Applications of Infrared Thermography for Noncontact and Noninvasive Mass Screening of Febrile International Travelers at Airport Quarantine Stations

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Abstract Infrared thermography (IRT), one of the most valuable tools, is used for noncontact, noninvasive, and rapid monitoring of body temperature; this has been used for mass screening of febrile travelers at places such as airport quarantine stations for over 10 years after the 2003 severe acute respiratory syndrome (SARS) outbreak. The usefulness of thermography for mass screening has been evaluated in many recent studies; its sensitivity varies from 40 to 89.4% under various circumstances. In this chapter, we perform IRT evaluations for detecting febrile international travelers entering Japan at Nagoya Airport, immediately after the SARS epidemic, from June 2003 to February 2004, and at Naha International Airport from April 2005 to March 2009. The correlation of body surface temperature measured via thermography with the axillary temperature was significant. Through IRT, febrile individuals were detected with good accuracy and the detection accuracy was improved by corroborating surveillance with self-reporting questionnaires. However, there are several limitations associated with the use of IRT for fever screening. For instance, taking antifebrile medications results in rapid modification of the body temperature and directly affects the efficiency of IRT. To solve this unreliability and obtain higher accuracy in mass screening, we have developed a novel infection screening system using multisensor data, i.e., heart and respiration rates are determined by microwave radar in noncontact manner and facial skin temperature is monitored through IRT. The detection accuracy of the system improved, which is notably higher compared to the conventional screening method using only IRT.

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1 Introduction

Infrared thermography (IRT) is a powerful tool for two-dimensional temperature mapping and thereby creating a thermal image. Due to noncontact, noninvasive, and rapid features of IRT monitoring, it has been widely used in clinical medicine and research. For instance, thermal image is an effective indicator for the diagnosis of breast cancer [1], peripheral vascular disorders [2], diabetes [1], fever screening [3] etc. In particular, it has been successfully applied to mass screening of febrile travelers at many quarantine stations of international airports after the severe acute respiratory syndrome (SARS) outbreak in 2003 [4–8].

Conventionally, entry quarantine was carried out in various ways, i.e., self-report from passengers, questionnaires on health condition, visual inspection by quarantine officers; this was done for reducing risks due to the entry of infected passengers into the country. However, quarantine screening by self-reporting questionnaires related to medical state do not provide accurate rate of infected individuals and true symptoms of those infected with epidemic diseases. For this reason, IRT was proposed for non-contact and rapid monitoring of body temperature for mass screening of international travelers. The usefulness of IRT for mass screening has been evaluated in many recent studies; its sensitivity varies from 40 to 89.4% under various circumstances [9–11].

In this chapter, we perform IRT evaluations for detecting febrile international travelers at Nagoya Airport, immediately after the SARS epidemic, from June 2003 to February 2004, and at Naha International Airport from April 2005 to March 2009. Our results indicated that IRT sufficiently detected febrile individuals and its detection accuracy was improved by corroborating surveillance with self-reporting questionnaires. However, there are several limitations associated with the use of IRT for fever screening. IRT deterred inspectors from utilizing due to its unreliability originated from following three causes:

(i) Individual-related causes would alter body surface temperatures. Internal causes such as water and alcohol consumption, pregnancy, estrus cycle, and hormone treatment would increase body temperature and external causes such as sweat and thick makeup would decrease body temperature. In addition, glasses and hats would cover the parts used for detection and body movements while scanning would result in unsuccessful image extraction.

(ii) Machine parameters may be influenced by factors such as ambient temperature, humidity, air ventilation, and performance differential.

(iii) Staff alternation would result in differences in judgment of images; these will be due to untrained or inexperienced inspectors, setting of inaccurate cutoff body surface temperature, and incorrect distance between the subject and IRT equipment.

Considering these issues with using IRT, we proposed a noncontact infection screening system for medical examinations that can be performed within 10 s by measuring vital signs (i.e., heart rate, respiration rate, and facial skin temperature) [12–15]. If a person is infected, not only the body temperature but also heart and respiration rates will invariably increase. Thus, our system automatically detects infected individuals within 10 s by a discriminant function using the measured vital signs. Heart and respiration rates are determined using microwave radar in a noncontact manner, and facial skin temperature is monitored through IRT. By adding heart and respiration rates as the new screening parameters, our infection screening system provides higher sensitivity than that of using only IRT.

This chapter is organized as follows. In Sects. 2 and 3, we introduce IRT evaluations for detecting febrile international travelers at Nagoya and Naha International Airports in Japan. In Sect. 4, we provide an overview of the hardware of the multiple vital sign based infection screening system, as well as the classification algorithm for screening of potentially infected patients. Finally, we draw conclusions in Sect. 5.

2 Fever Screening for SARS Symptoms at Nagoya Airport Through IRT in 2003

Between November 2002 and July 2003, there was an outbreak of SARS in southern China [16]. Nationwide surveillance for SARS in Japan was reinforced and IRT was set up at Nagoya Airport on May 12, 2003. On July 5, 2003, even though WHO announced that all known chains of person-to-person transmission of the SARS virus had been broken, quarantine stations at airports in Japan sustained their thermal scanning for febrile passengers. According to the data collected at Nagoya Airport in 2003 and 2004, we evaluated the efficiency of IRT as a means for quarantine.

2.1 Subjects and Methods

Out of a total of 137,473 subjects, 135,020 were passengers and 2453 were crew members from the 1280 flights arriving from Asian countries and Northern America to Nagoya Airport between June 2003 and February 2004; all these subjects were scanned through IRT (Neo Thermo TVS-700, Avio. Co., Ltd.). The isotherm low temperature was set at 35.4 °C, displaying the subjects above the set temperature in red (see Fig. 1). The distance from the subjects was approximately 3 m. The temperature accuracy was ±2 °C in an indoor environment. The subjects displayed in red on the screen were led to the Health Consultation Room for further measurements of either axillary or tympanic temperature by digital thermometers.

Using the Chi-squared test, we compared fever detections of temperature above 37 °C as detected by thermal scanning and those by self-reported questionnaires.

2.2 IRT Screening Results at Nagoya Airport

A total of 226 subjects (223 passengers and 3 crew members) were displayed in *red* by IRT scanning. Figure 2 shows a histogram of the axillary temperature of the above-mentioned subjects using digital thermometers; 31% of them had temperature 37.0–37.4 °C.

One of the symptoms for diagnosing SARS was a fever of above 38 °C. In this study, 0.054% of the scanned individuals met this criterion. Our follow-up survey found that 60% of these subjects had temperature between 38.0–38.9 °C along with influenza-like symptoms and acute upper respiratory inflammation. Three febrile

Fig. 1 Isotherm low temperature was set at 35.4 °C, displaying targeting subject in *red* above the set temperature
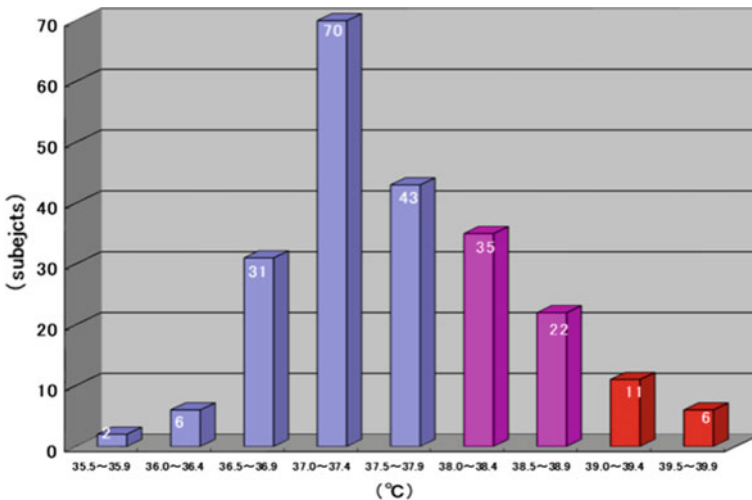

Fig. 2 Histogram of axillary temperature for 226 subjects (223 passengers and 3 crew members, all displayed in red by IRT) measured using digital thermometers

subjects with no clear explanation other than alcohol intake and one subject with sunburn were assumed to be detected as false positive. A self-reporting diarrhea subject, displayed in red by IRT, was diagnosed with dysentery. Sixty percent of the subjects with temperature between 39.0 and 39.9 °C also had influenza-like symptoms and acute upper respiratory inflammation. One subject without self-reporting diarrhea was found to be feverish by IRT and was revealed to have dysentery through a fecal examination.

By adopting the Chi-square test, we compared the detection rate of IRT with a temperature threshold of 37 °C to the detection rate obtained by self-reporting questionnaires. The detection rate of the IRT scan stochastically showed significant difference (significance level under 0.01%) from that of the questionnaires; thereby thermal scan was proved to be efficient for quarantine screening.

This indicates that active surveillance of feverish passengers and examinations at the Health Consultation Room will work efficiently for extracting patients in early stages or incubation period of infection.

3 Four-Year Large-Scale Evaluation of IRT at Naha International Airport in Japan[1]

Two years after the installation of IRT at quarantine stations of major airports in Japan, we conducted a large-scale test for IRT evaluation. A total of 617,289 international passengers who underwent quarantine screening at Naha International Airport from April 2005 to March 2009 were the subjects, out of which 7% of the passengers submitted self-reporting questionnaires.

3.1 Subjects and Methods

Facial skin temperature of all the passengers was measured at quarantine stations through IRT (Infra-eye 2000 DM-IN2000-05, Fujitsu Tokki Systems Limited, Japan). Passengers were made to stand at a distance of 2 m from the IRT to acquire the image for each passenger. The surface temperature of median forehead was measured for those who showed a temperature of above 35.4 °C by Thermofocus (Tecnimed Srl, Italy). Passengers who had a fever of above 37.0 °C as detected by Thermofocus were asked to fill questionnaires and their axillary temperature was measured by a digital thermometer (Thermo Digital Thermometer C202, Terumo Corp.). Clinicians examined those passengers who self-reported symptoms and axillary temperature was measured for those who consented.

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[1]Dr. Shigeto Abe was chief of Naha Quarantine Station in these period.

3.2 IRT Screening Results at Naha International Airport

(i) The effect of seasonal changes on detecting the temperature of feverish subjects

Feverish subjects are defined as passengers having fever as detected by IRT and Thermofocus with an axillary temperature of above 37.0 °C. The number of feverish subjects was 391 (0.063% of all subjects). We investigated the effect of seasonal changes on the detection of the temperature of feverish subjects. Figure 3 shows significant fluctuation in the detection of feverish subjects. We assumed this fluctuation was affected by age and destination of passengers during long holiday seasons, i.e., Golden Week, summer vacation, and New Year's holiday in Japan, and not affected by internal and external conditions of passengers.

(ii) Correlation between axillary temperature and facial skin temperature

The mean value of facial skin temperature scanned by IRT was 35.1 °C and that of axillary temperature measured by thermometer was 37.8 °C. The difference between these temperatures was 2.7 °C, which was greater than the difference of 1.6 °C between IRT set point (35.4 °C) and axillary temperature (37.0 °C). This shows the possibilities of IRT detecting false negatives for febrile subjects. Figure 4 shows the correlation plot of the facial skin temperatures monitored by IRT and the axillary temperatures measured by thermometer. The IRT measurement exhibited a

Fig. 3 Effect of seasonal changes on the detection of the temperature of feverish subjects
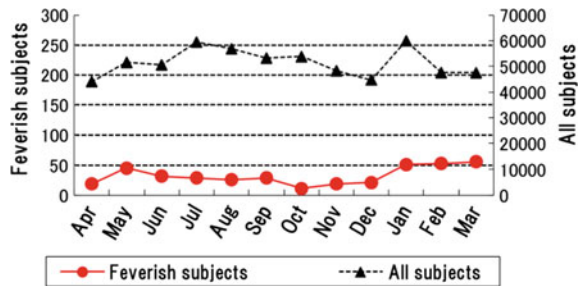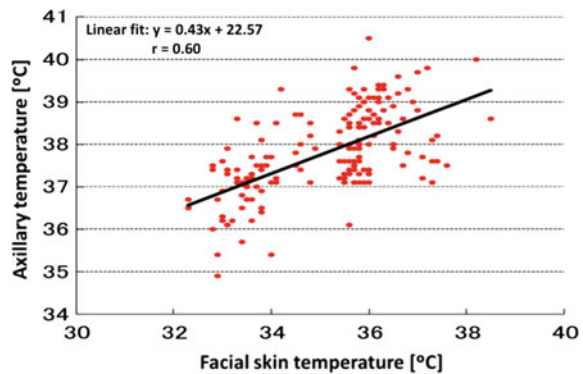

Fig. 4 Relationship between the facial skin temperature measured by IRT and the axillary temperature measured by thermometer

positive correlation with that of the thermometer ($r = 0.60$); the linear least square fitting equation is as follows:

$$y = 0.43x + 22.57 \tag{1}$$

Body surface temperature and axillary temperature, which is assumed to be core temperature, correlated significantly. The result is very similar to that obtained by Ng et al. [4]. In order to increase the correlation between body surface temperature and axillary temperature and maintain detection accuracy of thermography, standard operating procedure must be strictly conducted by quarantine inspectors.

The results indicated that IRT could sufficiently detect febrile individuals and the detection accuracy was improved by corroborating surveillance with self-reporting questionnaires. Questionnaires can be highly reliable when used in combination with thermal scanning that detects feverish passengers negligent to report their symptoms in the questionnaires. By excluding passengers in early stages or incubation period of infection, active border control can be reinforced and precautionary measures will prevent the infection from spreading within country.

4 Multiple Vital Sign Based Infection Screening System

4.1 Fundamental Idea of Infection Screening System

Since fever is one of the major symptoms of infectious diseases such as SARS and influenza, IRT is adopted for febrile passenger screening by monitoring their body temperature. However, facial skin temperature measured through IRT can be affected by many factors, such as antifebrile and alcohol intake, and ambient temperatures. Specifically, taking antifebrile medication results in rapid modification of body temperature and directly affects the efficiency of IRT. In order to achieve more accurate infection screening, we have developed an infection screening system, which monitors infection-induced alternation of heart and respiration rates as well as body temperature in a noncontact manner in our previous studies. The idea of using vital signs stems from the fact that infectious diseases are associated with inflammation and the increased rates of body temperature, heart, and respiration are included in the diagnostic criteria for the systemic inflammatory

Table 1 Diagnostic criteria for systemic inflammatory response syndrome

Criteria	Range
Body temperature	More than 38 °C or less than 36 °C
Heart rate	More than 90 beats per minute
Respiration rate	More than 20 breaths per minute
White blood cell count	>12,000/mm^3, <4000/mm^3, or >10% bands

Two or more of above criteria

response syndrome (Table 1) [17]. One of the criteria for infection is the white blood cell (WBC) count; however, this requires blood samples, which precludes its use as a fast and efficient screening parameter.

4.2 System Design of Infection Screening System for Airport Quarantine Stations

The proposed system automatically detects infected individuals within 10 s via a discriminant function by measuring vital signs, i.e., heart rate, respiration rate, and facial skin temperature.

Our first prototype was designed for airport quarantine stations in 2009 [18]; the schematic diagram of the noncontact infection screening system is shown in Fig. 5. The system consists of a laser Doppler blood flow meter (ALF21N, Advance, Tokyo), a 10-GHz microwave radar (Tau-giken, Yokohama), and an IRT (NEC SANEI, IS7800, Tokyo). The laser Doppler blood flow meter measures the pulse within a range of 3 cm from palmar surface. In order to monitor the respiratory motion of a subject's chest, the microwave radar radiates 10-GHz microwaves with an output power of 7 mW. The subject's facial skin temperature is measured via IRT, which is placed at a distance of 2 m from the target face. The pulse wave measured by laser Doppler blood flow meter, the respiratory curve measured by microwave radar, and the thermal image measured by IRT are displayed in real time.
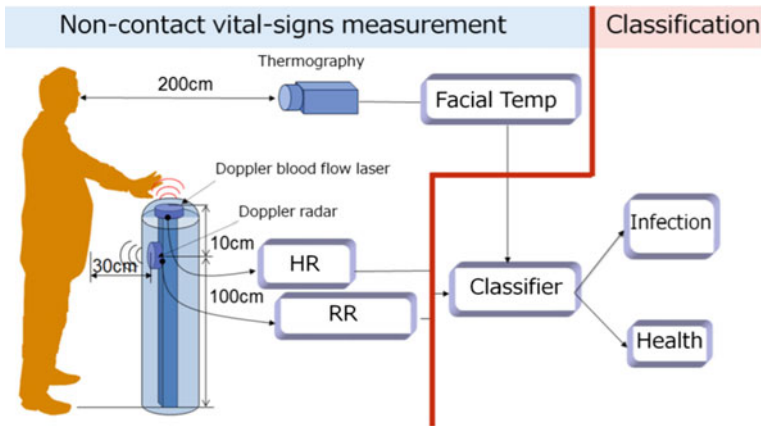

Fig. 5 Diagrammatic illustration of the noncontact infection screening system [18]

4.3 Classification Algorithms for Screening of Potential Infected Patients

In order to execute automatic detection of the patients with potential infection from measured vital signs, we proposed classification algorithms including linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), support vector machine (SVM), k-nearest neighbors (kNN), logistic regression (LR), naive Bayes (NB), and Kohonen's self-organizing maps (SOM) with k-means clustering [19, 20]. In this section, we provide a short introduction of the SOM with the k-means clustering algorithm, which had the most reliable screening accuracy.

The unsupervised algorithm was created by a two-layer neural network, i.e., SOM combined with a k-means clustering method. The input layer had three inputs: heart rate, respiration rate, and facial skin temperature (Fig. 6). First, the preprocessing of the input layer for these three parameters was conducted. Data from all subjects was used to construct an ASCII file, which contained four columns, i.e., three parameters and one label. Whereas the scale of the parameters is important in determining the nature of SOM, we normalized all the parameters using the logarithmic scale. After preprocessing of the input layer, the ASCII file was used to create various SOM clusters. The SOM clustering result was visualized on a two-dimensional color-coded map using the unified distance matrix (U-matrix). The U-matrix shows the distance between neighboring map units by a color tone. This classification is composed of various clusters corresponding to a variety of U-matrix distances (color tone). Second, the k-means clustering algorithm was employed to reduce the SOM clusters into two clusters ("Potential infection group" and "Normal group").
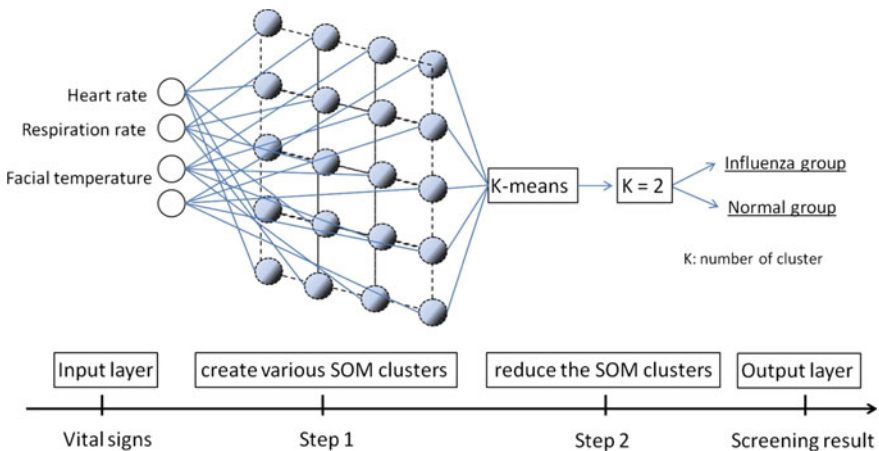

Fig. 6 Schematic representation of SOM combined with a k-means clustering algorithm to generate a nonlinear discriminant function [20]

Table 2 Classification results [21]

Method	Error rate (%)	Sensitivity (%)	Specificity (%)
LDA	10.9	91.2	85.7
QDA	9.8	93	85.7
SVM	9.8	93	85.7
kNN	10.9	93	82.9
LR	12	89.5	85.7
NB	14.1	89.5	80
SOM + k-means	9.7	98	77

We tested these classification algorithms on clinical data, i.e., 57 medicated influenza patients and 35 normal control subjects at the Japan Self-defense Forces Central Hospital. Moreover, we also compared the performance of all the proposed classification algorithms with the data (Table 2). Acquiring heart and respiration rates in addition to facial skin temperature allowed us to reduce the misclassification rate by more than 50%. In addition, mutual information scores and classification results indicate that the multiple vital sign approach for infection screening can present a solution to the problem of identifying infected individuals treated with antipyretics.

5   Conclusions and Future Work

In this chapter, we introduced the applications of IRT for mass screening of international travelers at airport quarantine stations. IRT could sufficiently detect febrile individuals in noncontact manner and the detection accuracy was improved by corroborating surveillance with self-reporting questionnaires. IRT is efficient in detecting infected passengers or those who come in contact with infected individuals in early seasons of epidemic; IRT will play an important role in avoiding the spread of infections with unclear characteristics. The benefits of implementing IRT for quarantine purposes can be summarized as follows:

 (i) Fever at entry will be recorded and the collected data will be used as a reference in other fields of medicine.
(ii) Questionnaires can be highly reliable when conducted with thermal scanning that detects feverish passengers who were negligent in reporting their symptoms in the questionnaires. By excluding passengers in the early stages or incubation period of infection, active border control can be reinforced and these precautionary measures will prevent infection from spreading within the country.

Furthermore, to overcome the limitations associated with the use of IRT for fever screening, we developed a novel infection screening system based on noncontact acquisition of heart rate, respiration rate, and facial skin temperature. Multiple vital
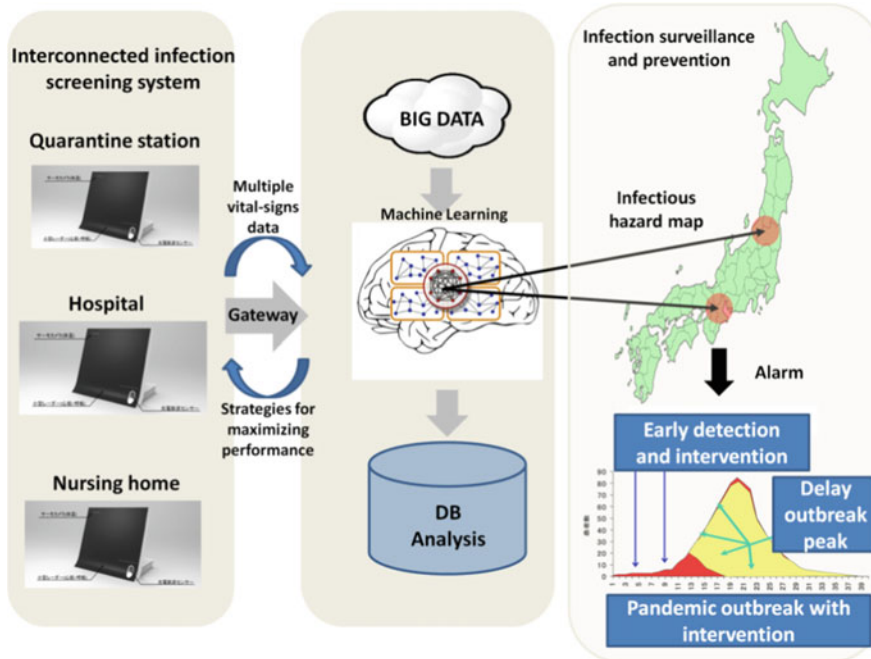
Fig. 7 Network of infection screening system used for early detection and prediction of pandemic outbreak of infectious diseases

sign based infection screening has a much higher potential to increase the detection rate than the traditional IRT-based screening.

To improve screening performance, as a part of future work, one of the most promising approaches is to connect multiple infection screening systems, which enables information sharing between different systems. This will allow us to apply big data analysis techniques, which can be used to predict outbreaks of infectious diseases much earlier than the existing methods (Fig. 7).

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