Substation Inspection System for Temperature Measurement and Automatic Fault Location Based on Dual-channel Images

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***Abstract*—Overheating and radiation from power equipment is a crucial factor for a variety of failures and anomalies. This paper presents a substation inspection system based on computer and embedded system for temperature measurement and smart fault location for power equipment, to improve the reliability and security of smart grid by effectively combining video surveillance, infrared temperature measurement, and image processing techniques. The accuracy for the temperature measurement was within one degree. With the registration of infrared image and visible image, the fault location can be located automatically. The RMES error for registration between visible image and infrared image was less than one pixel. The time cost is much lesser compared with other image registration methods. Thus, a comprehensive real-time on-line monitoring and smart fault location is achieved. With the accuracy, validity, and efficiency improved, grid maintenance and management is simpler and more economical.**

Keywords-condition monitoring; data integration; fault location; image fusion; inspection; smart grids.

I. INTRODUCTION

The current electrical grid is aging and overburdened, leading to costly blackouts. This can be related to the overheating of power equipment, which is a crucial factor for a variety of failures and anomalies. There are a couple of cases in point. In 2000, the one-hour outage that hit the Chicago Board of Trade resulted in $20 trillion in trades delayed. Sun Microsystems estimates that a blackout costs the company $1 million every minute. The Northeast blackout of 2003 resulted in a $6 billion economic loss to the region [1]. With the rapid advancement of technology, intelligent electronic devices are now widely used in substations [2]. Remote, online, and continuous monitoring of the temperature of power equipment is of great need to assure their security and reliability, which is one of the important goals of the smart grid. Modernization efforts are underway to make the current electrical grid "smarter", preparing for a smart grid, that is to say an electric system that is cleaner and more efficient, reliable, secure, resilient and responsive. A smart grid integrates advanced sensing technologies, control methods, and integrated communications into the electricity grid [3-8].

The trend for power equipment fault detection technology is condition-based maintenance prediction which requires real-time, online, accurate, continuous monitoring, and an automatic alarm and no human intervention. The ordinary detection methods have become unable to meet these requirements. Due to the large number of power equipment and environmental constraints in infrared inspection work, detection is time-consuming, laborious, and the testing personnel's actions are constrained by surrounding high voltage. With the development of the infrared imaging technologies, multimedia communication technology and image processing techniques [9]-[10], people have started to combine video surveillance systems, infrared imaging technologies and image processing techniques [11] for the changing of fault detection method from the manual inspection to condition-based maintenance prediction.

The aim of this paper is to present an inspection system to improve the reliability and security of the smart grid by combining video surveillance, infrared temperature measurement, and image processing techniques effectively.

II. DESIGN OF THE PROPOSED SYSTEM

A remote, online, continuous, real-time monitoring system for temperature measurement and smart fault location of power equipment is brought forward. The entire system is constructed with three main parts: inspection part, network transmission links and the monitoring site, the framework of which can be seen in Figure 1.

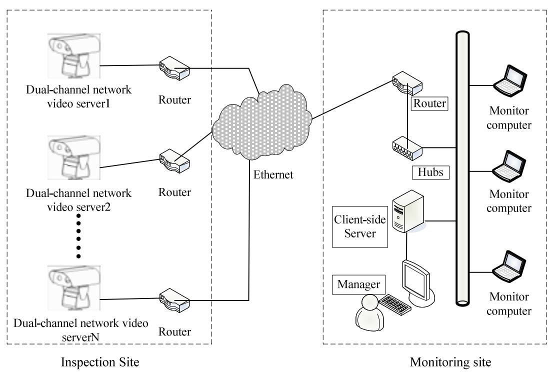

Figure 1. Framework of the proposed system.

The Infrared images and visible images of power equipment are both collected by the video server. The data transmission is through Ethernet. With the image fusion of the infrared image and visible image, the fault point can be located at the monitoring site.

A. *Design of dual-channel network video server*

As shown in Figure 2, the video server is constructed using a TME320DM355 processor, visible video capture module, infrared video capture module, temperature and humidity sensor module, Pan & Tilt (PTZ) control module, and network module. The size of captured visible image is 320×240, and the size of the captured infrared image is 324×256.

The software of the proposed network video server can be divided into two parts, according to the different processors. The development of the main processor is based on the Linux system, and the development of co-processor is based on the Verilog hardware description language.

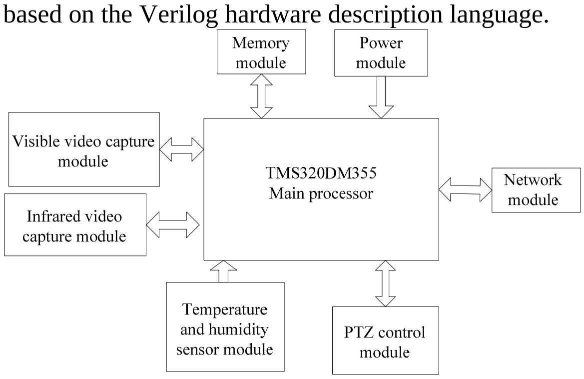

Figure 2. Hardware architecture of dual-channel network video server.

B. *Design of Client-side software*

The client-side software at monitoring site was developed in Microsoft Visual Studio 2005. And the software is testing under Windows XP or Windows 2007, and it is working stably. With slight revisions it can be transplanted to newer operating systems. It includes seven modules: video preview, video playback, alarm, inspection, user management, log management and equipment management.

III. SMART FAULT LOCATION ALGORITHM

The algorithm for temperature measurement and the fault location algorithm using image processing techniques are discussed in the following sections.

A. *Temperature measurement correction and bidirectional table lookup temperature measurement*

Temperature measurement using infrared thermometer relies on the infrared radiation emitted from the surface of the object being measured, which has a positive correlation with the temperature [12]. To get the accurate temperature of the detected object, a revised temperature measurement is proposed to reduce the affect of the three factors mentioned above, emissivity, environmental temperature and distance. To revise the impact of environmental temperature on the temperature measurement for power equipment, a bidirectional table lookup algorithm is proposed. The steps for this algorithm are as following:

The revision methods for the three factors - emissivity, environmental temperature and distance are as follows:

1. Correction of emissivity. Many measurement methods of emission rate correction have been proposed. Metal oxides were often used in power equipments. They have relatively high emissivity – ranging from 0.85 and 0.95. In this paper, the emissivity was set as 0.95 based on preliminary experiments. When detecting other objects, the surface of which may vary according to the applicaiton, the emissivity will be set based on the specifici emissivity detected in field.

2. Calibration of environmental temperature. A bidirectional table lookup algorithm is proposed in this part to overcome the shortcomings of neglecting the variation in thermal value at different environmental temperatures. It uses a 'Temperature - Calorific value' table, and also an 'Environmental temperature change - Calorific value change' table to measure temperature.

3. Calibration of distance. The distance between the object and the infrared detector is a major factor, which will affect the comprehensive atmospheric transmission rate greatly. The transmittance (y) changes along with the distance (x) changes: $y = -0.257x + 1$ (reference value). This study makes appropriate calibrations and compensations in the process of measuring temperature.

B. *Fault location algorithm*

In 1999, Lowe proposed Scale Invariant Feature Transform (SIFT) algorithm [13]. This algorithm can obtain distinctive scale invariant features and calculate their descriptors form images. However this method is time consuming and it can't meet the requirements of real-time applications. Therefore, a lot of a lot of improved algorithms were suggested, including PCA-SIFT [14], GLOH [15], among others. However, they all had shortcomings of different kinds. So Herbert Bay proposed Speeded-Up Robust Features (SURF) [16]. It approximates or even outperforms previously proposed schemes with respect to repeatability, distinctiveness, and robustness, yet can be computed and compared much faster.

In our system, we improved SURF, proposing a SURF based registration algorithm between infrared image and visible image. The flow chart of the registration algorithm between infrared image and visible image is shown in Figure 3.Through the algorithm we proposed, we can get the corresponding point in the visible image of any point in the infrared image. Thus, we can precisely locate the fault point detected in the infrared image in the visible image, helping us understand the location in case we can't make sure only based on the infrared one.

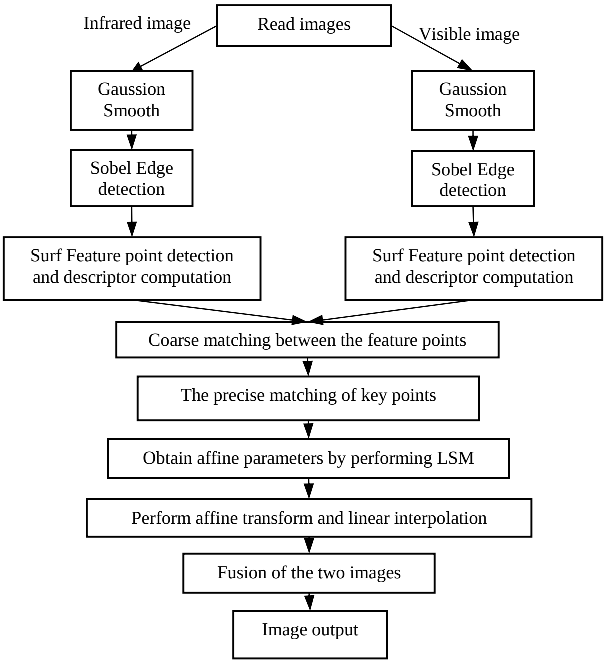

Figure 3. Flow chart of the registration algorithm between infrared image and visible image.

IV. DISCUSSION AND RESULTS

A. System stability test

The proposed system runs stably in the Shangdi 110KV substation, Beijing, China, since March 14th, 2012.

B. Bidirectional table lookup algorithm results

Synthesizing the comprehensive impact of distance, atmospheric absorbing, the environmental temperature revision and distance revision, the temperature revision is compensated to the corresponding thermal values. The compensation effect is more obvious, as shown in Figure 4. The temperature measurement error range with an increase in distance had reduced from 4 ℃ to less than 1.5 ℃.

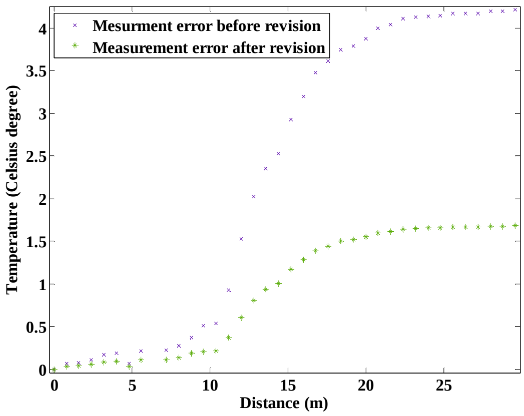

Figure 4. Temperature error comparison for measurement before and after revision.

C. Results of Surf based registration method for fault location algorithm

Through the proposed algorithm, the corresponding point in the visible image of any point in the infrared image can be obtained automatically. Thus, the detected fault point in the infrared image can be located in the visible image automatically, helping people recognize the location. The experiment results obtained by using SURF are compared with the results obtained by SIFT [15] as can be seen in Table I. As can be seen from Table 1, the registration algorithm is pixel level accuracy, can fully meet the requirement of the image fusion. The real-time property and robustness is excellent compared with other algorithms.

TABLE I. EXPERIMENT RESULTS IS COMPARED WITH SIFT

Registration algorithm	RMSE	TIME (s)	Matched pairs
SIFT algorithm	0.940	7.520	26
SURF algorithm	0.747	1.000	34

V. CONCLUSIONS

The contributions of the dual-channel inspection system proposed in this paper can be summarized as follows.

i) Hardware platform is developed based on embedded system with two processors, TMS320DM355 and FPGA. The proposed system has strong scalability, and can access multi-channel video and a variety of image processing algorithms.

ii) We presented a temperature measurement method to reduce the impact of emissivity, environmental temperature and distance between the thermal sensor and the object to be measured.

iii) We presented an edge detection based SURF algorithm to precisely locate the detected fault spot of power equipment using dual-channel image data.

The proposed system has innovations in hardware platforms, temperature measurement method, and overheating fault location algorithms, which can be a good solution for making the current electrical grid “smarter”.

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