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Development of an Infection Screening System for Entry Inspection at Airport Quarantine Stations Using Ear Temperature, Heart and Respiration Rates*

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Abstract— **After the outbreak of severe acute respiratory syndrome (SARS) in 2003, many international airport quarantine stations conducted fever-based screening to identify infected passengers using infrared thermography for preventing global pandemics. Due to environmental factors affecting measurement of facial skin temperature with thermography, some previous studies revealed the limits of authenticity in detecting infectious symptoms. In order to implement more strict entry screening in the epidemic seasons of emerging infectious diseases, we developed an infection screening system for airport quarantines using multi-parameter vital signs. This system can automatically detect infected individuals within several tens of seconds by a neural-network-based discriminant function using measured vital signs, i.e., heart rate obtained by a reflective photo sensor, respiration rate determined by a 10-GHz non-contact respiration radar, and the ear temperature monitored by a thermography. In this paper, to reduce the environmental effects on thermography measurement, we adopted the ear temperature as a new screening indicator instead of facial skin. We tested the system on 13 influenza patients and 33 normal subjects. The sensitivity of the infection screening system in detecting influenza were 92.3%, which was higher than the sensitivity reported in our previous paper (88.0%) with average facial skin temperature.**

I. Introduction

During the epidemic season of emerging infectious diseases, rapid screening of infected individuals in places of mass gathering is important to delay or prevent the transmission of the infection [1]. Infrared thermography as a potential tool for detecting fever is widely used for mass screening at gathering places such as airport quarantine stations [2-4]. However, thermography monitors facial skin temperature, which is susceptible to environmental factors such as air condition [5]. A recent study showed that the sensitivity of fever-based screening system with thermography did not exceed 70.4% at Narita International Airport, Japan [6]. Therefore, to achieve more accurate infection screening, we have developed a system which could monitor infection-induced alternation of heart and respiration rate as well as facial skin temperature in our previous study [7]. By adding those two parameters, the system provided a higher screening accuracy than thermography [8].

Our previous infection screening system had used the facial skin temperature measured by thermography as a screening indicator. As mentioned above, the facial skin temperature measured by our system using thermography can also be affected by its environment. For reliable detection of feverish people, many studies agree that ear temperature can provide a good approximation of body temperature [9, 10]. Therefore, to reduce the environmental effects on thermography measurement, we adopted the ear temperature as a new screening indicator instead of facial skin. In this paper, we developed a screening system with three parameters, i.e., respiration rate, heart rate, and ear temperature for airport quarantine entry screening. In order to assess the performance of the new system, we conducted the screening of influenza patients at the Japan Self-Defense Force Central Hospital.

II. Materials and Methods

In this section, two groups were studied: one for evaluating the efficacy of ear temperature as a screening indicator; the other for assessing the screening performance of newly developed system.

A. *A preliminary experiment on evaluating the efficacy of ear temperature as a screening indicator*

The experiment was carried out in a chamber with constant temperature and humidity (Shield Room, Tokyo, Japan). The environmental temperatures were set at 18ºC, 21 ºC, 24ºC, 27ºC, and 30 ºC, respectively. Temperatures of ear and facial skin were measured by a thermography camera (NIPPON AVIONICS, C210C, Japan). At the same time, the core body temperature was measured as a reference by a deep body thermometer (Coretemp CM-210, Terumo Corp., Tokyo, Japan), which could provide a non-invasive monitoring with a zero heat flow method [11]. The Coretemp probe was placed directly onto the abdominal area. The subjects sat down in a resting state for 20 minutes after all measuring devices being attached. The temperatures of ear, facial skin and core body were recorded under the each thermal environment as mentioned above. Ten healthy male subjects with a mean age

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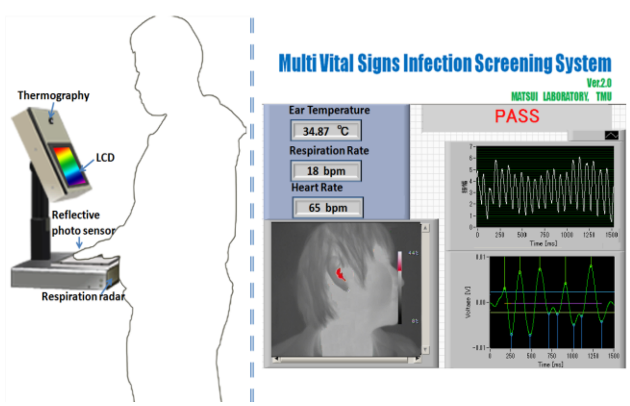
of 22.7 ± 1.25 years participated in this preliminary experiment. In order to evaluate the efficacy of ear temperature as a screening indicator, we compared the ear and facial skin temperature under the each thermal environment. All subjects were fully informed of the purposes and experimental procedures before giving their written consent to participate.

B. Design infection screening system with multi bio-sensors

The infection screening system consists of three biosensors, which are a thermography camera to monitor ear temperature (NIPPON AVIONICS, C210C, Japan), a 10-GHz radar to determine respiration rates (new JRC, NJR4175, Japan), and a reflective photo sensor to measure heart rates (ROHM, RPR-220, Japan). The 10-GHz radar measures tiny chest movements induced by respiration. The reflective photo sensor measures heart rate with the light alternation detected from the palmar tissue. These biosensors are integrated into one instrument body, which dimensions are 0.1 meter width, 0.15 meter depth, and 0.17 meter height. The diagrammatic illustration of the infection screening system is shown in Fig. 1-a. As shown in Fig. 1-a, the subject needs to touch the reflective photo sensor with a right hand to measure the heart rates. To reduce the risk of secondary infections caused by the touch, we adopted a special cloth to prevent secondary infections (NBC, Cufitec, Japan). The contact part of the sensor is covered with the cloth.

The outputs of the reflective photo sensor and 10-GHz respiration radar are transferred to a laptop computer and analyzed in real time. Thermography camera outputs the ear thermal image, which is converted by a video scan unit and is analyzed by LabVIEW Vision toolbox (National Instruments, Austin, Texas, USA). The pulse curves, respiratory curves, and ear thermal image are displayed on the Liquid Crystal Display (LCD) mounted on system. Within several tens of seconds, the infection screening system indicates its result via a neural-network-based discriminant function from measured parameters (Fig. 1-b).



(a) (b)

Figure 1. (a). The diagrammatic illustration of the infection screening system. The thermography was placed 0.45 meter from the ear of the subject, and respiration radar was placed 0.35 meter from the chest of the subject. (b). The pulse waves, respiratory curves, ear thermo image, and the screening results (“PASS” or “POTENTIAL INFECTION”) to subjects by a LCD mounted on system in real time.

C. Neural-network-based discriminant function to distinguish infected individuals from normal subjects

In order to assess the possibility of detecting infected individuals from normal subjects with monitored vital signs, we have proposed a neural-network-based discriminant function in our previous study [12]. The function was created by a two-layer neural network, i.e., Kohonen’s self-organizing map[13] (SOM) combined with a k-means clustering algorithm. The input layer has three inputs: heart rate, respiration rate, and ear temperature (Fig. 2). Firstly the pre-processing of input layer for these three parameters was conducted. The 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 with the logarithmic scale. After pre-processing the input layer, the ASCII file was used to create various SOM clusters. The SOM clustering result is visualized on a two-dimensional color-coded map using the unified distance matrix (U-matrix). The U-matrix shows 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). Secondly, the k-means clustering algorithm was employed to reduce the SOM clusters into two clusters (“Potential infection group” and “Normal group”).

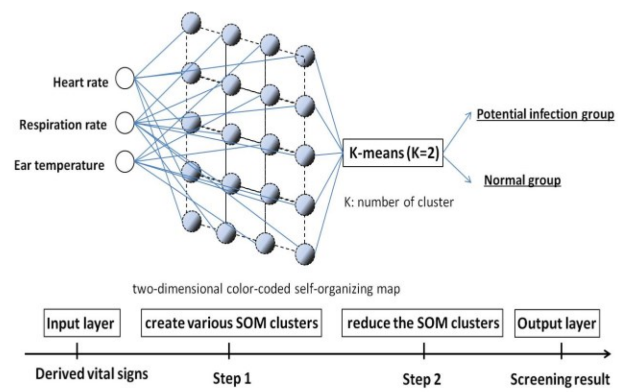


Figure 2. Schematic representation of the SOM combined with a k-means clustering algorithm created a non-linear discriminant function.

D. A clinical trial of seasonal influenza with newly developed infection screening system

The present study was carried out at the Japan Self-Defense Force Central Hospital. The total 13 inpatients were admitted with influenza-like illnesses, and diagnosed to have seasonal influenza based on the results obtained by QuickVue Rapid SP Influ kits (Quidel Corp., USA). The average age of the patients was 26 years (21-41 years). All the influenza patients were treated with antivirus. After starting treatment with antivirus, some of the patients’ body temperature dropped to normal.

The total 33 normal subjects were all students at Tokyo Metropolitan University. These subjects had no symptoms of fever, headache, or sore throat. The average age was 21 years (18-30 years).

Our study was approved by both the Ethics Committee of Japan Self-Defense Forces Central Hospital and the Committee on Human Research of the Faculty of System Design, Tokyo Metropolitan University. All subjects were fully informed of the purposes and experimental procedures before giving their written consent to participate.

III. Results

A. Comparing the ear temperature with facial skin temperature under different environmental temperature

The measured temperature values of ear, facial skin, and core body were averaged under different environmental temperature conditions. Fig. 3 shows the distribution plots of each temperature. Under the same environments, the temperatures of facial skin, ear, and core body were distributed in the range of 32.2-33.3 ºC, 34.8-36.2 ºC, and 36.3-36.6 ºC, respectively. The differences between ear and core body at different environmental temperature were in the range of 0.3-1.5 ºC, while the differences between facial skin and core body were in the range of 3.0-4.0 ºC.

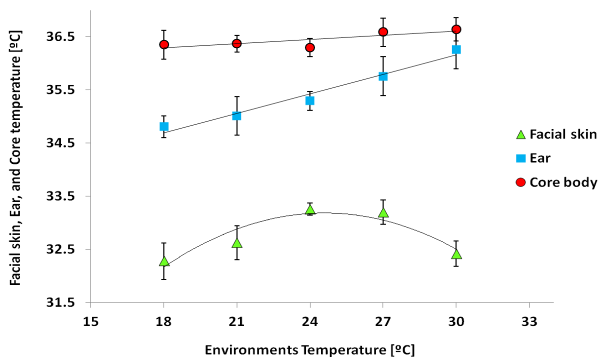


Figure 3. Values of facial skin, ear, and core body temperature averaged over the different environmental temperature.

B. Screening result of the infection screening system

A total of 46 subjects were recruited, consisting of 13 influenza patients and 33 normal subjects. The screening results of SOM with k-means discriminant analysis are shown in Fig.4. Influenza (I1, I2, …) and normal (N1, N2, …) subjects tend to be distributed in the upper part and the lower part of figure, respectively. Twelve out of thirteen influenza patients are included in influenza group, 32 out of 33 normal subjects are included in normal group. One influenza patient was diagnosed as normal by our screening system, the corresponding positive predictive value (PPV) and sensitivity were both 92.3%. One normal subject was contained in the influenza group; the corresponding negative predictive value (NPV) and specificity were both 96.9%.

The classified data were compared among influenza group and normal group. Statistical results are shown in Fig.5. The average heart rate was 68 ± 4 bpm for normal subjects and 90 ± 15 bpm for influenza patients, which is significantly larger than that of normal subjects ($p < 0.05$). The average respiration rate was 17 ± 2 bpm for normal subjects and 21 ± 3 bpm for influenza patients, which is significantly larger than that of the normal subjects ($p < 0.05$). The average ear temperature was 34.8 ± 0.2 ºC for normal subjects and 37.0 ± 1.1 ºC for influenza patients, which is significantly larger than that of the normal subjects ($p < 0.05$). In order to investigate the clustering tendency of respiration rate, heart rate and ear temperature, we summed up the data from all the subjects. We found the heart and respiration rates of the influenza patients were relatively high while their ear temperatures were lower than some of normal subjects. (Table. 1)

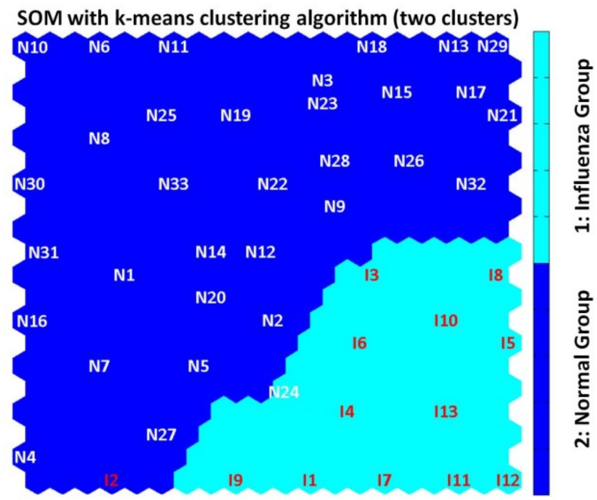


Figure 4. Screening result of SOM with k-means clustering algorithm. A total of 46 subjects are divided into two clusters. 12 out of 13 influenza patients are included in influenza group (light blue cluster), and one influenza patients is included in normal group (dark blue cluster). 32 out of 33 normal subjects are included in normal group, and one normal subject is included in influenza group. The corresponding positive predictive value (PPV), sensitivity, negative predictive value (NPV) and specificity are 96.9%, 92.3%, 96.9%, and 92.3%, respectively.

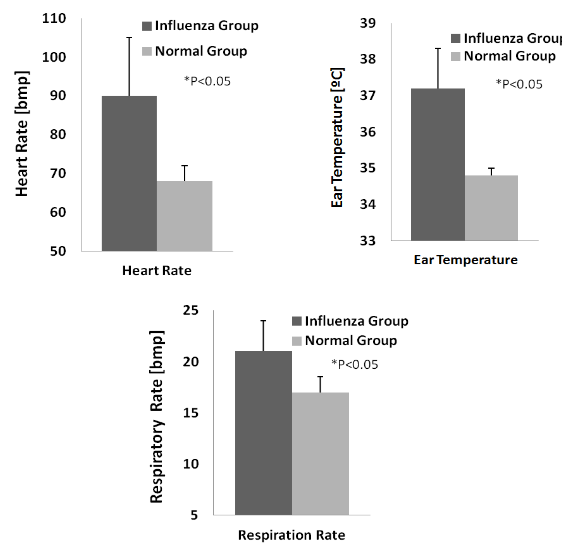


Figure 5. The classified data were compared among influenza group and normal group. The ear temperature, respiration rate, and heart rate were significantly different ($p < 0.05$) between the influenza group and normal group.

TABLE I. DISCRIMINANT FUNCTION OF THE INFLUENZA GROUP AND THE NORMAL GROUP CALCULATED FROM DATA SHOWN IN THIS TABLE (HEART RATE, RESPIRATION RATE, AND EAR TEMPERATURE) USING SOM WITH K-MEANS CLUSTERING ALGORITHM. ONE INFLUENZA PATIENT WAS DIAGNOSED AS NORMAL, SHOWED THE DISCRIMINANT FUNCTION AS "2" (GRAY AREAS).

Influenza patients				**Normal subjects**			
Ear temperature [ºC]	**Respiration rate [bpm]**	**Heart rate [bpm]**	**Discriminant Function**	**Ear temperature [ºC]**	**Respiration rate [bpm]**	**Heart rate [bpm]**	**Discriminant Function**
36.9	18	96	1	35.0	17	71	2
37.3	23	77	1	34.7	18	66	2
36.1	18	74	1	35.3	17	65	2
34.8	19	75	2 (False Negative)	35.8	17	63	2
36.1	18	74	1	35.4	18	64	2

IV. DISCUSSION AND CONCLUSION

We demonstrated a mass screening method of detecting influenza patients with newly developed infection screening system. The system presented the sensitivity of 92.3%, which was higher than the sensitivity (88.0%) reported in our previous paper with average facial temperature [8]. This mentions that to monitor multi-parameter vital signs, not only body temperature but also heart and respiration rates should be incorporated into the screening of infected or non-infected. By adding the new parameters, our infection screening system has improved the accuracy of detection for the mass screening in the places such as airport quarantine stations.

Also, to evaluate the efficacy of ear temperature as a screening indicator, we compared the temperatures of ear and facial skin under different thermal environments. The results point out that ear temperature is relatively free from the effects of environmental temperature, and more accurate than facial skin. Our finding indicates that ear temperature would be useful in reliable detection of people with fever under different thermal environments, which becomes a good indicator for our system. The limitations of our current study are that, the subjects covered one part of age group (18-41 years). It is important to examine this system with a large sample of clinical data to create more accurate discriminant function by SOM and k-means algorithm.

In conclusion, this rapid and sensitive infection screening system can be applied to delay or prevent transmission of infectious diseases and safeguard public health. Furthermore, this system automatically detects the infected individuals and be able to reduce the risks of secondary exposure for health care workers.

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