Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world*** Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Tracking hand movement in an infrared image

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Abstract:
The skin temperature and thermal comfort are closely related and change in skin temperature can predict thermal discomfort even before it is consciously perceived. The effect of changing thermal environment is most significant on the body extremities, particularly hands in cool and head in warm conditions. The skin temperature of the extremities can thus become a feasible control signal for personalized conditioning.

In order to use a skin temperature of the extremities in practice as a control signal, it is necessary to measure it in a way that does not hinder a user. The infrared thermography represents a method that has a potential to fulfill this criterion. However, remote sensing of temperature arises new challenges how to track a movement of the human body in order to get a correct temperature of the chosen body part. This paper discusses a method based on pattern matching for real time tracking of hand movement in an infrared image.

Keywords: Infrared thermography, Pattern matching, Thermal comfort

1 Introduction

The building industry nowadays is facing two major challenges – an increased concern for energy consumption and a need for comfort improvement. These challenges led many researchers to develop a personalized conditioning system. Personalized conditioning climatizes only a small space around a single person. This makes it possible to satisfy different needs of every individual and to reduce energy consumption due to higher effectiveness. Different personalized conditioning systems have been introduced, including personalized ventilation (Melikov 2004), local floor heating (Foda & Sirén 2012), or a combination of personalized ventilation with local convective and radiant heating (Melikov & Knudsen 2007; Watanabe et al. 2010). However, these systems are still controlled only by user interaction, which can lead to problems such as lower thermal comfort due to rebound or overshoot or loss of effectiveness due to incorrect use of the system. Therefore, it is needed to seek for methods that can help to automate the control process of personalized conditioning.

An effective automatic control of personalized conditioning first requires a parameter, which is related to comfort and convenient to measure in an office environment. Wang et al. (2007) showed that the fingertip temperature is related to a risk of cold discomfort. They identified a clear threshold of fingertip temperature of 30 °C, above which no risk of cold discomfort occurred. This implies a possible use of fingertip temperature as a control signal for personalized heating. Wang et al. measured in their experiments the skin temperature by thermocouples attached directly to the body. However, for practical application it is necessary to measure the skin temperature in a way that does not hinder an overall comfort of the users.

Since the hands are in an office usually directly exposed to the environment, it is possible to measure the fingertip temperature by an infrared thermography. However, using infrared thermography arises a challenge how to track a moving finger. This paper introduces and discusses a method based on pattern matching for real time tracking of hand movement in an infrared image.

2 Methods

2.1 Thermal chamber experiments

In order to test a feasibility of using a remotely sensed fingertip temperature as control signal for personalized heating a human subject experiment was set up in the climate chamber at Eindhoven University of Technology.

Six subjects (five male and one female) performed a normal office work. The workplace was equipped with a laptop with external monitor, keyboard and mouse. The subjects were exposed for two hours to a uniform thermal environment with operative temperature of 18 °C. The conditions were designed as slightly cool to cool (predicted mean vote of -2 to -1).

Every fifteen minutes the test subjects were filling a questionnaire regarding their overall and local thermal comfort and sensation.

2.2 Thermal imaging

In this study we used a thermocamera Flir ThermaCAM S65HS to remotely measure the fingertip temperature. Specification of the camera are given in Table 1. The camera was placed on a stand above the computer monitor in a distance of 1.5 m from the keyboard. A thermal image of the desk area with the keyboard and mouse was taken every five seconds.

Table 1 ThermoCAM S65HS specification

Field of view/min focus distance	20° x 15° / 0.3 m
Spatial resolution (IFOV)	1.1 mrad
Thermal sensitivity	50 mK at 30° C (86°F)
Detector type	Focal plane array (FPA) uncooled microbolometer; 320 x 240 pixels
Spectral range	7.5 to 13 μm

2.3 Pattern matching

For the finger tracking we developed an algorithm based on pattern matching in LabVIEW (National Instruments 2014). Figure 1 shows an example of pattern matching in a static image – after a pattern is taken the algorithm finds similar areas in the whole image.

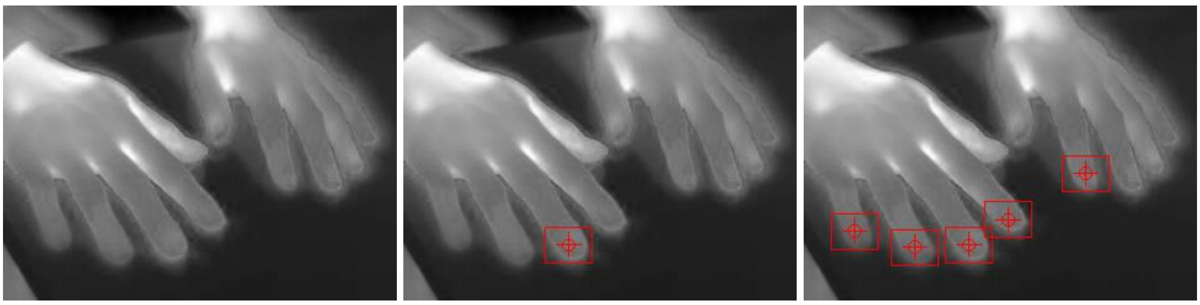

Figure 1 Pattern matching in a static image (from left: source image, marked pattern, matched patterns)

The pattern matching algorithm for real time finger tracking works in following steps:

1. The templates as shown in Figure 2 are searched for.
2. The matched patterns are sorted by maximum temperature in each match.
3. The matched pattern with the highest maximum temperature is chosen as the correct match of fingertip and the algorithm returns this temperature. This step is based on assumption that the background of an infrared image is colder than the fingertip.
4. In case of no matched pattern the algorithm returns default temperature of 30 °C.
5. The fingertip temperature is averaged of last 12 values (moving average). This is done to lower the fluctuations of measured value in case of false detections.

Figure 2 Finger template images

A block diagram of the tracking algorithm is given in Appendix.

3 Results & Discussion

Figure 3 presents a comparison of the fingertip temperature as measured by the tracking algorithm and post processed for one test subject. The post processed values were carefully read from the infrared images after the experiments for every 15 minutes of the two hours exposure. The fingertip temperature as measured by the tracking follows the post processed temperature within ± 2 °C until the fingertip drops under 30 °C. Similar trend was observed for all the test subjects. It was also observed that, when the temperature continues dropping, the number of false or no detection greatly increases and the tracking algorithm cannot reasonably follow the fingers anymore. This is caused by the loss of contrast in the image because the fingertip temperature is getting closer to the temperature of background.

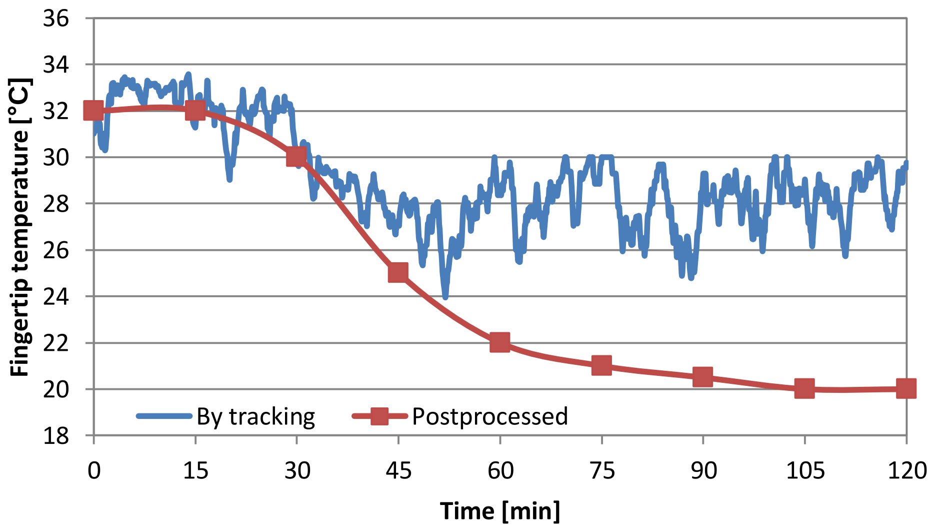

Figure 3 Fingertip temperature as measured by tracking algorithm and post processed (one test subject)

Figure 4 shows fingertip temperature (post processed values) and overall thermal sensation during two hours exposure as averaged for all six test subjects. Thermal sensation correlates with fingertip temperature with R^2 value of 0.93. Thermal sensation can thus be reasonably predicted by fingertip temperature under assumptions of our study (mild cool thermal conditions).

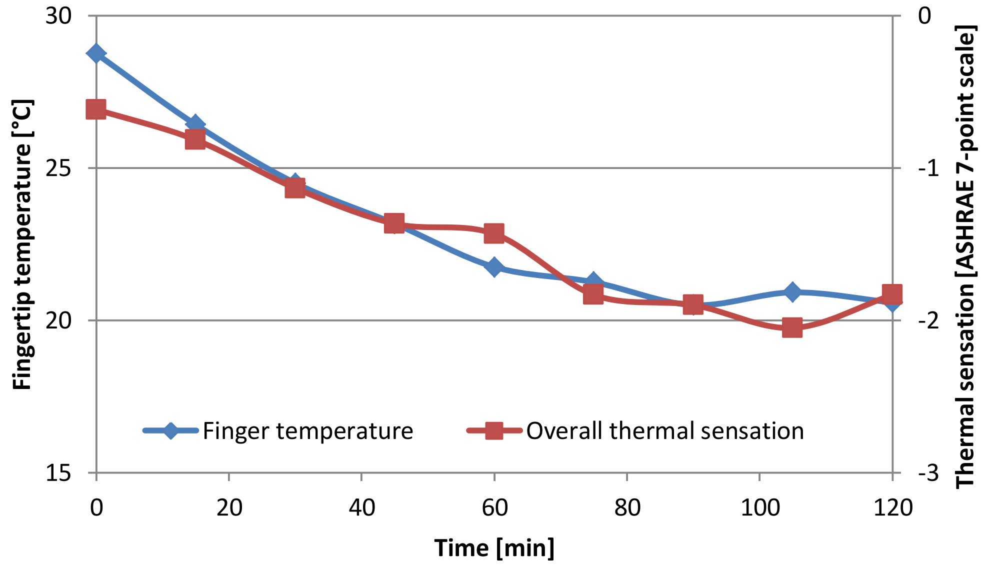

Figure 4 Thermal sensation and fingertip temperature (average for all six test subjects)

A comparison of our study with the study of Wang et al. (2007) is shown in Figure 5. Each of our data points, shown as yellow empty squares, represents one subjective response of one subject with corresponding fingertip temperature (post processed value). Although Wang et al. used a slightly different thermal sensation scale (extended ASHRAE 7-point scale) and different measuring technic, the data of both studies shown a good agreement. The data points that represent a risk of cold discomfort cluster mostly under the fingertip temperature of 30 °C and thermal sensation under neutral.

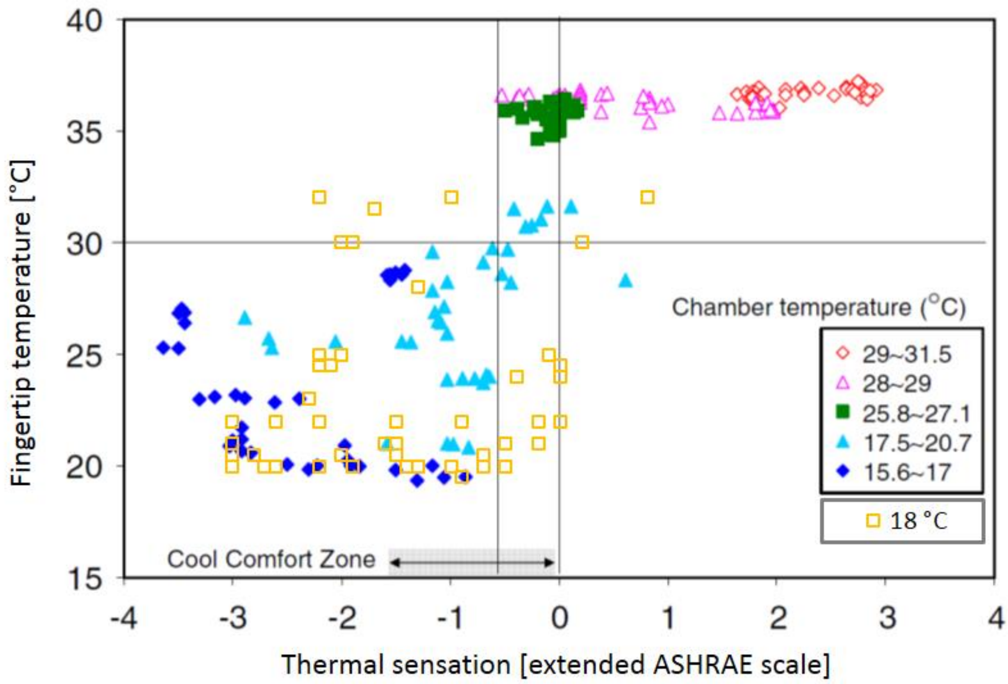

Figure 5 Comparison of our study with the study of Wang et al. (2007), our data are represented by yellow empty squares, adapted from (Wang et al. 2007)

4 Conclusions

The method for finger tracking in an infrared image has been presented in this paper. This method can reasonably track the fingers, when the fingertip temperature is above 30 °C, which ensures thermal comfort, and the background temperatures are within a normal indoor temperature range. These criteria are presumably fulfilled for an intended application of this measuring method, which is using the fingertip temperature as a control signal for a local heating.

5 Limitations and future research

The tracking algorithm as presented in this paper is limited to relatively narrow range of temperatures that normally occur in an office environment. As the intension is to use the fingertip temperature as a control signal for personalized heating, it is needed to study how the finger can be tracked, if a hand heating mat or a radiation heating focused on hands is applied.

In our study we used a very sophisticated and expensive thermocamera. It is needed to use a low cost infrared array in order to make a control method based on remotely sensed temperature available for wide range of customers. However, a low resolution of a simple infrared array may not allow for a finger tracking. This problem can be solved by coupling the infrared array with an optical camera used for tracking.

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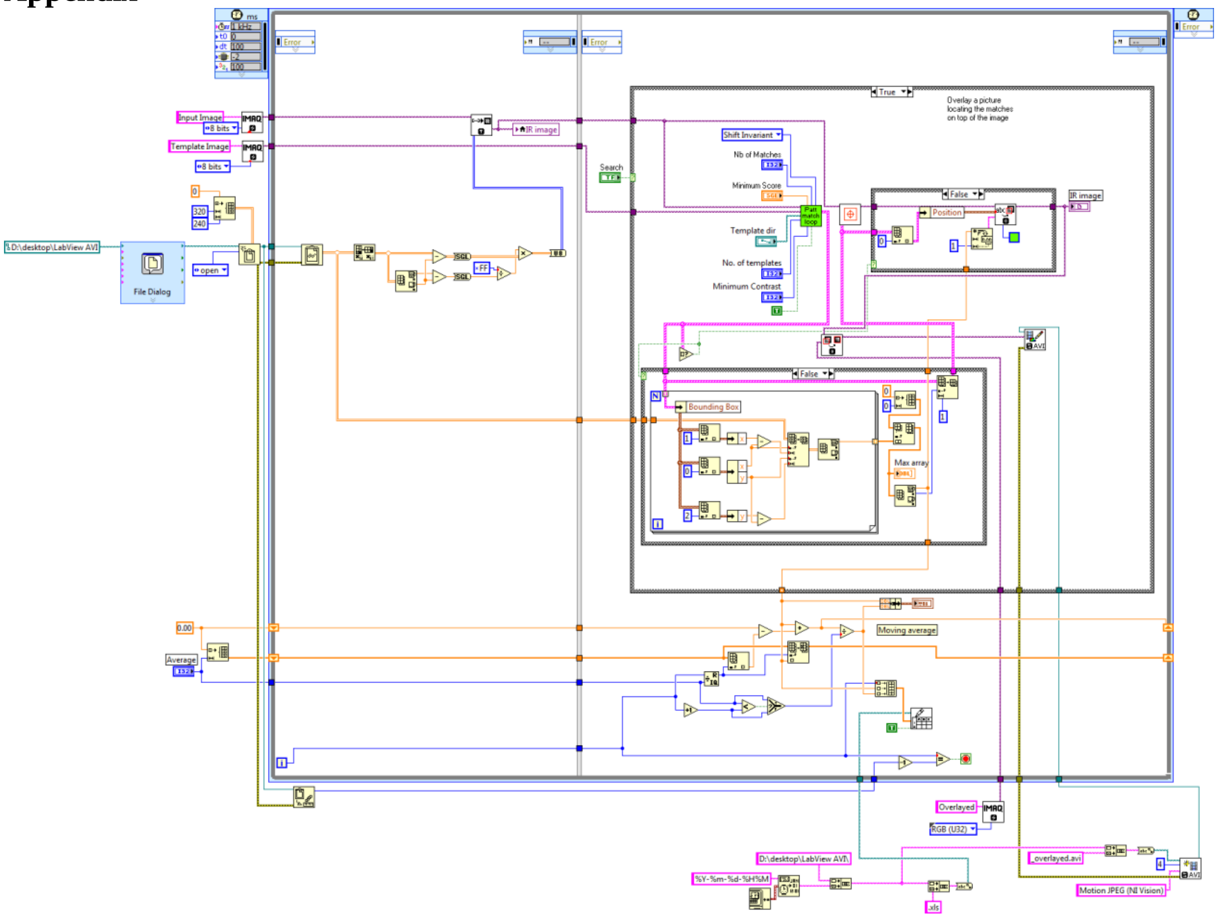
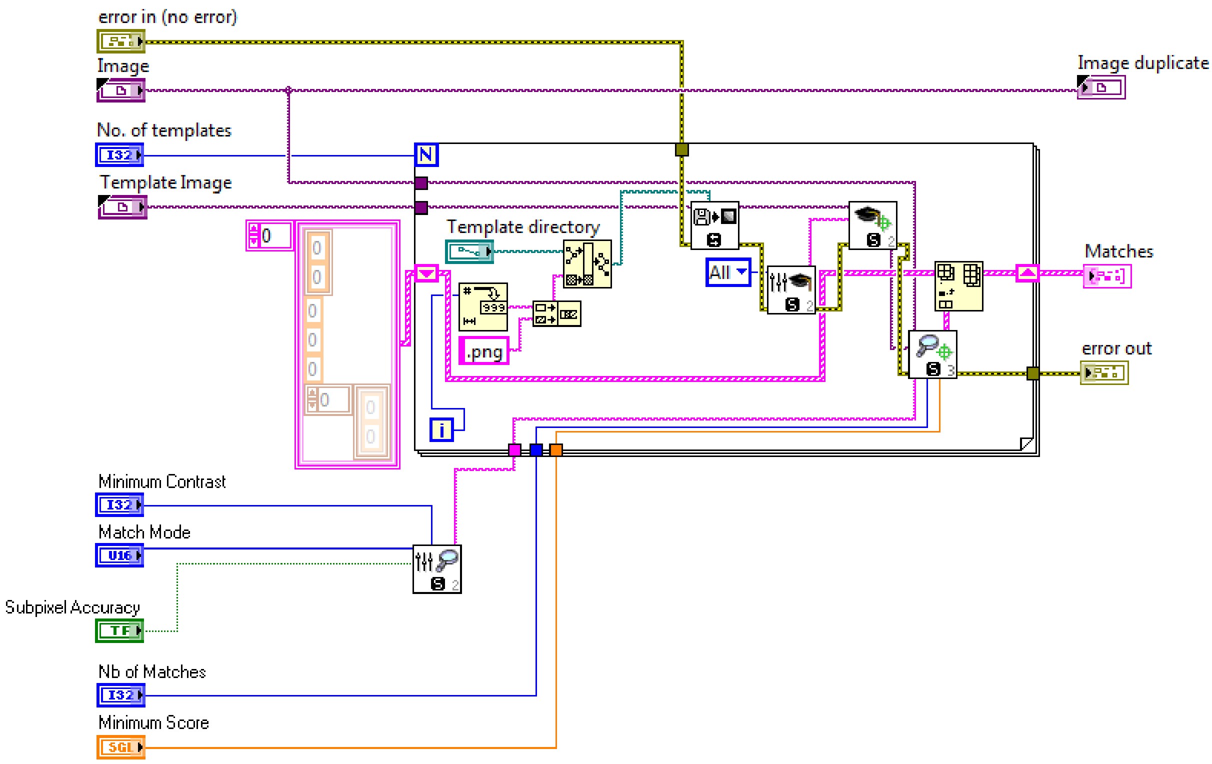
Appendix



Pattern matching algorithm for real time finger tracking – block diagram



“Patt match loop” block from Pattern matching algorithm