LOW COST INFRARED ARRAY AS A THERMAL COMFORT SENSOR

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ABSTRACT

Energy in buildings has to be deployed in a more effective way, bearing in mind a comfortable indoor climate and full occupant satisfaction. Recent developments show that heating or cooling locally can improve both, the thermal comfort and energy effectiveness. Personalized conditioning systems are in principle able to satisfy the individual thermal comfort requirements, and at the same time they are conditioning only a small space around a single user and are thus more energy effective.

However, personalized conditioning systems are still controlled only by direct user interaction, which can lead to problems such as temperature overshoots or energy wastes. For automation of the control process it is necessary to look into individual parameters that can predict thermal discomfort. It has been shown that the fingertip temperature is a good predictor of cold discomfort. Therefore, it has a potential to be used as a control signal for automatic personalized heating. For practical use it is necessary to develop a low cost sensor that can sense the fingertip temperature without direct interfering with the user.

In this paper the initial tests of low cost infrared arrays are presented that can be used for this application. Two infrared arrays of resolution 4x4 and 16x4 pixels were tested in terms of their accuracy and feasibility for skin temperature measurement. The static tests proved these sensors to be adequate for the intended purpose. One of the infrared arrays was then combined with a visual camera allowing a real-time tracking of the hand movement. Development of this integrated visual and infrared sensor and their relation to thermal comfort are presented in this paper.

Keywords: Image processing, Infrared thermography, Thermal comfort, Tracking

INTRODUCTION

Currently building sector accounts for approx. 40% of total energy consumption in EU and US [1]. Most of this energy is used to keep the indoor climate in a narrow range of conditions prescribed by thermal comfort standards. However, narrowing this range still does not ensure that the building occupants are thermally comfortable [2]. These issues led in recent years to development of personalized conditioning systems, which allow users to adapt their microenvironment to their desires [3]. Personalized conditioning systems can also help to decrease building energy consumption by higher effectiveness [3], [4].

Personalized conditioning systems are nowadays controlled just by user interaction. This can lead to certain problems. For instance personalized heating controlled by user interaction will be only turned on when the user experiences cool discomfort, and turned off when warm discomfort will occur. Incorporating automated or semi-automated control can improve overall satisfaction and performance of the system. Therefore, there is a need for a parameter that can predict thermal discomfort.

Wang et al. [5] identified distal skin temperature, particularly finger and hand temperature, as a good predictor of cold discomfort under cool uniform conditions. In order to use distal skin temperatures as a control signal it is needed to measure them in a way that does not negatively affect overall user comfort. Recent tests show that infrared thermography is a feasible method for this application [6]. However, only an expensive and sophisticated thermocamera was used in these tests.

This paper describes the development of a low cost sensor that integrates temperature measurement by infrared thermography and tracking of hand movement.

METHODS

Static tests of accuracy of infrared arrays

At a first stage two low cost infrared arrays, OMRON D6T 44L [7] and Melexis MLX90620 [8] (see Table 1), were tested for their accuracy and repeatability of measurements in a static setting. Both sensors were connected to a PC via an Arduino microcontroller [9].

	OMRON D6T 44L 	**MELEXIS MLX 90620** 
Matrix	4x4	16x4
Frame rate	4 FPS	0.5 to 512 FPS
Temperature resolution	0.14 K	0.08 K
Accuracy (by manufacturer)	± 1.5 K	± 1.0 K
Range	5÷50 °C	-20÷300 °C
Field of view	44.2° x 45.7°	40° x 10.4°

Table 1 Tested sensors

The measurement setup is shown in Figure 1. A carousel with six heated surfaces with different emmissivity simulated a measured object. One of three plates with a cut-off opening in a shape of a finger (finger negative) was placed in front of the heated surface. A thermal image of this setup was captured by the infrared arrays for all combinations of heated surface and plate in front. The temperature of the heated surface was at the same time measured also by a thermistor that can be taken as a reference. The distance and position of an infrared array from the measured object were varied in order to get different placement and size of the "finger" according Figure 2.

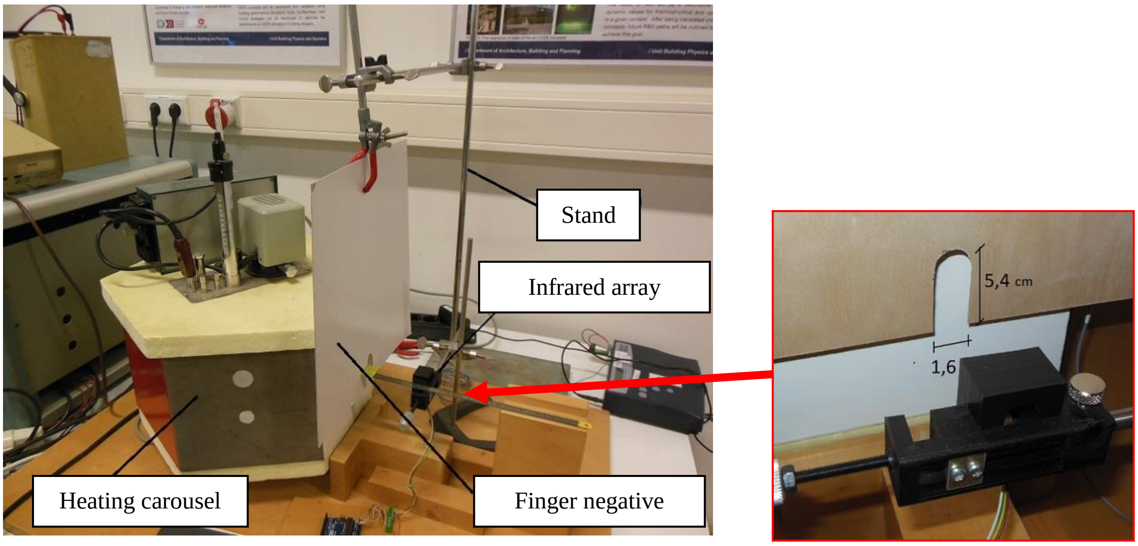

Figure 1 Static tests - measurement setup

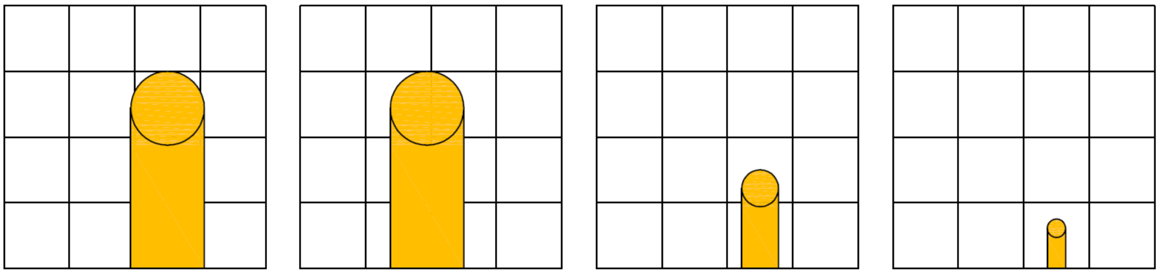

Figure 2 Finger placement on 4x4 pixel matrix – different positions and distance of the sensors

Movement tracking in visual spectrum

Figure 3 shows a principle of coupling an infrared array and an optical tracking. A Pixy CMUcam5 [10] is used in this case for tracking in the visual spectrum. It is a camera with integrated circuit for image processing that allows tracking of a particular colour in an image. A hand can thus be tracked by skin colour, if a proper background is used. The position of the hand identified in a visual image can then be used to point a temperature value from an infrared image (infrared and visual image are de facto overlaid).

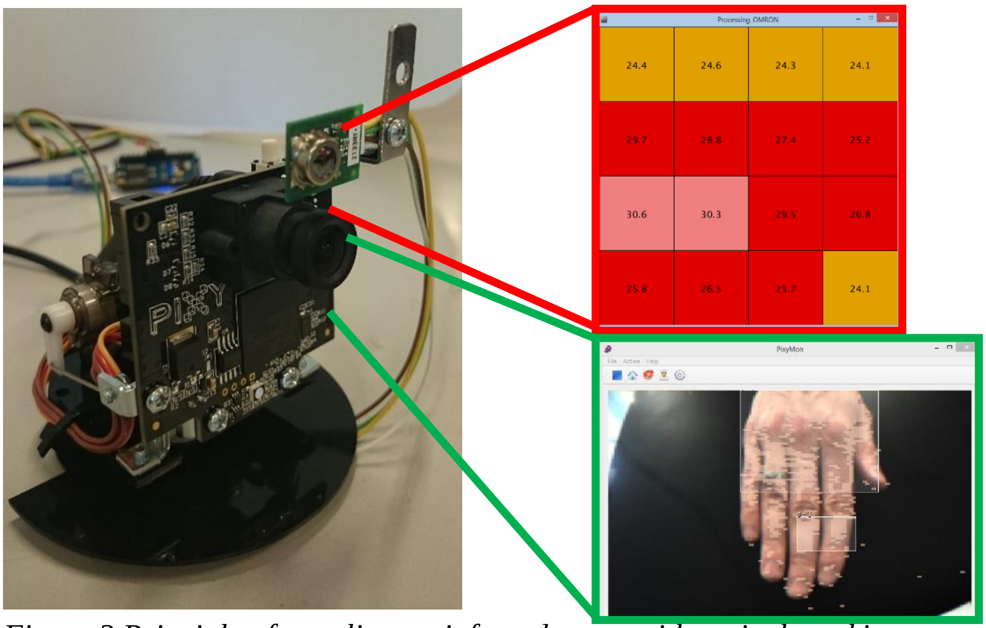

Figure 3 Principle of coupling an infrared array with optical tracking

RESULTS & DISCUSSION

Static tests of accuracy of infrared arrays

Figure 4 shows two tests of OMRON D6T 44L. These tests represent a first case of Figure 2, so the measured object fully filled three pixels. The black heated surface has an emissivity close to human skin (0.98) and wooden and white backgrounds are surfaces that commonly occur as an office desk top layer. From the charts it is clear that the sensor accuracy is even better that the value given by the manufacturer (± 1.5 K) and in most cases falls under ± 0.5 K. Considering that the temperature drop related to a change in comfort reaches about 10 to 15 K [5], this accuracy is good enough for the intended application. The accuracy of Melexis MLX90620 under our tests was considerably lower. Therefore, we decided to use OMRON D6T 44L in our further tests.

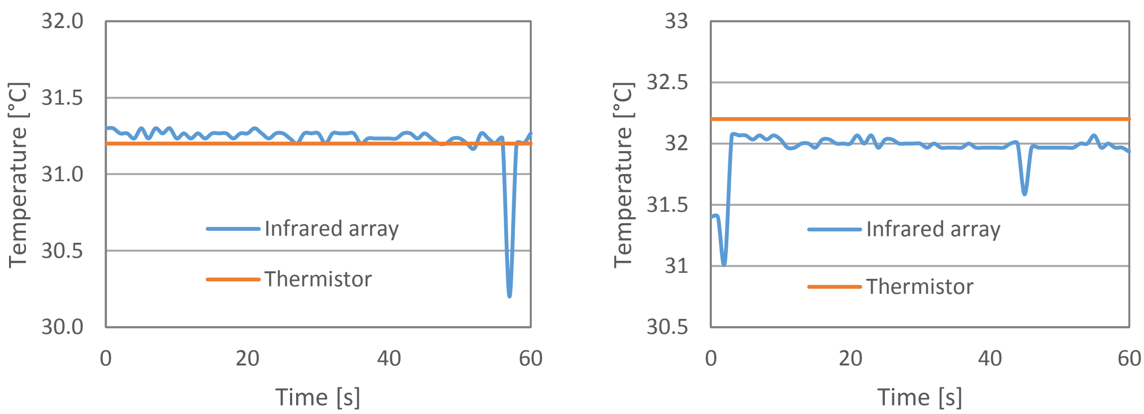

Figure 4 Average object temperature (3 pixels) corresponding to the first case of Figure 2, OMRON D6T 44L, black heated surface, wooden background (left), white paper background (right)

Temperature values of pixels that are not fully filled with the measured object would require an extrapolation using known background temperature. However, in our application we expect pixels nearly fully filled and we will adjust the sensor position accordingly.

Movement tracking in visual spectrum

In our previous study we have used a pattern matching algorithm to search for the shape of a finger in a high resolution infrared image [11]. This is only possible as long as there is a temperature difference between the skin temperature and the background. However, under mild cool conditions the fingertip temperature comes close to the environmental temperature, which causes a lack of contrast in an infrared image and the pattern matching algorithm fails. Tracking in a visual spectrum can overcome this problem and opens a possibility to use a low resolution infrared array. It is also not possible to use the pattern matching with a low image resolution of low cost infrared arrays.

Because of the above mentioned reasons we will test hand tracking using a Pixy CMUcam5 [10]. This a camera with integrated image processing that can track a particular colour. This allows tracking for a skin colour on a proper background and using the spotted object as a pointer for a temperature value from an infrared image.

Future tests

It is necessary to test the new integrated sensor for its reliability and accuracy. This should be done in comparison with contact methods of measuring skin temperature, such as using wireless temperature loggers iButtons [12]. At the moment it is also not clear how reliable tracking a hand based on skin temperature is. This has to be tested using different background surfaces.

As already mentioned Wang et al. [5] found a relation between distal skin temperature and thermal sensation. However, their experiments were conducted under uniform and steady state conditions. Our recent, yet unpublished, tests imply that relating skin temperature and thermal sensation is becoming more complex in a non-uniform thermal environment. After applying personalized heating under mild cool conditions we have observed a significant increase in thermal sensation, but only a slight change in distal skin temperatures. This does not disqualify distal skin temperature as a possible control signal for personalized heating. However, a combination with other parameters might be necessary. This should be tested also in comparison with control based solely on user interaction.

CONCLUSIONS

Development of a new sensor is described in this paper. This sensor integrates a temperature measurement by low cost infrared array and movement tracking in visual spectrum. The intended application is remote measurement of hand skin temperature that can be used as control signal for personalized heating.

The future tests will focus on accuracy and reliability of this new sensor and the application with personalized heating.

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