Breathing detection by far infrared (FIR) imaging in a home healthcare system

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Abstract

A new home healthcare system that uses far infrared (FIR) cameras to detect breath is proposed. The principle is that the camera detects the temperature change at the nasal hole due to breathing. Experiments show the possibility of continual breathing observation in a remote non-intrusive manner.

Keywords[1]:

Far infrared camera, facial thermal image, nasal temperature, noninvasive sensor

Introduction

Recently, countries such as North America, Japan, Europe, Australia and New Zealand have become aging societies. The rate of people over 65 years old in such countries, 15.3 % in 2005, will exceed 25 % by 2050. This is especially true in Japan; the value was 19.7 % in 2005 and will exceed 37 % by 2050 [1]. Among 65+ people in Japan, the rate who went to or had been in hospital was 15.2 % in 2002 and 15.4 in 2005, that is about 3 times more frequently than other age groups; those who had used care services in home or in care centers was about 15 % [2]. Of the total 47.04 million households in Japan, 18.53 million (39.4 %) were occupied by 65+ people in 2005. Among those, 4.07 million (22.0 %) households had solitary occupants and 5.42 million (29.2%) had only a married couple [2]. Therefore, ensuring that elderly people can live comfortable, healthy, and safe lives through the support of convenient technologies is a major goal for individuals and governments of aging societies.

It is clearly recognized that not only elderly people, but people with all age have the same situation.

Among them, infants, in particularly, should also be taken care of because they can not communicate with other people enough.

The ICT (Information and Communication Technologies) whose typical examples are broadband and ubiquitous technologies has been considered to be a key to coping with these problems.

Fiber-To-The-Home (FTTH) service is rapidly becoming the common denominator. The number of FTTH users is increasing worldwide, especially in the Far-east Asia region. Among them, their number in Japan is exploding. At the end of March, 2008, 12.1 million users contracted for optical fiber to their home. The number will exceed 20 million by 2010. The rate of acceptance is significantly higher than for any other broadband medium such as ADSL (Asymmetric Digital Subscriber Line). After everyone has adopted FTTH, people will be able to enjoy a lot of new services.

Ubiquitous technology will be established by the use of wireless devices such as IC tags whose research, development, and standardization activities have been very frenetic [3]. This technology is capable of information exchange anytime everywhere.

Therefore, the next generation home, which will host ICTs and include vital information sensing functionality, is being considered as the new infrastructure for the home [4]. In the aging society, the home itself will play an important role because individuals will or have to stay longer in their homes.

Research is rapidly advancing in several areas: Several international conferences dedicated to ICT have been held for medical application [5] and home healthcare [6]. Designs for advanced homes such as the future home [7], Smart Home [8], Gator Tech Smart House [9], Sensing room [10] and POF (Plastic Optical Fiber) based home networks [11] have appeared. Almost all activities have been focused on the early development of technologies or systems. Standardization of new technologies such as BAN (Body Area Network) has commenced in IEEE. The authors have presented the image of the next generation convergence home network (NgCHN), together with some preliminary experiments [12, 13].

Vital information sensing is one of major issues in realizing actual home healthcare systems because it influences human activities, or QoL (Quality of Life). A variety of wearable sensors that can capture vital data have been presented [5, 6]. Unfortunately, they are not truly practical since even though they are small, light and non-intrusive, they need to be continually attached to or held against the body. Therefore, remote sensors such as pressure sensors embedded in the floor of the house, or motion sensors in every room must be considered for capturing human data.

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Thermo imaging by far infrared (FIR) cameras is being used for detecting thermally active bodies. It allows remote data capture and so offers the users many advantages. In a recent application, intelligent vehicles use FIR to detect pedestrians on the road at night for collision avoidance [14], while international travelers are well aware of the SARS (severe acute respiratory syndrome) detectors at airports. Moreover, a driver surveillance system that uses nasal temperatures has also been researched [15]. Therefore, FIR image capture will yield new vital information sensing systems for home healthcare.

This paper describes experiments on an FIR imaging system to detect human breathing; its feasibility for application in a home healthcare system is discussed.

Basic principle of the proposed system is as follows; Humans usually emit more heat (far infrared radiation) than other indoor objects in a home. Therefore, FIR image regions containing humans are brighter than the background. Moreover, FIR cameras are less sensitive to visible light than normal visible cameras, and so can provide 24 hour coverage. On the other hand, current FIR cameras have low spatial and temporal resolution due to the sensing devices available.

As generally known, body temperature depends on blood flow and blood flow depends on psycho-physiological changes such as the vasoconstrictive effect. In particular, the area around the nasal part contains more AVA (Arteriovenous anastomoses), which control capillary blood flow, than other body parts. Thus the nasal part demonstrates wider fluctuations in temperature than other regions.

Our procedure to detect human breathing is as follows: i) traces the face even at night, ii) extracts the region that includes the nasal part, iii) averages the data, iv) sets a discrimination threshold, v) counts the events that exceed the threshold and measure their length, and vi) report the obtained values.

This paper describes first the experimental setup; how to extract the nasal region is detailed in the next section. The results of a breathing detection experiment are given. Feasibility of applying the proposed system to home healthcare is also discussed.

Methods

Facial thermal images are captured by an FIR camera whose specifications are described below.

Experimental setup: A subject sat in front of the camera in a room (Fig.1). Room temperature was around 25 degrees Centigrade and remained constant throughout the experiments.

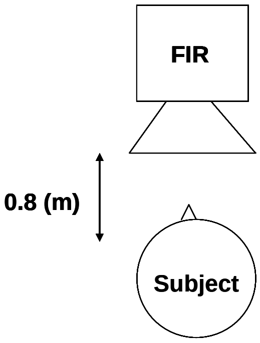


Fig.1. Experimental setup

Specification of the FIR camera used:
- Type: NEC/Avio, TH7102MX [17]
- Capture wavelength: 8 – 14 um
- Thermal resolution: 0.06 degree
- Size of sensor (active area): 320 x 240 pixels
- Contrast: 256 levels (8 bit)
- Frame rate: 30 frames/sec.

The procedure used to calculate the temperature is depicted in Fig.2: After capturing FIR images, the nasal region (NR) is extracted from the first frame as a template (size was set in the experiment). Details are described in the next section. Template matching is then performed on each frame yielding the NR in each frame. Average temperature for each extracted NR is then calculated. Sequence of the temperature obtained is converted into NR time variation of temperature. If the temperature exceeds the threshold the frame is counted and the continuous sequences of frames are taken to indicate breaths.

Results and discussions

Figure 3 shows thermal image examples of the full face captured by the FIR camera in the experimental setup. The subject was a normal young male. The images clearly indicate the temperature difference on the face. Here, the temperature range (maximum to minimum) was set to 8 degrees i.e. from 31 to 39 degrees Centigrade. Figure 4 shows the nasal regions that were extracted from the first frame. Figure 4 (a) corresponds to 92 x 57 pixels and (b) to 50 x 20 pixels.

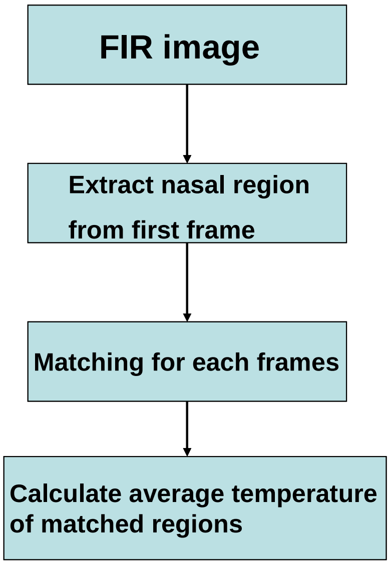


Fig.2. Procedure used to calculate the temperature

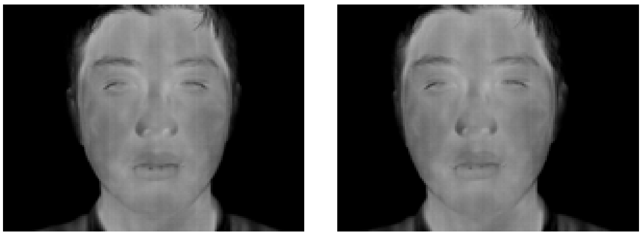
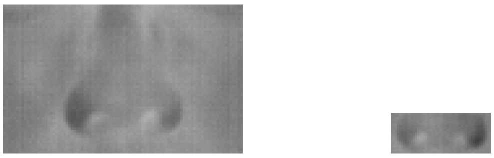


Fig. 3 Captured thermal image examples (Full face image). In the image, darker areas correspond to lower temperatures. Temperature range was set to 8 degrees.



(a) (b)

Fig. 4 Extracted template examples (Nasal parts) extracted from the full face thermal image. (a) corresponds to 92 x 57 pixels, and (b) 50 x 20 pixels.

Nasal region size was determined by considering how much the average temperature of the region changed as well as the ease of template matching. We consider here the following model; Temperature in the template is constant except at the nasal holes which vary due with breathing. If we breathe in (out), the temperature around the nose decreases (increases). The amount of temperature difference is about one degree. Therefore, detecting the temperature change allows us to detect breathing events.

Average temperature change (Δt_{tp}) of the template is derived by the following equation (1);

$$\Delta t_{tp} = \frac{2 \times p \times r^2 \times t_{n_{pp}}}{S_{tp} \times (256 / t_{full})} \qquad (1)$$

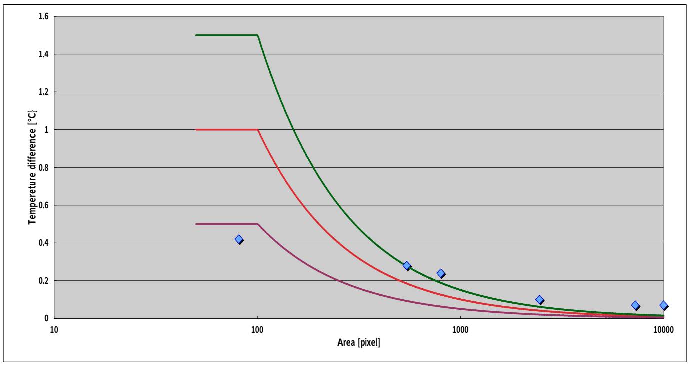


Fig. 5 Size of template and its dependence on temperature variation. Three lines correspond to the temperature difference at nose hole of 1.5, 1.0, and 0.5 degrees (from the top). Plots are measured values.

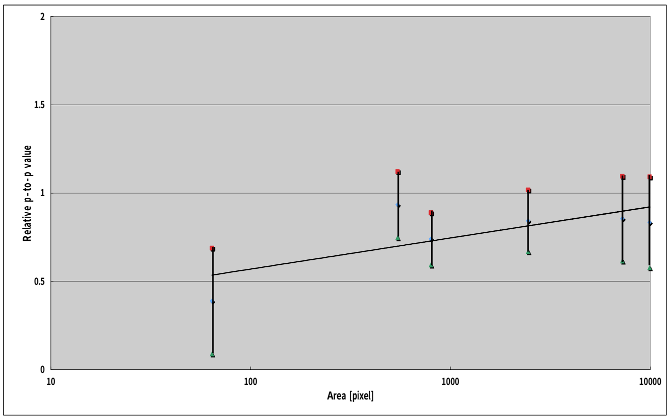


Fig. 6 Measured relative temperature variation due to breath-area of template.

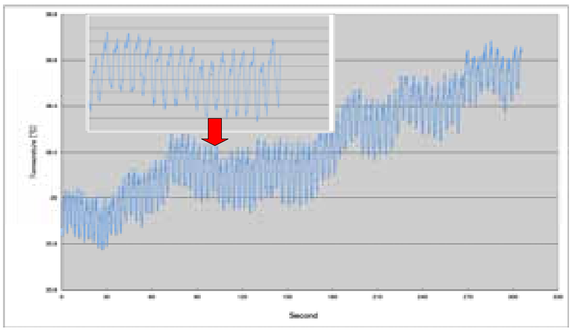


Fig. 7 Measured average temperature variation of the template with size of 32 x 17 pixels.

where *r*: radius of nose hole, $t_{n_{pp}}$: temperature change of nose hole, S_{tp} : area of template, and t_{full} : temperature range of the camera

The three solid lines in Fig.5 show the results calculated by (1) where the temperature change of nose hole (t_{npp}) corresponds to 1.5, 1.0, and 0.5 degrees from the top, respectively. Measured temperature change for templates with different areas are also plotted in the figure. As shown, they fit the curve of 1.0 or 1.5 degrees. Preliminary experiments that examined noise (background noise) indicated that the camera has a +/- 0.5 degree variance even for an object with stable temperature. Therefore, as indicated in the figure, a template with area less than about 2,000 pixels is needed to gain the S/N (Signal to Noise ratio) needed. The measured value around 100 pixels does not fit the curve of 1.0 or 1.5 degrees due to template mismatching.

Smaller areas yield higher S/N values, but make area matching in successive frames more difficult.

Figure 6 shows measured relative temperature variation due to breathing versus area of template. Here, the value of 1.0 on the vertical axis corresponds to the peak to peak value of the temperature variation for the first template. Vertical line corresponds to measured average value with standard deviation. According to the observation, an area with around 500 pixels has higher relative value and smaller deviation.

Table 1 – Accuracy of the proposed method

Subject	Age	Duration [minutes]	Measured count	Actual count
A	24	10	41	41
B	23	5	83	83
C	22	5	57	58
D	22	5	34	34
E	22	5	47	45

The results in Figs. 5 and 6 indicate that a template with area of around 500 up to 1,000 pixels is quite feasible for detecting breathing events.

Figure 7 shows the measured results of temperature variation at the nose with the extracted template of 47 x 17 pixels (area: 544 pixels) for 5 minutes. The small window in the figure shows an enlargement of the curve. The average temperature change of templates with each breath is at least 0.2 degrees. As observed in the small window, the curve shows the presence of some noise due to background noise and template mismatching.

As clearly shown in Fig. 7, the curve well reproduces the subject's breathing action. By counting the number of frames over the threshold, the event duration, it becomes easy to monitor breathing.

We have tested the accuracy of the proposed method with 5 young healthy male subjects. Each subject sat in front of the FIR camera as indicated in Fig.1 and captured for 5 minutes (one subject for 10 minutes). During capture, the actual breaths were counted. Table 1 shows the experimental results. Almost all measured counts correspond to the actual value. The value for subject C indicates a -1 count. The reason is that C had a stuffy nose and breathing was awkward. As a result, measured value did not fall under the threshold. The value for subject E indicates +2 counts. This is because the measured values decreased momentarily twice to under the threshold. This might be improved by ignoring short duration value changes.

SAS (Sleep Apnea Syndrome) is one of the severe illnesses associated with breathing. SAS is usually detected by polysomnography which requires the attachment of several sensors to the human body. Therefore, use of polysomnography is somewhat limited. The FIR-based system proposed herein has the potential to monitor sleep status non-intrusively at any time even in a house.

SIDS (Sudden Infant Death Syndrome) is a major causes of children's death in Japan and in Europe and the United States [17]. Use of several sensors attached on the children's body is also somewhat limited.

Therefore, the system proposed herein has also the potential to monitor the emergency status even in a house.

Conclusion

In this paper, experiments on the use of FIR imaging to detect human breathing were described. Nasal templates are developed and used to identify the temperature changes associated with breathing events. Averaging of the captured signal clearly showed the count and duration of breathing events.

The experiments conducted indicate the feasibility of the proposed method as well as the technical study items that still remain. They include the camera location during sleep, tracing the face when the face moves, and an adaptive threshold setting method.

Applying the method described in the paper will yield new non-intrusive home healthcare systems.

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