Design an Easy-to-use Infection Screening System for Non-contact Monitoring of Vital-signs to Prevent the Spread of Pandemic Diseases

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***Abstract*—The outbreak of infectious diseases such as influenza, dengue fever, and severe acute respiratory syndrome (SARS) are threatening the global health. Especially, developing countries in the South-East Asia region have been at serious risk. Rapid and highly reliable screening of infection is urgently needed during the epidemic season at mass gathering places, such as airport quarantine facilities, public health centers, and hospital outpatients units, etc. To meet this need, our research group is currently developing a multiple vital-signs based infection screening system that can perform human medical inspections within 15 seconds. This system remotely monitors facial temperature, heart and respiration rates using a thermopile array and a 24-GHz microwave radar, respectively. In this work, we redesigned our previous system to make a higher performance with a user-friendly interface. Moreover, the system newly included a multivariable logistic regression model (MLRM) to determine the possibility of infection. We tested the system on 34 seasonal influenza patients and 35 normal control subjects at the Japan Self-Defense Forces Central Hospital. The sensitivity and specificity of the screening system using the MLRM were 85.3% and 88.6%, respectively.**

I. Introduction

Recently, the first human infection with the novel avian influenza A (H7N9) virus was reported in mainland China in March 2013 [1]. Infectious diseases such as influenza, SARS, and dengue fever are serious public health problems and challenge to the scientific communities, because they cause annual epidemic or occasional pandemics [2]. Many airport quarantine facilities adopted fever-based screening to identify infected individuals using infrared thermography systems to control global pandemic [3]. Unfortunately, some studies indicate that fever-based screening during early-stage of infectious diseases is limited because many factors can affect thermographic measurements, such as, antifebrile intake, alcohol consumption and ambient temperatures [4].

Based on this background, we proposed an infection screening system that can rapidly and accurately perform medical inspections for the people at mass gathering places [5, 6]. As a result of being infected, not only body temperature but also heart and respiration rates increase. Therefore, our system detects infected individuals via a discriminate function using measured vital-signs; the detection accuracy of the system improved to 88.0% in our case control study [7]. This is notably higher compared to the conventional screening method using only thermography.

In this work, we focused on redesigning our previous system to achieve an easy-to-use and high performance system. Two key concepts were used in redesigning the system: (1) we aimed at developing a fully non-contact infection screening. Because our previous system had used a reflective photo sensor to measure pulse rate, the subjects need to touch the photo senor which may cause secondary infections. To measure the heart and respiration rate in reliable and non-contact way, we adopted a 24-GHz I/Q channel microwave radar and designed a signal-processing printed circuit board (PCB) to amplify and extract the respiration and heartbeat signals [8]. (2) To distinguish between infected individuals and normal control subjects, a multivariable logistic regression model (MLRM) was used to establish the classification model using the derived vital-signs. We demonstrated the effectiveness of this newly designed system on seasonal influenza patients at the Japan Self-Defense Forces Central Hospital.

II. Methods and Materials

A. The Infection Screening System Hardware Configuration and Software Development

The infection screening system consists of a compact thermopile array [9] to measure facial temperature (CHINO, Tokyo, Japan) and a 24-GHz microwave radar (New-JRC, Tokyo, Japan) to measure heart and respiration rates (Fig. 1). A signal processing PCB was designed to amplify the radar signal and extract the respiration and heartbeat signals. The thermopile array receives infrared rays from the facial skin at approximately 2,000 pixels, and converts the rays into voltage through a thermopile. We measure the highest temperature of the face from the all 2,000 pixels. A 7-inch tablet PC was embedded in the system, and a 14bits A/D converter (National Instruments, USB-6009 OEM, USA) with a sampling rate of 100 Hz was used for communicating between the tablet and sensor parts. The system can be powered by a 12 V wall plug AC/DC adapter or a battery. The software was developed on LabVIEW (National Instruments, Texas, USA) for data acquisition, analysis and display.

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When the user seat at a distance (approximately 30–50 cm) away from the system for 15 seconds, related signals were recorded and analyzed, and then the facial temperature, respiration rate, heart rate, and screening results ("PASS" or "POTENTIAL INFECTION") are displayed on the tablet screen.

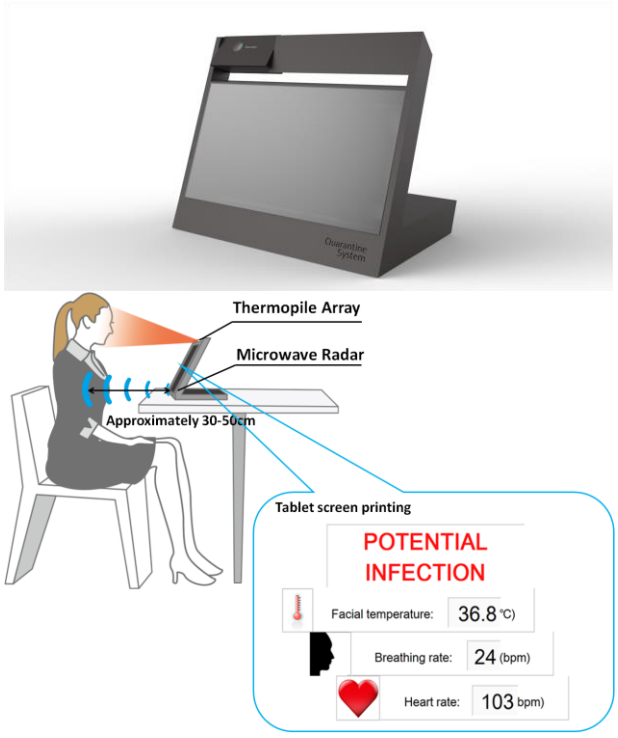

Figure 1. The diagrammatic illustration of the infection screening system. The system was placed approximately 30–50 cm from the subject. The facial temperature, respiration rate, heart rate, and the screening results ("PASS" or "POTENTIAL INFECTION") were shown to subjects in real time.

B. *The MLRM-based Discriminant Function to Distinguish Infected Individuals from Normal Control Subjects*

Our previous infection screening system included a linear discriminant analysis (LDA) and was used to screen influenza patients at Japan Self-Defense Force Central Hospital [7]. However, the main disadvantage of LDA was that could be used only when screening parameters were normally distributed. In the present study, a MLRM was used to establish the classification model using the derived vital-signs. Multivariable logistic regression is a well-known statistical method for analyzing binary outcomes [10]. Unlike LDA, which has been developed for normally distributed explanatory variables, logistic regression fits many types of distribution well. Therefore, the logistic regression method is flexible, robust and allows meaningful interpretation. The MLRM was assigned as follows:

$$Y(X_1, X_2, X_3) = \log\left(\frac{P_i}{1-P_i}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \quad (1)$$

where P_i is the probability of the outcome of infection; α is a constant; β_1, β_2, and β_3 are the regression coefficients corresponding to facial temperature, heart and respiration rates, respectively; and X_1, X_2, and X_3 are the three vital-sign variables. The results from the classification model were used to calculate the sensitivity and specificity of the infection screening system via a 2 × 2 contingency table. All statistical analyses were performed using R (2.15.3) software (http://www.r-project.org/) and its associated packages.

C. *Screening of Seasonal Influenza Patients Using Newly Developed Infection Screening System at a Hospital*

This study was designed as a cross-sectional investigation at the Japan Self-Defense Force Central Hospital from January to February 2014. The patients in this study included 34 inpatients (31 male and 3 female) diagnosed to have influenza by using QuickVue Rapid SP Influ kits (Quidel Corp., USA). These patients were treated with antiviral medications (i.e., oseltamivir or zanamivir), some of the patients' axillary temperature dropped to normal and their average axillary temperature was 37.6°C (36.1°C < axillary temperature < 39.3°C). The average age was 27 years (19–51 years). The normal control subjects (35 subjects: 30 male and 5 female) were the students at Tokyo Metropolitan University. These normal control subjects had no symptoms of fever, headache, or sore throat. Their average axillary temperature was 36.4°C (35.5°C < axillary temperature < 37.2°C), and average age was 23 years (21–29 years).

Measurements using the infection screening system were performed at 13:00–15:00 with the above influenza patients and normal control subjects. The heart rate, respiration rate, and facial temperature of each subject were detected using the infection screening system. The reference axillary temperature was measured using a clinical thermometer (TERUMO, C220, Japan) for both influenza patients and normal control subjects. This study was approved by the Committee on Human Research of the Faculty of System Design at Tokyo Metropolitan University and the Ethics Committee of Japan Self-Defense Forces Central Hospital. All subjects were fully informed of the purposes and experimental procedures before giving their written consent to participate.

III. Results

The MLRM classification model was calculated using the three vital-signs of the 34 influenza patients and 35 normal control subjects. The discriminant function was calculated as follows:

$$Y(X_1, X_2, X_3) = \log\left(\frac{P_i}{1-P_i}\right) = -45.6 + 0.8X_1 + 0.1X_2 + 0.6X_3 \quad (2)$$

where X_1 is facial temperature, X_2 is heart rate, and X_3 is respiration rate. The three regression coefficients corresponding to facial temperature, heart rate, and respiration rate were statistically significant (χ^2 *test,* $p < 0.01$). The screening system determines that the subject is infected when Y values are positive and not infected when Y values are negative. Y values can be used to differentiate patients with influenza from those who are non-infected.

The discrimination result of MLRM model is illustrated in Fig. 2 by plotting the Y values versus the axillary temperature of the two groups. The 29 out of 34 influenza patients' Y

values were positive, 31 out of 35 normal control subjects' Y values were negative. Four normal control subjects were misclassified and showed the positive Y values; five influenza patient were misclassified and showed the negative Y values. The corresponding sensitivity and specificity were 85.3% and 88.6%, respectively.

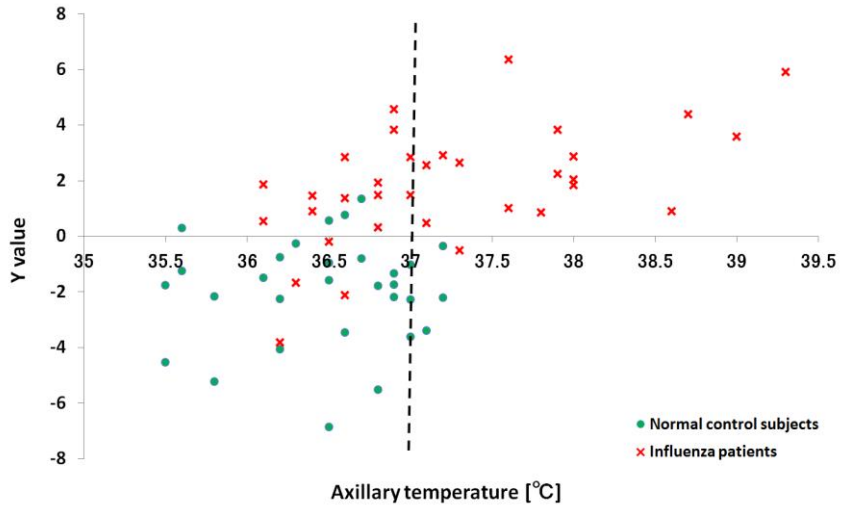

Figure 2. The scatter plot shows the relationship between Y value of MLRM and axillary temperature. The screening system determines that the subject is infected when Y values are positive and not infected when Y values are negative. The 29 out of 34 influenza patients' Y values are positive, 31 out of 35 normal control subjects' Y values are negative. Five influenza patients were misclassified and showed negative Y values; Four normal control subjects were misclassified and showed positive Y values.

The Y values and three vital-signs are shown in part in Table 1. The heart and respiration rates of the influenza patients were relatively high even their facial temperatures were lower than some of normal control subjects (Table 1, gray area). Moreover, some of the influenza patients showing the normal values of vital-signs were misclassified into normal group, which can be explained that the patients had been treated with antiviral medications at recovery stage.

TABLE I. THE DISCRIMINANT FUNCTION OF THE NORMAL CONTROL GROUP AND THE INFLUENZA GROUP CALCULATED FROM DATA SHOWN IN THIS TABLE (HEART RATE, RESPIRATION RATE, AND FACIAL TEMPERATURE) USING MLRM MODEL.

Normal control subjects

FT [°C]	RR [bpm]	HR [bpm]	Y values
32.7	14	59	-4.9
35.1	18	61	-0.7
35.3	13	78	-1.9
34.9	16	82	-0.2
34.0	21	85	3.0

Influenza patients

FT [°C]	RR [bpm]	HR [bpm]	Y values
37.1	20	95	5.7
34.4	21	101	5.1
34.2	19	106	3.9
34.7	18	98	2.9
34.2	15	67	-2.9

FT: facial temperature; RR: respiration rate; HR: heart rate

The vital-signs data were compared between influenza group and normal control group using Student's t-test. Statistical results are shown in Fig.3. The facial temperature of influenza patients (35.6 ± 0.9°C) averaged 0.8°C higher than that of normal control subjects (34.9 ± 0.8°C); the respiration rate of influenza patients (19.7 ± 2.9 breaths/min) averaged 3.6 breaths/min faster than that of normal control subjects (16.1 ± 2.9 breaths/min); and the heart rate of influenza patients (82.4 ± 11.6 beats/min) averaged 18.9 beats/min faster than that of normal control subjects (63.5 ± 9.7 beats/min).

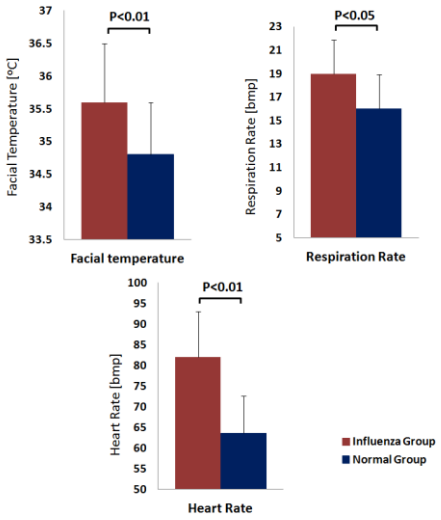

Figure 3. The vital-signs data were compared between influenza group and normal control group. The facial temperature ($p<0.01$), respiration rate ($p<0.05$), and heart rate ($p<0.01$) of influenza patients are significantly higher than those of normal control subjects.

I. Discussion

Infectious diseases such as influenza and SARS are serious public health problems and challenge to the scientific communities. Therefore, our research group considers how to develop a method for rapid screening of infected individuals at early stages to prevent the spreading of the virus. In present study, we have updated our previous system to achieve an easy-to-use and high performance system. The new system can contactless monitor of facial temperature, heart and respiration rates, with the MLRM to determine the possibility of infection.

Infrared thermography has been applied to fever screening at airport quarantine stations for almost 10 years after the 2003 SARS outbreak [11, 12]. Taking an antifebrile readily modifies the body temperature and directly affects the thermography sensitivity. Therefore, some recent studies indicated that fever screening using thermography is still insufficient in detecting the patients with suspected infectious diseases [4, 13]. In this study, we also obtained similar fever-screening results using clinical thermometer (based on a threshold reading of 37.0°C). As shown in Fig. 2, although the clinical thermometer accurately measures the human-body temperature, half of the patients were misdiagnosed as normal because of medication. To solve this fever-screening issue, our approach adopted multiple vital-signs to improve the screening accuracy. We may set the target beneficiaries such as, airport quarantine facilities in developing countries, and public health centers in resource-scarce areas, etc. Developed countries have active infection control programs and sufficient stocks of vaccines. However, needy communities in developing countries, where people have little access to healthcare, have high risks of becoming infected [14]. If it were possible to have control over the diseases within those countries, it could be minimize the spread, thereby diminishing the threats of infections.

There are several potential limitations of our current system. (1) We adopted a microwave radar to capture the heartbeat and respiration signals in non-contact manner, however, when the subjects have some random body movement will directly affect the detection of the heart and respiration rates. Hence, an advanced signal processing method should be developed to reduce the noise signals. (2) The influenza patients' data were obtained from Japan Self-Defense Force Central Hospital, the sample of data had a small age group (average age was 25 years) and a certain degree of physical fitness. Therefore, it is necessary to collect data for people of a variety of ages, races, and body morphologies in our next work.

II. Conclusion

In conclusion, the results indicate that the newly developed system is effective in distinguishing infected individuals even they don't have fever. Moreover, the system was designed in portable size and user-friendly interface. These features suggest that the system can be utilized as clinical practice in hospital or other mass gathering places for prevention of pandemic diseases.

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