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Field test studies of our infrared-based human temperature screening system embedded with a parallel measurement approach

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A B S T R A C T

This paper introduces a parallel measurement approach for fast infrared-based human temperature screening suitable for use in a large public area. Our key idea is based on the combination of simple image processing algorithms, infrared technology, and human flow management. With this multidisciplinary concept, we arrange as many people as possible in a two-dimensional space in front of a thermal imaging camera and then highlight all human facial areas through simple image filtering, image morphological, and particle analysis processes. In this way, an individual's face in live thermal image can be located and the maximum facial skin temperature can be monitored and displayed. Our experiment shows a measured 1 ms processing time in highlighting all human face areas. With a thermal imaging camera having an FOV lens of $24^\circ \times 18^\circ$ and 320×240 active pixels, the maximum facial skin temperatures from three people's faces located at 1.3 m from the camera can also be simultaneously monitored and displayed in a measured rate of 31 fps, limited by the looping process in determining coordinates of all faces. For our 3-day test under the ambient temperature of 24–30 °C, 57–72% relative humidity, and weak wind from the outside hospital building, hyperthermic patients can be identified with 100% sensitivity and 36.4% specificity when the temperature threshold level and the offset temperature value are appropriately chosen. Appropriately locating our system away from the building doors, air conditioners and electric fans in order to eliminate wind blow coming toward the camera lens can significantly help improve our system specificity.

1. Introduction

When infectious diseases cause an outbreak as did the deadly avian flu in mid-March of 2003, a quick but efficient screening process is needed to identify patients at risk of contacting the disease in a public place. Because a non-contact two-dimensional (2D) thermal imaging camera provides several key advantages over traditional thermometers with respect to limiting risks to the operator and avoiding transfer of contagious microorganisms through contact, it was installed as a first-line tool along with the WHO guidelines at the national entry and exit terminals in several countries such as Thailand, China, and Singapore [1,2]. In this way, hyperthermic persons are identified by finding maximum reading skin temperature in the periorbital area and comparing it with an appropriate temperature reference value [3,4]. Single-level and multilevel isotherm algorithms can be applied on a 2D thermal image to highlight hyperthermic regions on the human face [5]. However, these approaches require people to stay in line and the temperature measurement is performed one person at a time with an interval of about a few seconds. In addition, several hyperthermic areas are highlighted in a binary color mode, implying that the operator can easily get confused because the human face on the thermal image is not shown in full and the temperature value of that person is not clearly displayed.

For massive human temperature screening in a large public area like hospitals, health-service stops, and mass-transit sites, it is highly desirable to measure or screen human temperature with a faster rate of 2–3 people per time. Hence, with these issues in mind, this paper proposes a parallel approach for efficient human temperature screening. Our key idea is based on the combination of simple image processing algorithms, infrared technology, and human flow management [6]. With this multidisciplinary concept, we utilize the available 2D space in front of the thermal imaging camera in such a way that N ($N > 1$) people can conveniently walk in toward the camera for simultaneous temperature measurement. Then, we locate all human faces through simple image filtering, image morphological, and particle analysis processes in order to find and display their corresponding maximum temperature values.

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2. Methods

Instead of permitting only one person to stay in a 2D space in front of a thermal imaging camera, we use this available 2D space to arrange as many people as possible at a distance Z from the thermal imaging camera as shown in Fig. 1a. The remaining people walk toward the thermal imaging camera but with a few steps behind those whose temperatures are being monitored. The distance Z and the lens field-of-view (FOV) along the x axis limit the maximum number of people per temperature screening time. In addition, because the current thermal imaging camera provides better than 30 fps, these people can walk in toward the thermal imaging camera at a typical walking speed and out through the designed directions without affecting the flow.

2.1. Camera lens selection issue

In addition to the utilization of the 2D space for our massive temperature screening, camera selection parameters in terms of the lens FOVs and the number of pixels covering such temperature-sensitive eye areas are important issues. Note that this section does not include other camera parameters such as its thermal sensitivity because most usable thermal imaging cameras available in the market with reasonable prices provide a thermal sensitivity of better than 0.1 °C. For example, the standard lens for an A-20M 160×120-pixel thermal imaging camera from FLIR Systems, Inc., has 19° and 14° FOVs along horizontal and vertical axes, respectively, with an instantaneous FOV (IFOV) of 0.12° [7]. If we want to discern a further object, we can choose a tele lens that provides narrower FOVs of 9° and 7° with a 0.05° IFOV. A wide-angle lens is also available if we wish to see objects in a wider area. It gives wider FOVs and IFOV of 34°, 25°, and 0.21°, respectively. Given these lens parameters and assuming that the eye spacing or the spot size is 3 cm, the head-to-head spacing is 25 cm, and the edge spacing of 1 cm (see Fig. 1a), the relationship between the number of pixels in one axis around the eye areas and the number of people observed at the measurement line is shown in Fig. 2a. As the number of faces on one thermal image increases from 2 to 6, the number of pixels around the eye area is reduced from $9 \times 9 = 81$ to $3 \times 3 = 9$ for all lens types. Only when the number of people is 3, the wide-angle lens offers $(6 \times 6) - (5 \times 5) = 11$ pixels more, enough to find a maximum skin temperature with high correlation with respect to the core body temperature.

Another consideration is the optimal spacing between the measurement line and the thermal imaging camera. It is known that as the number of people needed to observe on one thermal image increases, the thermal imaging camera has to be further away from its subjects. The suitable lens is required to achieve the smallest working area. Fig. 2b shows the relationship between the distance Z and the number of people at the measurement line, indicating that the wide-angle lens offers smallest spacing. For example, distances of 0.9 and 1.6 m are preferred for simultaneous temperature monitoring of 2 and 3 people, respectively. On the other hand, the standard and tele lenses need further distances of 1.7 and 3.6 m for monitoring only two people.

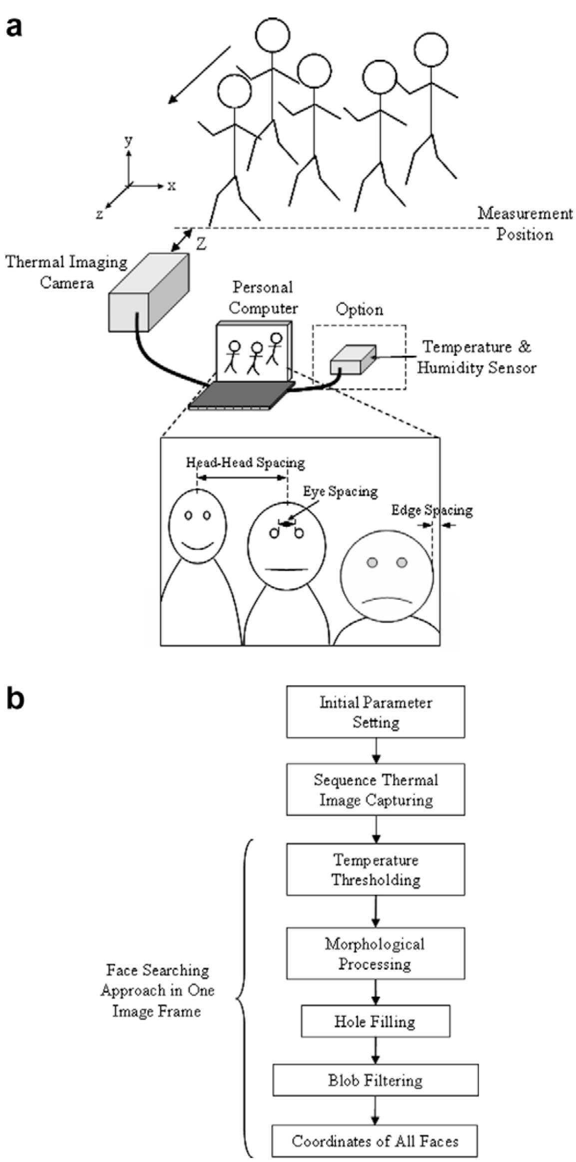

Fig. 1. (a) Diagram of setting up our non-contact infrared-based human temperature screening system suitable for a large general public. (b) Flowchart of our image processing steps in locating all human faces on a 2D thermal image.

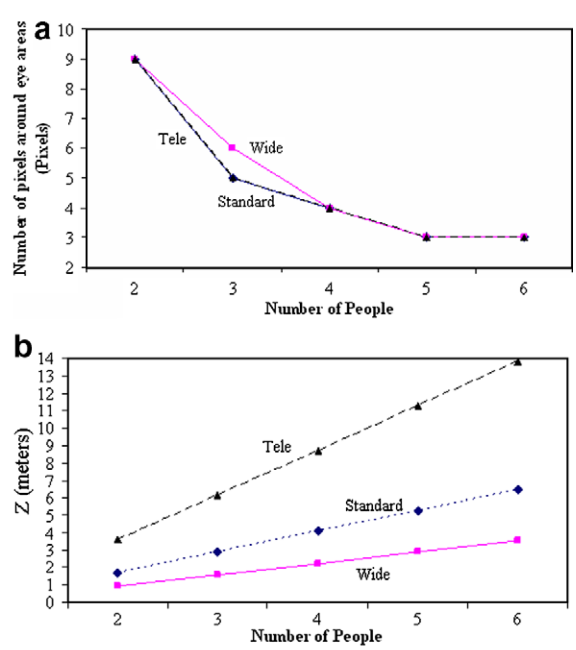

Fig. 2. (a) Plot of the number of pixels around eye areas versus the number of people under temperature monitoring in a 2D thermal image. (b) Relationship between the distance Z and the number of people under temperature monitoring in a 2D thermal image.