low-voltage transformer at transformer substations and an autotransformer located at the power supply place of the KTX branch points. And the second experiment was done with an installed utility pole on the road.

In Figures 7, 8, and 9, the pictures on the top left and bottom left are the thermal and the color images, respectively, and the right side of the picture is an image showing the temperature distribution overlaid on the real picture. The thermal image expresses the relative temperature within a screen. A red color can be seen as a relatively high temperature in the image.

Fig. 7. Low-voltage transformer and autotransformer.

Fig. 8. Matched image of autotransformer.

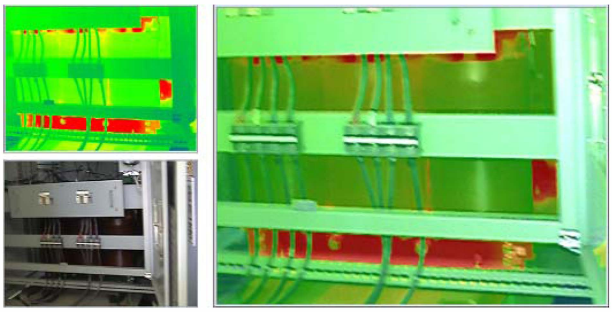

Fig. 9. Matched image of low-voltage transformer.

Unlike the experimental images from indoors, the experimental images of the utility pole filter the air region pixels by applying a threshold value, because the air region temperature is lower than the temperature of the utility poles shown in Figure 10.

Figure 11 shows an additional shot which is experimental image of a distribution line facility. Moreover, it was confirmed that the distribution of heat is correctly shown over the color image.

Fig. 10. Matched image of distribution line facility

Fig. 11. Additional experimental image.

4. CONCLUSION

Distribution line diagnosis system has been implemented using a unified image information (thermal and color images). To correct for the camera, we make a jig and it can be observed from two cameras at the same time. After calibrating two cameras, the overlapping image in a color image and a thermal image represents into one image. Proposed camera calibration method shows the way to match a color camera and a thermal image camera, effectively. And it provides precise matching for the development of a compact image-based power distribution line inspection equipment.

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