



Real-Time Temperature Detecting and Emergency Response System Using Infrared Thermography

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Abstract. Traditional fire or smoke detecting and alarming system detect the fire or smoke that has reached the ceiling after a fire or smoke has happened. By the time the fire or smoke has reached the ceiling, a certain period of time has passed. In the stage of emergency response, time is critical. An irreplaceable accident could have been happened during this certain period of time. Through certain judgmental criteria and mechanisms, an immediate and effective response can be taken before a fire or smoke has happened. In this real time monitoring system, we have integrated a complete accident identification technology and an emergency response mechanism in a fire or smoke detecting and alarming system by using the infrared thermography technology. A real time monitoring system of temperature reading and trending analysis is added to allow a user to verify an anomaly and to take proper actions before an accident has happened. Moreover, by applying this system, the time delay problem in the traditional fire or smoke detecting and alarming system can also be improved.

Keywords: smoke detecting, emergency response, infrared, thermography

1. Introduction

The traditional smoke or temperature detectors in a fire system are installed in the ceiling. By the time smoke has reached to the above three meters height, at least ten seconds has past. The correspondent reactor would be decreased as a consequence. In the semiconductor industry, the most popular smoke detecting equipment is the “Very Early Smoke Detection Apparatus, VESDA.” Its detecting principle is described as following. A pump is installed inside the detecting apparatus; this pump would collect the air in the detecting area and send the sample air to the detecting room for analysis. When the concentration of the analyzed air reached to the set up dangerous level, the detecting system would send out an alarming signal. The detecting speed of this VESDA has been proved to be

faster than the traditional fire detectors. The limitation of this VESDA is that it can only work in some specific areas and if the detecting apparatus are not distributed completely, areas without detectors are still possible for a fire hazard.

This paper is presenting a monitoring mechanism to upgrade the safety of equipment and fab from the viewpoint of reducing equipment risk. Furthermore, by applying this monitoring system, the labor, accident, area and material related to the monitored equipment can also be managed more efficiently. The infrared thermography-detecting device is applied in this system to define the raised temperature value quickly and actively. An emergency response plan should be proposed accurately according to a Fault Tree Analysis, FTA. Comparing to the traditional fire system, the shortages such as slow reaction and improper distribution etc., can be improved. In order to establish the structure of this infrared thermography monitoring system, first, we would introduce the related infrared thermography theories and principle and then we would further apply a quantitative and a qualitative method of fault tree analysis to grade the failure modes.

2. Principle Introduction and Theory Induction

2.1 Introduction of Infrared Thermography

Infrared is a kind of magnetic wave; it is originated from the thermal radiation. The infrared wavelength is distributed from $0.75\mu\text{m}$ to $1000\mu\text{m}$ as shown in figure 1. Nowadays, most infrared thermography detectors apply the infrared wavelength from 2 to $14\mu\text{m}$. Two categories, short wavelength ($2\sim 5\mu\text{m}$) and long wavelength ($8\sim 14\mu\text{m}$) are further divided.

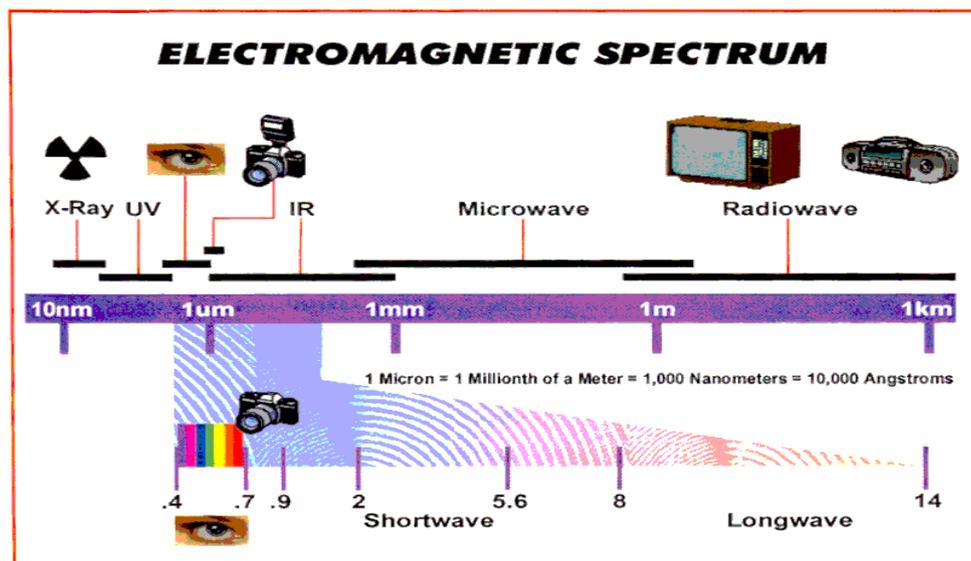


Figure 1 Wavelength distribution of electromagnetic

Every object emits radiation; the temperature detecting method of the infrared thermography is measuring the radiation emitted by an object. After a proper calculation, the temperature value of an object can be obtained. In this paper, a black body radiation theory is applied to explain the temperature measuring method of infrared thermography detectors. The radiation emitted by a blackbody is depends on its wavelength and its relation is described as equation 2-1.

$$M_{\lambda} = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{ch/\lambda kT} - 1} = \frac{C_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1} \quad [W \cdot cm^{-2} \cdot \mu m^{-1}] \quad (2-1)$$

Where M_{λ} is the emittance response to each wavelength of electromagnetic, λ is the wavelength (μm), h is the Planck's constant, T is the absolute temperature, k is the Boltzmann's constant, c is the speed of light and c_1 is the first radiation constant ($2\pi hc^2$). Figure 2 is the curve of this relation and the equation is the famous Planck's Law.

In order to obtain the overall emittance of a black body, we first integrate the whole wavelength of λ (wavelength range 0 to infinite), and then the Stefan-Bolzmann's equation is obtained as below.

$$W = \sigma T^4 \quad (2-2)$$

Where W is the overall emittance, σ is the Stefan-Bolzmann's constant and T is the temperature of a blackbody. According equation 2-2, if we can measure the overall emittance, then we can calculate the temperature value of an object.

The equation of the relations between emittance and temperature is the basic of infrared thermography. But in fact, the black body radiation is an ideal situation of electromagnetic emittance theory; the emittance of a real object is another story. The accuracy of an infrared thermography detector, environmental temperature, environmental humidity and measuring distance etc. would all influence the actual temperature measured. Before activating the infrared thermography monitoring system, the environmental parameters must be set up properly first; otherwise the temperature measured is meaningless. The next section is an introduction of the grading of failure modes by failure tree analysis, FTA. Users can inspect a rising temperature abnormally item by item immediately and find out the root cause of the abnormally.

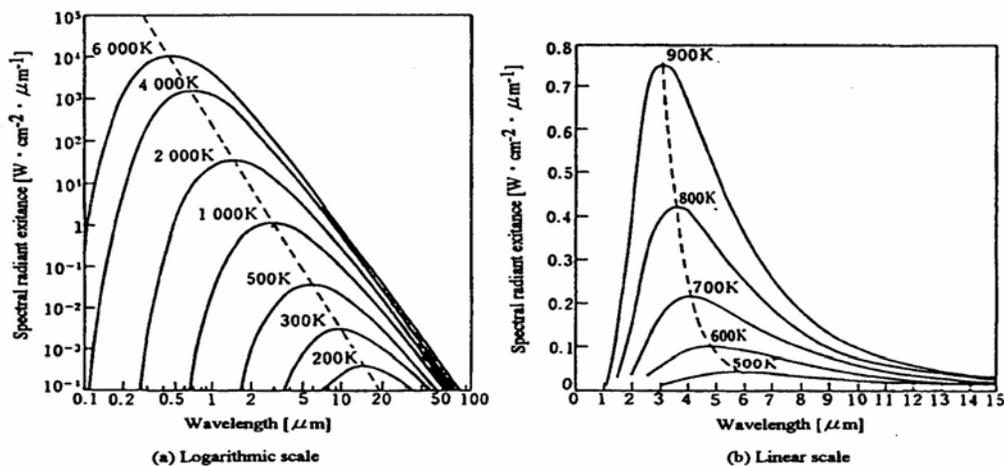


Figure 2 Relation chart among M_{λ} , T and λ

2.2 Grading of Failure Modes by Fault Tree Analysis

The failure tree analysis of failure modes is applied in this system to find out all of the basic events of temperature rising modes. Furthermore, the events are graded according to the probability and the importance. When alarming of infrared thermography monitoring system happens, the root cause can be found immediately by inspecting the graded basic events. Only in that way the efficiency of a fire detecting system can be improved. Following is the example of how we built up the grading system of the FTA basic events. For detail equation application, please refer to reference. Figure3 is the structure of analyzed failure tree. In this structure, five basic events are used and its logical relationship is also shown in this figure.

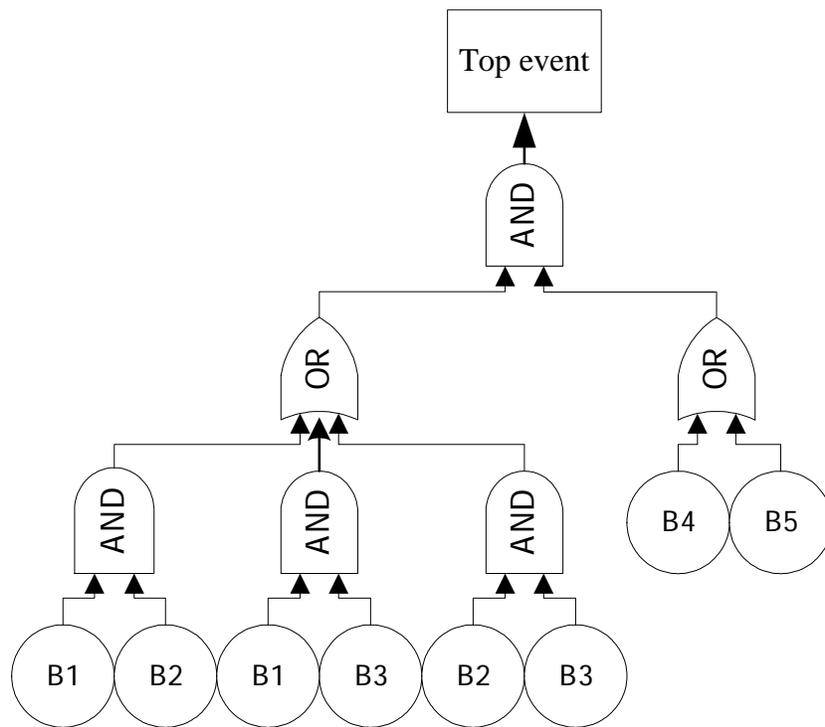


Figure3 Fault tree

Let B_i be the basic events in the fault tree, $i=1,2\dots5$. Assume that the outcome of each basic event has a binary indicator variable Y_i and $Y_i = 1$ when basic event i occurs, otherwise $Y_i=0$. The top event has a binary indicator variable $\Psi(Y)$ and $\Psi(Y)=1$ when the top event occurs, otherwise $\Psi(Y)=0$. The $\Psi(Y)$ is the structure function for the top event, and $Y=(Y_1, Y_2\dots Y_5)$.

According to the definition defined by reference [1], let $N(B_i)$ denote the number of states in which basic event B_i is critical. Then

$$N(B_i) = \sum_{2^{s-1}} [\psi(Y_1, Y_{i-1}, 1, Y_{i+1}, \dots, Y_5) - \psi(Y_1, Y_{i-1}, 0, Y_{i+1}, \dots, Y_5)] \quad (2-3)$$

The structural importance of basic event, B_i is shown as below,

$$I(B_i) = N(B_i) / 2^{5-i} \tag{2-4}$$

Table 1 is the calculated results of $N(B_i)$ and $I(B_i)$ for the example.

Table 1 Calculated results of $N(B_i)$ and $I(B_i)$

Basic event	$N(B_i)$	$I(B_i)$	$P(B_i)$ (%)
B_1	6	$6/2^4=3/8$	80
B_2	6	3/8	88
B_3	6	3/8	25
B_4	4	1/4	45
B_5	4	1/4	84

Let the failure rate of each basic event to be $P(B_i)$, according to the geometry figure of probability and importance shown as below, the basic event B_i can be categorized into a level. (Please refer to Figure 2-4.) The grading of each level is in accordance with each basic event.

As shown in Figure 4, B_1 is in level 4 and same as B_2 . B_3 is in level 5 and so on. When alarming of raised temperature happened, users can inspect if a failure mode has happened according to grading of basic events.

According to the application of the above-mentioned methods, a real time monitoring structure of infrared thermography can be built. Following is the description of the monitoring mechanism and the procedure of application.

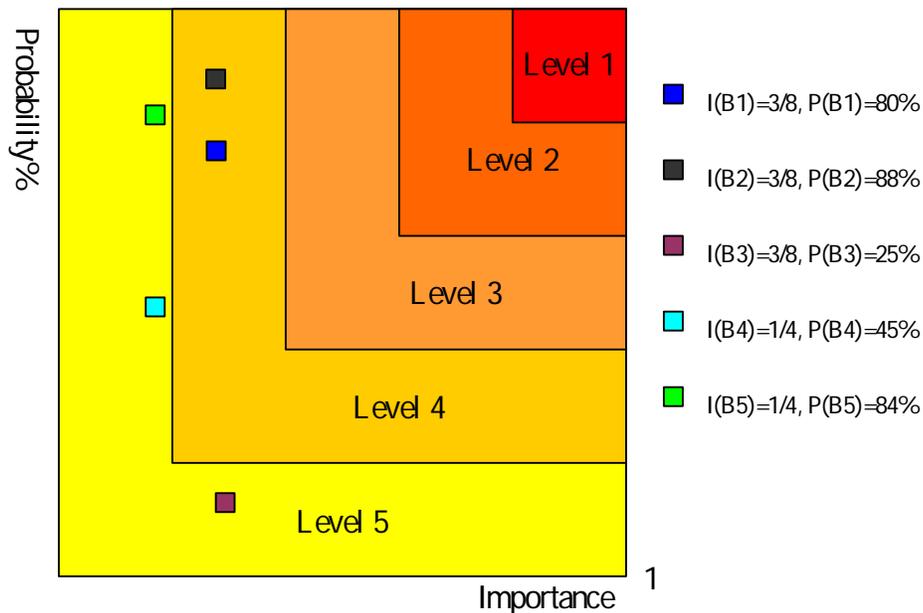


Figure 4 Grading methods of basic events

3. Real Time Monitoring by Using Infrared Thermography

Using infrared thermography detectors to detect temperature has been wildly and rapidly applied in recent years. It has become an important diagnosis apparatus because of the following reasons.

It is a non-destructive inspection method. There is no need to destroy the main body of the inspected equipment.

It is a non-contacted diagnosis method; temperature value can be measured from a certain distance actively. The safety of an inspector is assured.

It is a quick response method; the average response time is within 1ms, comparing to other ordinary temperature measuring apparatus such as thermocouples, the response time is quicker.

A bigger temperature measuring area can be scanned by an infrared thermography. The higher temperature area can be seen easily instead of waiting the temperature or smoke to reach to a sensor.

In this paper an infrared thermography temperature-detecting device is installed with the CCD camera etc. related apparatus to build an integrated real time monitoring and alarming system of infrared thermography. The design purpose, structure and establishment are described as following.

3.1 Design Purpose

The major functions of this monitoring system is as below,

1. Set up the Failure Modes and Effects Analysis, FMEA for the whole plant area and according to the analyzed results, establish the real time monitoring to the equipment or device with higher severity level. When temperature reached to the individual set up alarming temperature value, the alarming mechanism should be activated.

2. Establish the qualitative and quantitative fault tree analysis for each temperature rising modes and grade the basic events geometrically.

3. Send out the alarming signal immediately right after a fire has happened and dispense the alarming signal via different channels to approach the best function of the alarming system. Different kinds of alarming channels are the speaker, cell phone message, e-mail and Internet image monitoring.

4. Transmit signal via Internet to achieve sever monitoring function, so that the server or central control unit can monitor the actual situation far away from site. Through reading the images taken by infrared thermography camera, the director of central control unit can control people's movement under an environment filled with smoke and direct the emergency response procedure. Moreover, the equipment on site can be stop by the central control unit on time.

5. Build up the Emergency Response Data Base, Material Safety Data Sheet, On Site Fire Control Data Base and Profession & Certification Data Base of Facility Engineers. When a fire happened, the central control unit should be able to investigate this Emergency Response Data Base immediately via the data base interface and understand if each on site responsible individual's professions is enough to handle the fire hazard and maintenance. The central control unit can further understand the layout of fire control system on site via this database and find out the conducting procedure of the fire control system. Moreover, the central control unit can also search if there is any

dangerous chemical or hazardous material, any high voltage or high temperature equipment etc. on site to ensure the safety of the emergency response individuals their working efficiency.

According to the above design goals, a structure is built up and accomplished in this paper.

3.2 System Structure and Equipment Specification

This system structure is built on the on site central control unit and is named to be the main sever. Another sever that would be responsible with alarming and response database is named response sever. The system structure is shown as figure 5.

3.2.1 System Structure

The major functions of the main sever in this system are establishing warning temperature, capturing temperature values, capturing CCD images, storing files and transmitting data etc. As for hardware structure in this system, one infrared thermography camera, one CCD camera, one megaphone system and one internet connected system are connected to the main sever.

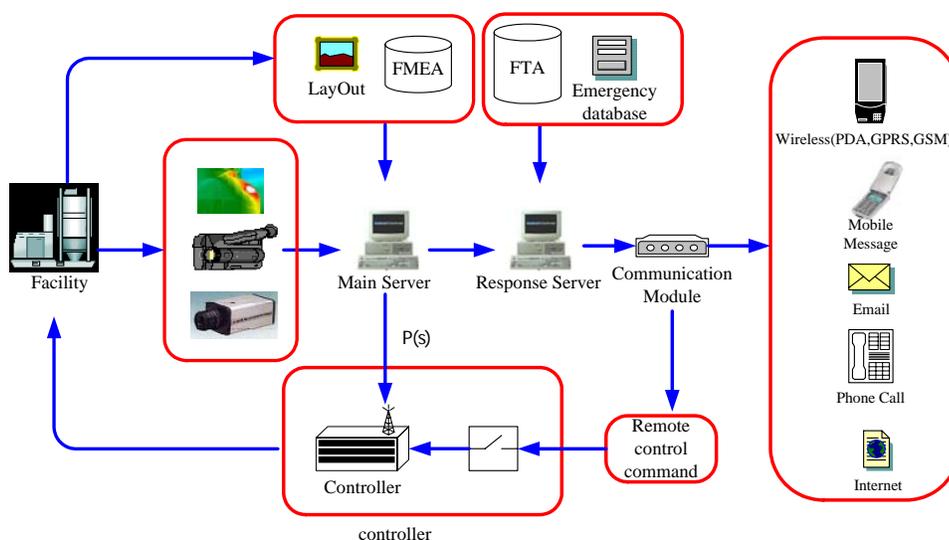


Figure 5 The Structure of Monitoring System

As for the response server, the functions are remote alarming, remote controlling, Internet transmitting and e-mail distribution etc. The Internet connecting system and the cell phone message sending system are connected to this sever. Through the cell phone message and e-mail, the related individual can know if the temperature is over the establishing warning temperature value on time. In the e-mail system, the equipment risk data base, fire protection facility data base, individual profession and MSDS etc. data base can also be access easily. Moreover, through this proactive emergency response system, not only a hazard can be prevented and the handling procedure of emergency response can be conducted more effectively, but also the responsible individual can better understand the equipment, environment and chemical characteristic and take those understanding as a guideline when responding to an

emergency situation.

3.2.2 Performing Method and Result after Actual Conduction

In order to let this system to be more realistic, in this paper, we provide an implementing procedure as shown in figure 6. The risk analysis database for the whole plant must be established first, and the equipment with higher importance and risk must be identified as the object of the real time monitoring system. There are many ways to conduct the risk analysis, but in this system, the FMEA is adopted and the implementing sheet is shown as table 2.

Table2 Failure Modes and Effect Analysis Sheet

Title of a tested object	List the equipment and device		
Function description	List the major functions of the tested object		
Failure mode, failure reason and influence	Probability	Severity	
List all failure mode, failure reason and influence	Value	(10 degrees)	
Prevention and inspection mechanism			
Suggest the prevention and inspection mechanism according to the failure modes			

The next step is to establish the FTA analysis by each rising temperature anomaly, find out the root cause of the anomaly and calculate the probability and importance of each anomaly and grading them. The emergency response procedure of each basic event is then established accordingly. Only when the rising temperature anomaly happened, the response system can be more effective. Lastly, we should set up the parameters such as emissivity, environmental temperature, humidity and alarming factors of the infrared thermography camera. After the parameters have been set up, the monitoring system can then be activated. The system would monitor the temperature periodically. If the monitored temperature is over the warning value, according to the analysis results of the FTA, the system would grade the severity by its basic event and take a proper response plan. At the mean time, the system would send out various type of warning signals including telephone message, cell phone message, internet image transmitting, e-mail and cell phone image transmitting etc. The interface program of the real time monitoring system of infrared thermography is shown as figure 7.

The monitoring system would record the alarming temperature, infrared thermography image and its related CCD image as well as its emergency response action after activation of each alarming and further take the record to be a future reference when a similar accident has happened. Users can also search a record by its timing, accident, equipment, responsible person, fab area, temperature range, warning temperature etc. parameters from the history database. The searching screen is shown as figure 8.

In this real time monitoring system of infrared thermography, each step must be conducted exclusively to ensure the accuracy of the measuring result.

4. Conclusion and Direction of Future Study

The temperature measuring technology of infrared thermography is a reliable nondestructive diagnostic inspection method and its biggest advantage is quick response. It is also a non-contact inspection method that gives it the key values of efficiency and safety. This system has taken the two major advantages, real time and full time along with its complete alarming system and it has evoked the biggest function of infrared thermography technology.

Another important contribution of this paper is the connection with the emergency response database when conducting an emergency response plan. Through assistance of the emergency response database, the director of the central control unit can search an action in correspondence to its failure mode and history data in a fast and appropriate way and handle the emergency accident effectively to eliminate a possible major hazard.

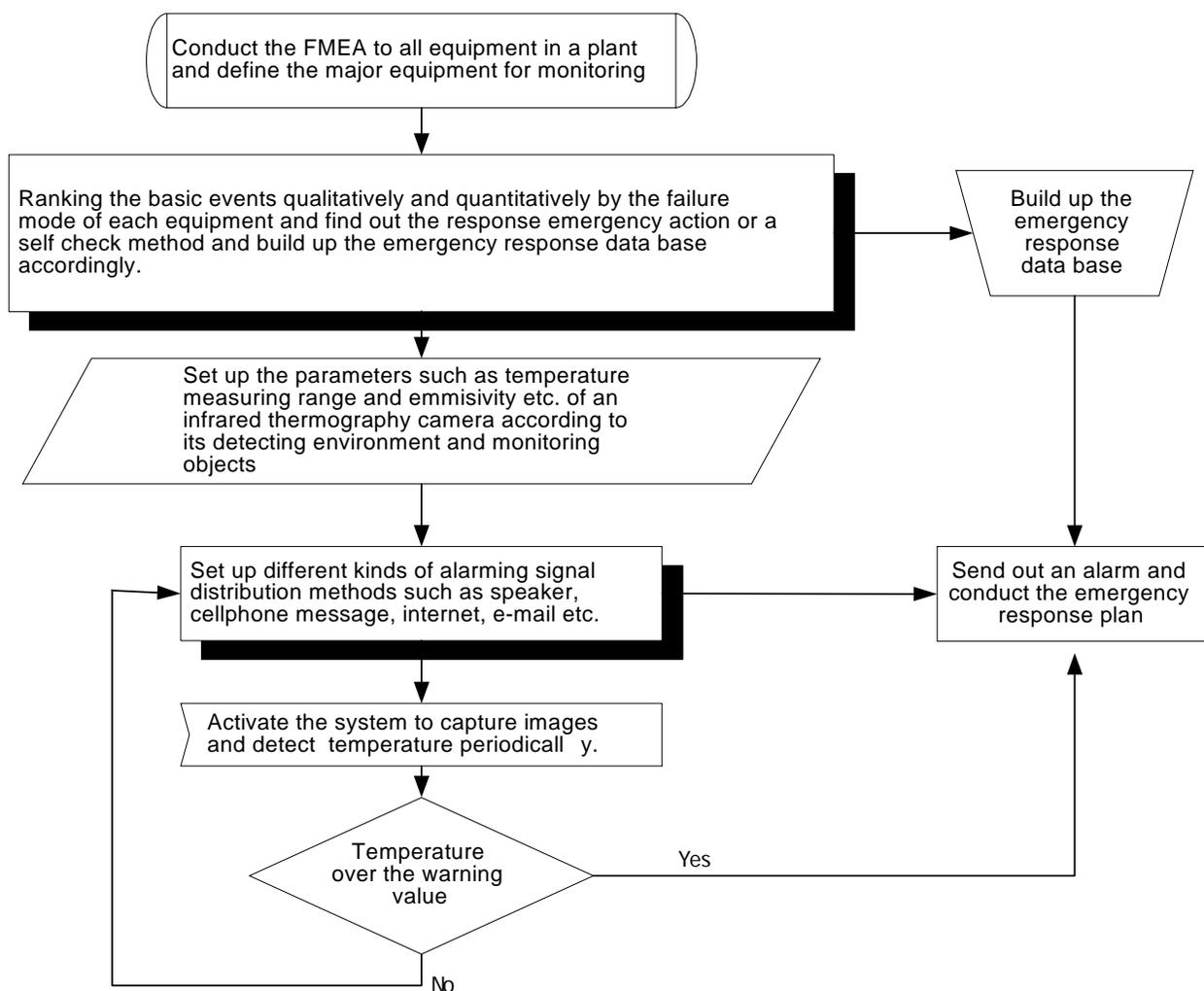


Figure 6 Implementing Procedures

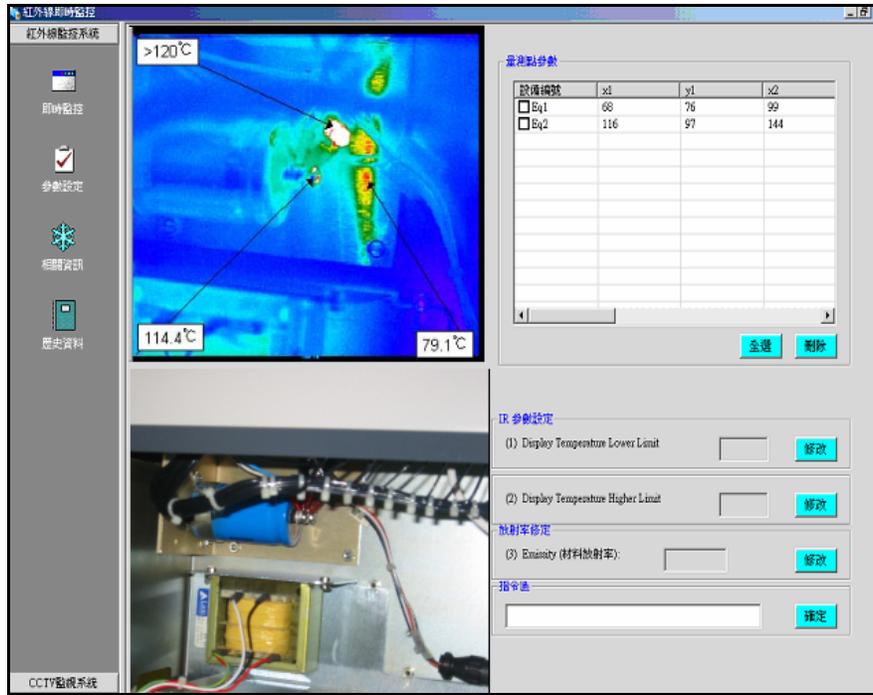


Figure 7 Screen of Real Time Monitoring System

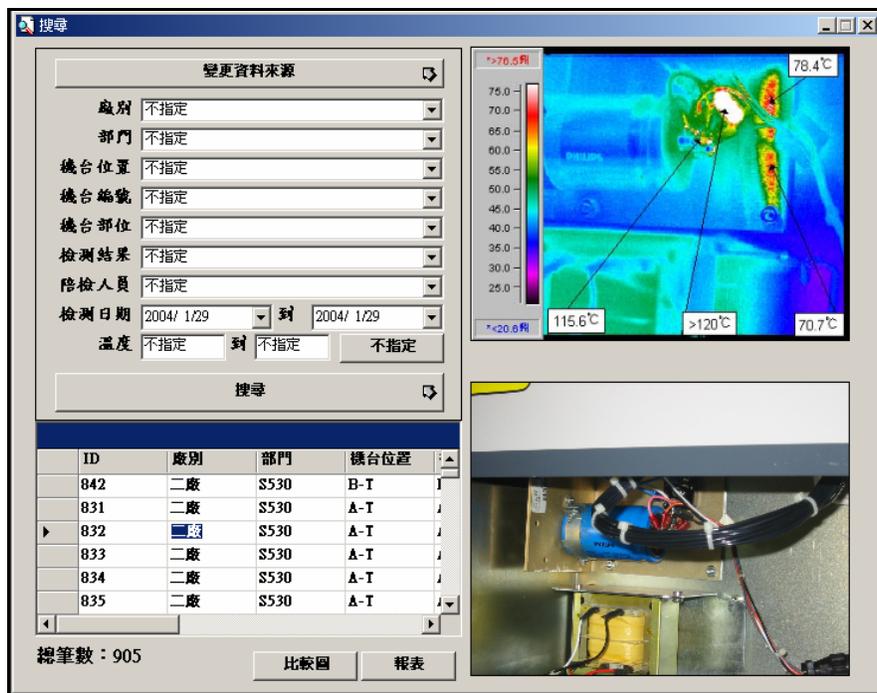


Figure 8 Screen of History Data Inquiry

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