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Short Communication

Fever screening of seasonal influenza patients using a cost-effective thermopile array with small pixels for close-range thermometry

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SUMMARY

Objective: Infrared thermography systems have been used for fever screening at many airports since the outbreak of severe acute respiratory syndrome (SARS) in 2003. However, many of these systems are expensive and non-portable. Therefore, we developed a cost-effective and compact (2.9 × 5.8 × 2.0 cm) thermopile array for fever screening of patients with infectious diseases in the clinical setting.
Methods: The array was created with small pixels (48 × 47 = 2256 pixels) fabricated on a silicon wafer using microelectromechanical systems technology. We tested this array on 155 febrile and afebrile patients (35.4 °C ≤ axillary temperature ≤ 39.3 °C) with seasonal influenza at the Japan Self-Defense Forces Central Hospital.
Results: The maximum facial temperature, measured by the array at 0.3 m from the subject, exhibited a positive correlation with axillary temperature measured using a contact-type thermometer ($r = 0.71$, $p < 0.01$). The sensitivity and specificity of the thermopile array in identifying the febrile subjects were 80.5% and 93.3%, respectively, setting the threshold cut-off of maximum facial temperature at an appropriate value.
Conclusions: Our cost-effective thermopile array appears promising for future close-range fever screening of patients with infectious diseases at primary care doctor clinics, health care centers, and quarantine stations in developing and developed countries.

1. Introduction

Fever screening of patients with suspected infectious diseases is important to prevent the transmission of infections in places of mass gathering. Infrared thermography is a fast, non-invasive, and non-contact method of monitoring body temperature. For these reasons it has been used extensively for fever screening at airport quarantine stations in many countries since the outbreak of severe acute respiratory syndrome (SARS) in 2003.[1,2] However, many thermography systems used in airports are expensive and non-portable. In this regard, we designed a thermopile array for fever screening of patients with suspected infectious diseases in clinical settings.

Two key concepts were used in designing this thermopile array. First, we aimed to promote the widespread use of thermal imaging for mass screening, particularly in developing countries, where cost-effectiveness is necessary. Hence, we developed this thermopile array for measuring body temperature using low-cost thermopile detectors. Second, the thermopile array was designed as a compact module to facilitate its integration into medical applications such that clinicians would find the device convenient to use. In fact, we have applied this thermopile array to a vital sign-based infection screening system that is currently under development.[3] Moreover, we evaluated the feasibility of this thermopile array for the detection of elevated body temperature in seasonal influenza patients.

2. Methods and patients

The thermopile array (Chino Corp., Tokyo, Japan) comprises 48 × 47 = 2256 pixels with multiple thermopile detectors. Because human skin emits infrared light at a wavelength range of 2–20 μm, we set the measurement wavelength at approximately 10 μm. The thermopile array was calibrated at a range of 20–40 °C and a

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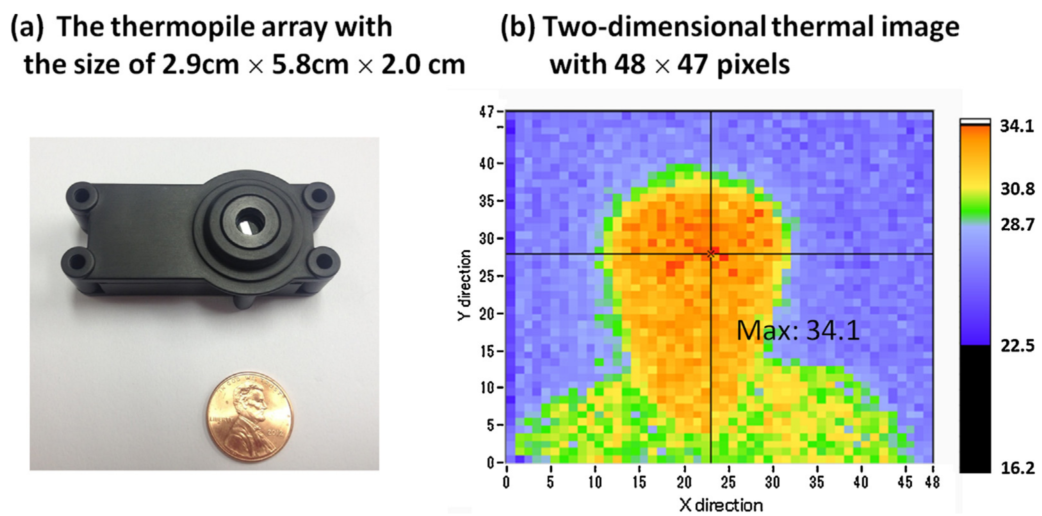

Figure 1. a Compact thermopile array, with a size of 2.9 × 5.8 × 2.0 cm. (b) Example of a two-dimensional thermal image with 48 × 47 pixels and the value of maximum facial temperature.

temperature resolution of 0.5 °C. The size of the thermopile array was 2.9 × 5.8 × 2.0 cm (Figure 1a).

The present study was carried out at the Japan Self-Defense Forces Central Hospital. The 155 inpatients (aged 25 ± 6 years; 35.4 °C ≤ axillary temperature ≤ 39.3 °C) were diagnosed with seasonal (2012–2014) influenza based on several symptoms such as fever, headache, and sore throat, as well as the result obtained using a rapid test kit (Quidel Corp., USA). All patients were prescribed an antivirus medication (oseltamivir or zanamivir), and some patients had a normal body temperature.

The thermopile array was placed 0.3 m from the face of each participant. Because the facial temperature is much higher than the surrounding ambient temperature, the maximum facial temperature (around the inner corner of the eye) can be derived from a two-dimensional thermal facial image by simple image processing (Figure 1b). Subjects who wore eyeglasses removed them before the facial temperature measurements. The thermal image data were obtained at 6-Hz intervals. Thermal image acquisition and image processing were performed using LabVIEW (National Instruments, Austin, TX, USA). We set the ambient temperature to 22.2–23.8 °C and the relative humidity to 36–40% to ensure reproducible environmental conditions. To obtain measurements for cross-referencing, we measured the axillary temperature using a contact-type clinical thermometer (MC-107BW; Omron, Japan). We compared the maximum facial temperature obtained by the thermopile array with the axillary temperature measured using the contact-type thermometer. Moreover, we also evaluated the sensitivity and specificity of the thermopile array in identifying the febrile subjects.

3. Results and discussion

The correlation plot of the maximum facial temperature monitored by the thermopile array and the axillary temperatures measured using the contact-type thermometer for the 155 seasonal influenza patients is shown in Figure 2. The thermopile array measurements exhibited a positive correlation with the contact-type thermometer measurements ($r = 0.71$, $p < 0.01$). Comparison of the maximum facial temperature and reference axillary temperature showed an average mean difference of 1.03 °C with a standard deviation of 0.19 °C. As mentioned above, some of the influenza patients had mild or no fever after medication. Therefore, we evaluated the thermopile array for discriminating febrile patients from afebrile subjects by setting the threshold cut-off of maximum facial temperature in the thermopile array. This approach has been used and generally approved in some recent studies on the evaluation of thermography systems.[4,5] By using the axillary temperature as the reference, the axillary temperatures of 36/155 febrile patients were >37.5 °C. The sensitivity and specificity were 80.5% and 93.3%, respectively, for setting the threshold cut-off of maximum facial temperature at 36.5 °C. The explanation for this is that although the thermopile array accurately measures human body temperature, some of the patients were misdiagnosed as normal because they were taking medication to reduce fever. The results indicated that the thermopile array accurately captured elevated human body temperature in close-range thermometry.

The outbreak of an infectious disease, such as swine or avian influenza, is a threat to global health. Using thermal imaging techniques for fever screening has become a standard procedure at airport quarantine stations because they are more accurate than self-reports. Commercial thermal imaging systems typically cost several thousand dollars;[6] meanwhile, some researchers

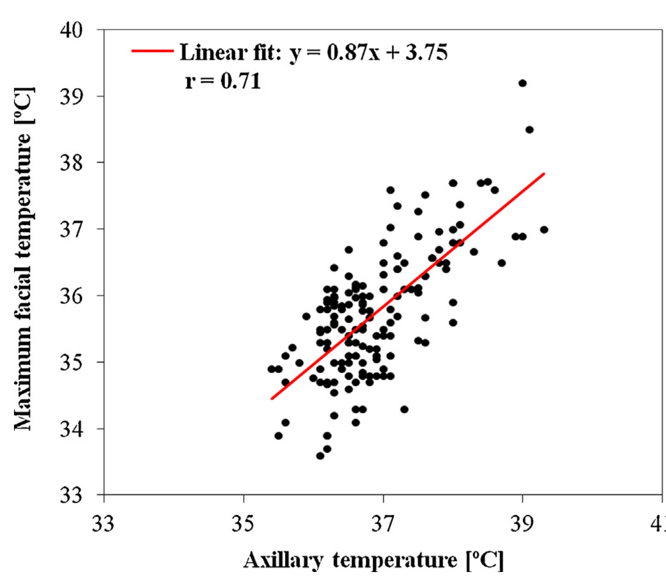

Figure 2. Relationship between the maximum facial temperature measured by the thermopile array and the axillary temperature measured using a clinical thermometer.

have developed inexpensive do-it-yourself infrared scanners to promote the widespread use of thermal imaging technology.[7] In this study, we proposed a cost-effective sensor with ~2000 pixels to measure human body temperature. However, the main limitation of our thermopile array is that the operational distance between the thermopile array and the subject is ≤0.5 m, as opposed to approximately 1.0–3.0 m for some high-resolution commercial thermography systems. Therefore, this thermopile array will be more suitable for close-range fever screening of patients with infectious diseases at primary care doctor offices, health care centers, and quarantine stations in developing and developed countries.

Ethical approval: This study is part of a vital sign-based infection screening system project approved by the Ethics Committee of the Japan Self-Defense Forces Central Hospital.

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Conflict of interest: The authors declare no conflict of interest.

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