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SENSING THERMAL STRESS AT OFFICE WORKPLACES

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ABSTRACT

Thermal stress at office workplaces can lead to decreased productivity and health issues of office workers. A new method was investigated to detect heat stress with thermal imaging using consumer infrared (IR) cameras in combination with mobile devices. The camera can be integrated into a "Mobile Health Check Kit for Offices" either giving direct feedback to the user or detecting a situation of discomfort and possibly adjust the environment.

Based on the IR-images in combination with the corresponding RGB-images, the face or a particular region of the face can be detected in order to extract respective temperature values for the selected area. We conducted a series of human subject tests where the test persons had to vote their thermal sensation and comfort while a thermal load was imposed on their head. The data recorded by the camera during the tests were post-processed to extract average temperature values of the face and of a specific region in the face. The evolution of the measured face and region temperature was compared to the subjective sensation and comfort voting. In some cases, the correlation was high, while in other cases the face and region detection were subject to errors.

Keywords: Thermal comfort, Thermal stress, Infrared camera, Face detection

1. INTRODUCTION

Due to the increasing communication need combined with the information overload, knowledge workers are faced with more complexity in their daily tasks. For this reason it is very important to provide work conditions with a positive effect on mental performance. In recent years, various researchers have investigated and evaluated the stress effects on cognitive performance (Henckens, 2009). There are many reasons for stressful situations at work, thermal stress being one of them. Several studies proofed that productivity decreases when the indoor air temperature goes beyond a certain comfort range (e.g. Fisk, 2011). The head is the most sensitive body part when it comes to heat stress, as hypothalamus temperature should stay in a very narrow range (Zhang, 2003).

The purpose of this research is to determine heat stress at work places in order to adjust the environment accordingly, i.e. reduce heat load in hot conditions or increase heating in cold conditions. Therefor, infrared cameras in combination with mobile devices (smartphones, tablets) were used to record the temperature increase of a person, which was subject to radiative heat. Detecting the face and the region in which the temperature increase occurs proved to be one of the main challenges. With the described method of recording facial temperature increase we hope to detect other-than-thermal stress scenarios (e.g. mental stress/anxiety/effort in exams), which may result in a raise of body temperature. Previous research has shown that thermal infrared imaging can be used to detect strong emotions (Ioannou, 2013).

2. BACKGROUND AND STATE OF THE ART

2.1 Thermal stress and thermal comfort

The impact of thermal stress on human beings has been investigated since the early 1970ies starting in the military sector. Based on human subject tests with soldiers, numerical models were developed to predict thermal sensation and heat balance in human beings (Stolwijk, 1971; Kobrick, 1988). The heat balance of the human body depends on the ambient conditions (conductive, convective, radiative and latent heat transfer), on the heat sources and sinks in the body (metabolic heat, work, shivering, breathing) and on the heat transfer within the body through blood flow (heart rate, vasodilation, vasoconstriction). If the human thermoregulatory system is not longer able to maintain core and skin temperatures in a certain range, extreme sensations can occur and people will feel either too hot or too cold.

In the 1990ies, thermal comfort became a matter of interest in the building sector. The numerical comfort models were further developed (Tanabe, 1994; Huizenga, 1999) and used to assess existing buildings and develop new methods to provide comfortable conditions (Wang, 2009). In an important study with more than 100 human subjects, Zhang (2003) related the sensation of single body parts to local and overall comfort. One of the main findings with respect to thermal discomfort was related to the sensitivity of the head to hot conditions and radiation. This proved to be a big problem in modern office buildings where large windows allow for direct radiation on the office worker's heads (Hoffmann, 2012).

2.2 Smartphones as mobile Mini-Labs

Nowadays smartphones have increasingly become everyday tools – they are quasi ubiquitous. Furthermore, besides their well-known use as helpful tools for communication, these mobile devices are also equipped with many internal sensors. For example, they have a built-in microphone and camera, an acceleration sensor, a magnetizing force sensor and a density of light sensor, a gyroscope, a GPS receiver and, in some cases, temperature, pressure, and air humidity sensors. In addition to this, smartphones could also be connected with external sensors such as – for example – the infrared camera of FLIR, which has been used in this project. Equipped with all these sensors, mobile devices can gather physical data enabling the investigation of multiple scientific phenomena with one single tool. The data captured by these sensors can be retrieved using additional programs, so-called apps, which generate tables, graphs or other forms of representation of these data automatically on the smartphone screen. So it is possible to cover phenomena in mechanics, acoustics, electromagnetism, optics and radioactivity (Kuhn, 2014; Kuhn et al., 2014; Kuhn & Vogt, 2013). Therefore, they can be considered as small, mobile Mini-Labs, which can replace complex sets of test instruments and simplify experimental settings. An additional benefit is that such phenomena could be analyzed either inside, e.g., a laboratory, an office etc., or outside in everyday environment. Furthermore, since nowadays almost every person possesses their own smartphone, scientific phenomena could be analyzed anywhere and anytime by everyone.

2.3 Object / Face Detection

Object detection is defined as a task of finding objects in a given image, which belong to one and the same class (e.g., faces, eyes, cars, or balls). One very important and common use of object detection is in the area of biometric applications where the goal is to detect objects in a given image that are relevant for biometric analysis e.g., faces, eyes, iris, or thumb impression. The aim is to localize these objects so that they can be used for further analysis like face, iris, or thumb recognition.

In the past few years, many researchers from different fields (engineering, neuroscience, behavioral science) have shown a strong interest in the area of face detection and recognition due to the variety of applications in these fields. Face detection is a quite challenging and important task because if there is an error in this step, it will have severe effects on the next steps. For instance, if there is an error in face detection, it is almost impossible to perform face recognition. The challenges in face detection include pose variation (front, non-front), occlusion, orientation, illumination and different facial expression.

This means that once the face is detected, it is possible to estimate various factors related to the face e.g., pose and facial expression. In addition to this, it can also be used to analyze different changes occurring in a face with the change in time. These changes can be long term (e.g., wrinkle, aging effect, or color) or short term (e.g., temperature).

However, for analyzing a face from different perspectives, it is important to first detect it. Basically, there are several methods available for face detection. The easiest way is by using template matching where the face is detected by finding a correlation between input and template/standard face image (Sung, 1998). Similarly, another very common approach for face detection is to perform skin detection where faces are detected based on the cluster of detected skin (Garcia, 1999). Methods that are more sophisticated use invariant features extraction and classifiers for extracting faces in a given image (Zhu, 2012).

3. EXPERIMENTAL SETUP

Two research groups, one in Japan and the other in Germany, worked in parallel on the experiment.

The Japanese approach focused on a direct feedback of the measured data to the user by connecting the sensing device to the user's laptop. The IR-camera is used as an additional sensor in a "Mobile Health Check Kit", which gives temperature information to the user as a direct feedback/information.

In Germany, the sensing device was not coupled to the test person's own computer. Instead the user responded to regular surveys asking for his or her thermal sensation and comfort. This can be considered as the user's indirect feedback on the temperature condition. The main question to answer was if it would be possible to detect thermal stress through monitoring temperature data of a specific facial region and/or the entire face.

3.1 Thermal Imaging Sensor as direct feedback in the Mobile Health Check Kit for Office

In Japan, we built the system for monitoring the stress of office workers, as shown in Figure 1. We call it "Mobile Health Check Kit for Office". It is based on the laptop having Intel RealSense such as NEC LaVie Hybrid Advance (HA850/AAS) and the thermal image sensor is added on the top.

Intel Realsense is used for monitoring heart rate, counting eye blinking as well as mouth movement. In addition, we measure the number of key typing, typing sound, and mouse distance. These measured data dimensions are integrated in our developed desktop application and are visualized by the graph.

The thermal image sensor (Figure 2) is developed originally in our lab. As a main sensor module, we use FLiR Dev Kit sold by sparkfun. We connect the sensor module to a microcontroller for transmitting sensed image to the laptop via USB. In the laptop, our software analyzes the image for detecting a face part. It is based on Open CV. Finally, our software outputs the temperature value of the worker's face center.

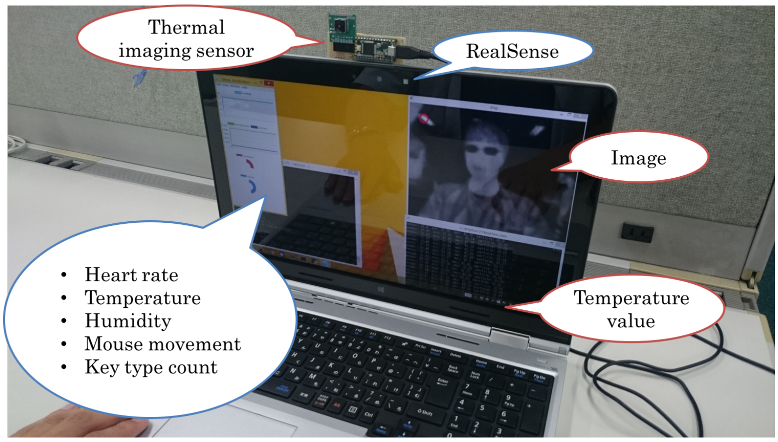
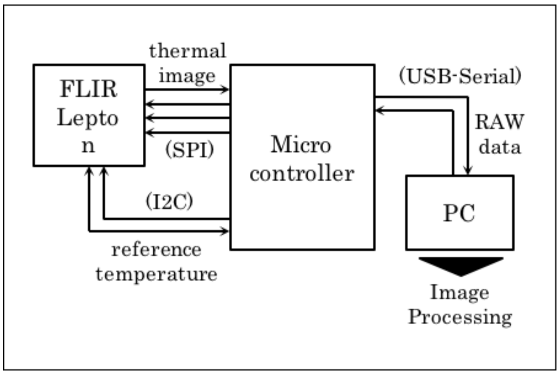


Fig. 1. "Mobile Health Check Kit for Office".



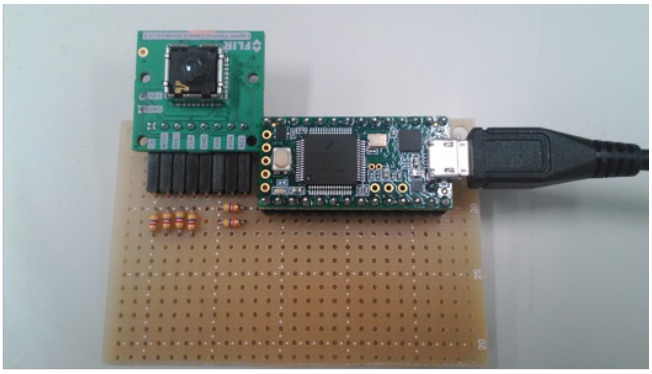


Fig. 2. Thermal image sensor.

3.2 Indirect feedback on imposed thermal stress

In Germany, in order to study the sensing of thermal stress, test persons were exposed to thermal load in a typical office situation while doing typical office work. The thermal load was induced by an infrared lamp and directed towards the head of the person. It represents the heat flux due to direct solar radiation when office workers are sitting close to a window on a sunny day.

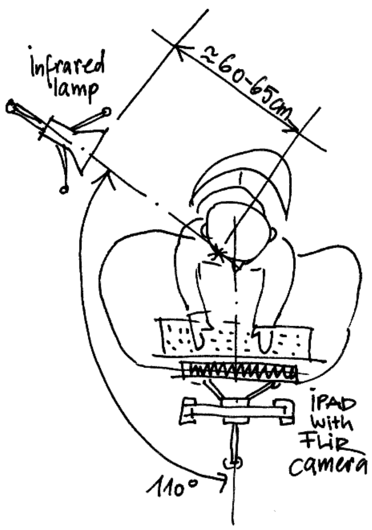


Figure 3. Test setup to impose thermal stress on the head.

The IR lamp is an Infrared R95E model from Philips with a lamp power of 100 W. The IR radiation is in the near infrared (NIR) range, which has a penetration depth in skin of a few millimeters and is sensed as a strong local heating of the skin. The distance between the test person and the IR lamp was set to a range of 60-65 cm after a series of pre-tests, to find a distance which yields a considerable thermal effect but is still tolerable for a longer duration. The angle between the test person's line of sight and the direction of the IR rays was set to 110°, in order to minimize distraction caused by glare and still allow for the locally heated face region to be visible in the IR recording from the front. The thermal load was imposed for a period of 20 min, followed by a monitored cool-down phase of 10 minutes. The test setup is shown in Figure 3.

Measuring temperature with an IR-camera

IR or thermographic cameras are devices that generate images from infrared radiation, similar to photo cameras generating images from visible light. Photosensors in IR cameras are able to measure wavelengths up to 3.5–15 µm. Since IR radiation is not visible to the eye, IR cameras transform the recorded wavelength data to a given color palette in the visible range. That means that a certain color in the generated IR photo represents a certain measured temperature. Additionally, it is possible to save the recorded IR raw data for extracting the individually measured temperature (i.e. wavelength) of every pixel in the generated image.

The IR camera used in this setup is a FLIR ONE™ 2nd generation for iOS from FLIR Systems, Wilsonville, OR. It has two cameras, an IR and a photo camera, to match the radiation data with visible information (object edges are calculated from visible data and are overlaid to the IR picture in the default FLIR application). The IR camera measures temperatures from -20 °C to 120 °C (-4 °F to 248 °F) and detects temperature differences as small as 0.1 K (0.18 °F). Its sensor measures wavelengths from 8 to 14 µm. The IR camera resolution is 160x120 pixels, whereas the visible camera resolution is 640x480 pixels (VGA). The field of view of the IR camera is 46°.

In addition, room temperature is measured with data loggers from manufacturer Lascar, model EL-USB-2+, with a resolution of 0.5 K.

Identifying a specific region

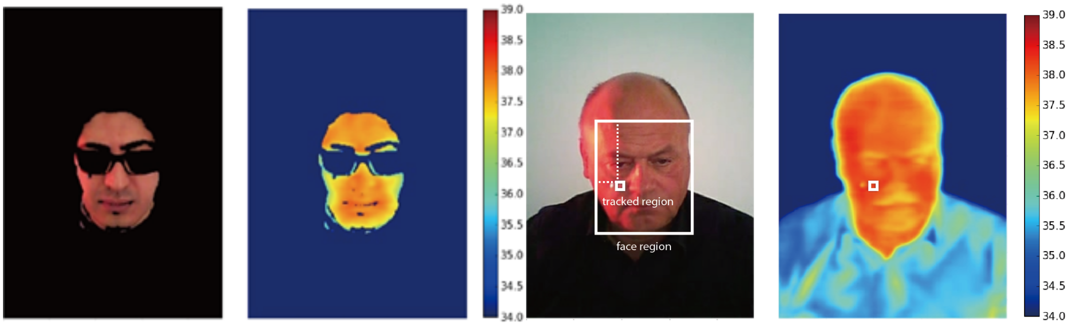
For analyzing temperature variations on the face region exposed to infrared light, it is important to first detect the face in the captured image. In order to ease the identification of a fixed region in the face despite unavoidable slight movements of the head, a circular marker of 6 mm diameter was stuck to a specific point in the face of the participant.

Haar Cascade (Viola, 2001) based face detection was used on the images captured using visible (RGB) camera of FLIR ONE™. A pre-trained classifier available in OpenCV was used to extract face coordinates in the visible (RGB) image. Figure 4 shows the visible (RGB) image of two persons with face detection results.

In order to get detailed insight into thermal changes, two different analyses are performed. In the first setup (referred to as IR face), the skin region is extracted based on color values (the range of the color for skin is determined experimentally) and the result of face detection. The mean temperature of the region corresponding to the skin of the face is computed, which is then used to analyze the thermal changes in the face. Skin detection is performed in the RGB image. In order to extract temperature values, the coordinates of the detected skin area are mapped to the IR image. Figure 4 (a) shows the detected face in RGB and Figure 4 (b) shows the extracted temperatures of the complete face.

In the second analysis (IR region), thermal changes are analyzed only in the region (constantly exposed to IR lamp) around the marker placed at the face. To do so, a small rectangle is specified and tracked on face around the marker. The mean temperature value of this region is used to analyze the thermal change only in the region exposed to IR lamp. The estimation and tracking of the IR exposed region is performed in RGB image and to extract the temperature values of the region, the coordinates are mapped to IR image, which is captured using IR camera of FLIR ONE. Figure 4 (c) shows the tracked region in RGB image and Figure 4 (d) shows the mapping of the respective tracked region in IR image.

It is to be noted that during experiments the data is recorded at 9 frames per second (fps). However, for the analysis purpose it is sampled down to 1 fps. This sampling is performed based on the observation that there is no significant increase in temperature within one second.



(a) (b) (c) (d)

Figure 4: Face detection and thermal analysis. (a) Skin detection result based on the color and the face position. (b) Thermal image for analyzing change in complete face. (c) Face detection and tracked region in RGB image. (d) Thermal image with relative position for temperature investigation

Evaluation of thermal sensation and comfort

In parallel to the IR-recording, the participants of the study were asked to evaluate their subjective thermal sensation and comfort. Sensation was assessed on an integer scale ranging from -4 (very cold) to 4 (very hot), while comfort was assessed on a forced feedback scale from -3 (very uncomfortable) to 3 (comfortable) as shown in Figure 5.

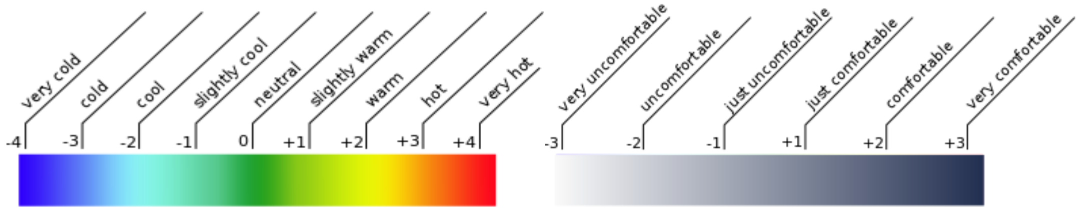


Figure 5. Scales of thermal sensation (left) and thermal comfort (right).

The overall thermal sensation is composed of varying sensations in the various body parts. For directing the participants' attention to the details of their thermal sensing and to assess their initial condition of thermal sensation, the sensation values for all 16 body parts according to the UC Berkeley 65 Node Model (Huizenga 1999) were asked in the beginning of the session. The values of overall comfort, overall sensation, and thermal sensation of the head were evaluated every minute.

To this end, a periodical reminder and voting system was implemented as a web application such that the test persons could use their own laptops for the study and work with minimized interruptions (Figure 6). Every 10 min, the thermal sensation values for 5 additional body parts were evaluated for control purposes: chest, back, pelvis, hands, and feet.

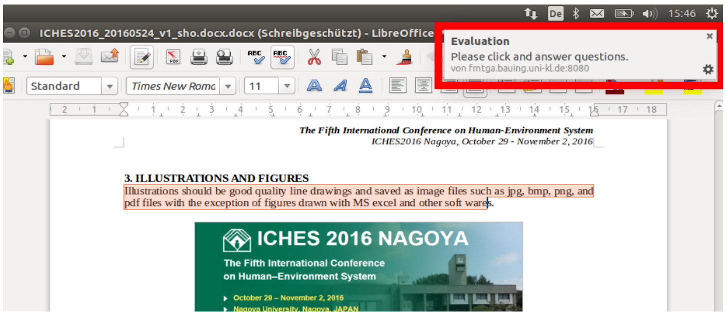


Figure 6. Screenshot of the voting reminder in the web browser (upper right).

4. RESULTS

We conducted a series of 10 experiments according to the setup described in Section 3.2. Two of these failed due to technical issues with hard disk and camera. The first run revealed that the periodic calibration of the IR sensor-field obfuscates trends in measurement, that otherwise seemed to clearly reflect the temperature increase due to thermal load. The auto-calibration feature of the IR-camera was then switched off in favor of a manually triggered calibration before each recording. As a plausibility check we analyzed the measurements in the area of the background area (white wall behind the test subject), which we supposed to be constant or rather correlated to the ambient temperature. In two of the experiments we recognized changes in the level of the whole measured temperature range including the background. These two experiments were also excluded.

Figure 7 shows the results of the successful test runs, each presented in three diagrams:

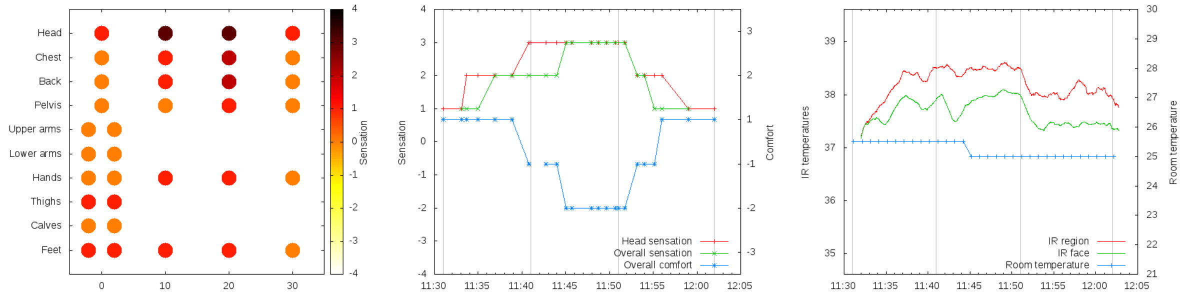
a) manual comprehensive inquiry of thermal sensation values every 10 minutes,
b) individual feedback about thermal sensation and comfort approximately every minute,
c) measured temperature from the IR-camera (IR face and IR region) and room temperatures.

At the initial survey, two of the test persons (003 and 004) stated a cool to cold sensation at their extremities, while all others reported a neutral state for most body parts with slightly elevated sensation values for a maximum of 1-3 body parts. Except for 003, head sensation increased to warm or hot after 10 min and to hot or very hot after 20 min. As for 003, head sensation decreased slightly before the lamp was turned off. The increase of head sensation was rated between 1 and 4 points on the thermal sensation scale. After the lamp was turned off, all human subjects reported a drop of head sensation by at least 2 points on the sensation scale within the last 10 min of the test.

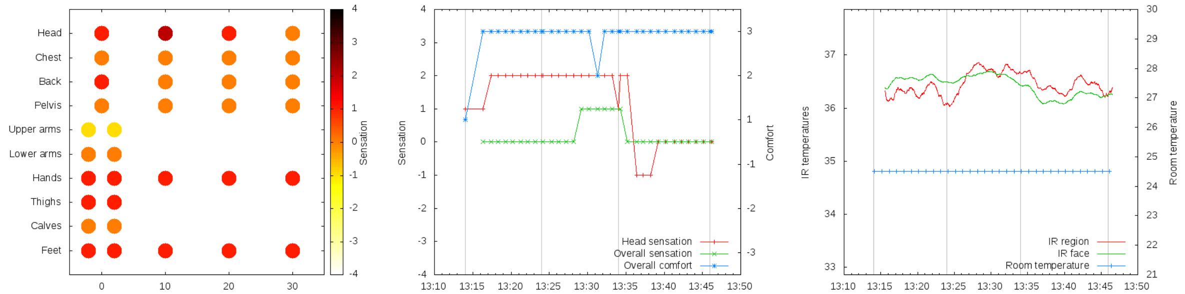
The increase of thermal sensation during the first 20 min with heat load was not limited to the head, but was found in other body parts, too. For some test persons, the body parts with increased thermal sensation (other than the head) cooled down after the heat load was turned off, for others the slightly warm sensation of other body parts remained (005 –hands, 009 – hands).

Except for 002, overall sensation increased less and later than head sensation but started dropping together with head sensation when the heat source was removed. Changes in overall comfort occur together with changes in head sensation or with changes in overall sensation, depending on the test person.

Those who had a cool or cold sensation for at least one body part (003 and 004), stayed comfortable for a longer period of time than those who felt neutral or slightly warm.



002 - 17.05.2016 11:31-12:02 CEST



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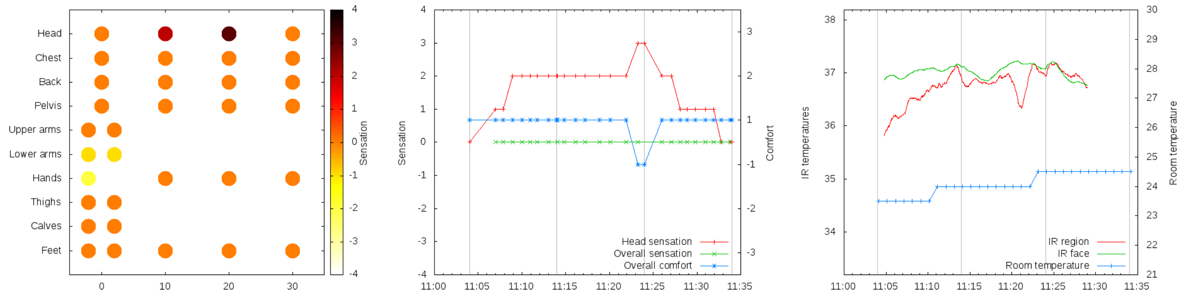

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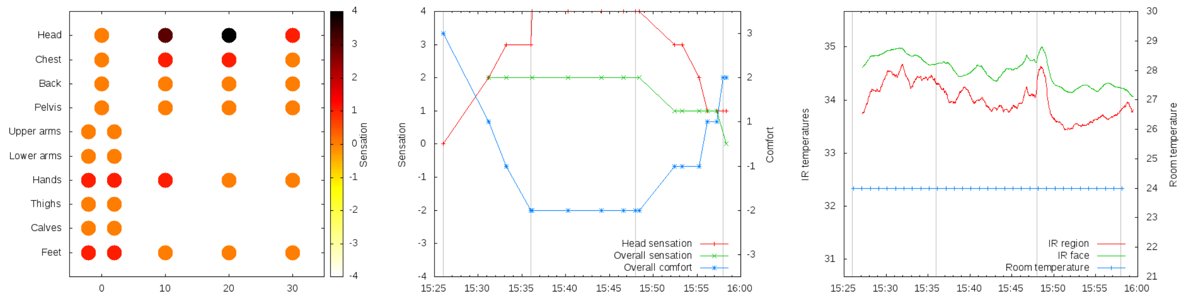
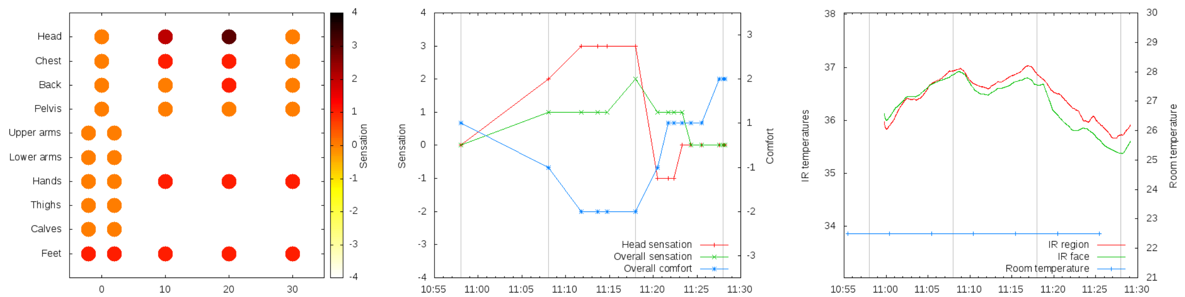


006 - 18.05.2016 15:26-15:58 CEST



009 - 08.06.2016 10:58-11:28 CEST

Figure 7. Results for five test runs: comprehensive sensation inquiry (left), individual periodic sensation/comfort feedback (center), and moving average of measured temperature values (right).

5. DISCUSSION

In general, IR-face and IR-region temperatures reflect the subjective votes approximately, but the quality of the correlation between measured temperature data and the perceived thermal sensation varies significantly amongst the 5 human subjects. After a thorough analysis of our test data, several biases could be identified (see below). Strong variations within IR-face or IR-region temperatures are evidence of systematic errors in the measurements.

For test person 009, the identification of the region and of the face was very accurate which results in a steady temperature course over the 30 min and little difference between region and face temperature, with the region temperature being slightly higher than the face temperature after 15 min. For this person, we could clearly detect temperature increase and decrease as expected and correlate the temperature evolution to his subjective voting.

5.1 Limitations of the subjective vote method

There are several limitations to the applied subjective vote method. Human subjects should have thermally adapted to ambient conditions before they start voting. Each person might have a slightly different understanding of e.g., hot or very hot. In addition to that, the sensitivity to cold or warm conditions differs significantly amongst individuals, which is obvious for the 5 test persons. In order to achieve results that are statistically significant, the number of human subjects has to be significantly higher.

The individual assessment of thermal sensation and comfort values was triggered every minute with a visual notification designed to be preferably unobtrusive for the work carried out by the test person. Depending on the time needed to fill in the survey, the responses are recorded with slightly irregular frequency. Due to the additional more verbose verbal assessment every 10 min, at least one of the individual feedback requests was skipped and values are missing. Since participants had to answer the questions proactively instead of being forced to give feedback, a lower responsiveness to the assisting reminder may result in lower frequencies of the answers as can be seen in tests 006 and 008.

5.2 Influences on IR-region and IR-face temperatures

The validity of the measured values is negatively influenced by several factors both with respect to the thermal sensation and comfort feedback as well as with respect to the measured temperature values. Regarding the measured temperature values we identified three possible different influences: camera calibration, occlusions, and surface curvature.

First, since the camera calibration, which is usually executed every 1-2 min, is switched off for the duration of a whole test session of 30 min, the error of the measured temperatures might increase during the recording of thermal data.

Second, parts of the face can be occluded by colder body parts, hair, glasses, or the marker. The first two occlusions have an effect on the IR-face values, while the latter mainly affects the IR-region value. The effect of colder body parts can be clearly seen in experiment 002, where the test person frequently placed the left hand below the chin or near the mouth, thus lowering the face average. Regions occluded by hair and glasses can be excluded from the calculation of average temperature values, since they are easily identifiable by applying a lower threshold to the IR-values. The marker was meant to add an alternative way to detect the region of interest. However, in the analysis we applied a detection method using relative coordinates in relation to the detected face. Naturally, this method targets approximately the same part of the face where the marker is positioned. This led to irregular distortions of the measured values.

A third influence is the non-Lambertian behavior of the skin regarding IR radiation. As reported in Cheng et.al (2012), measured temperatures drop noticeably for surfaces tilted by more than 40° and show a very clear drop from 60° (angle between face normal and camera view axis). Thus, the individual characteristics of the face curvature constitute a significant factor in the validity of the measured values. The effect is especially noticeable in the IR-region values, in cases where the position of the region of interest shifts towards the outer face boundary. Depending on the face geometry and the head position and orientation, the region may enter the critical area or even move out of the face as in experiment 005.

6. CONCLUSION AND OUTLOOK

We found the presented method for sensing thermal stress at office workplaces to be a promising approach. The identified issues in the fields of face and region detection, IR-recording, as well as sensation and comfort evaluation are encouraging for further development and investigation.

The consumer IR-camera used in the experiments proved to be suitable for the recording of the required data. However, further investigations have to verify proper calibration of the camera by correlating the measured values to reference values acquired from image regions with constant temperatures, e.g. in the background.

The approach used in this paper for face detection and identifying a specific region on the face works relatively well when the face is in upright position and when there is no occlusion. However, it is not robust to different poses of the face. Therefore, when the participant's face angle is changed, tracking a specific region becomes problematic and errors are possible. In the future, we are planning to incorporate face pose estimation along with detection of other facial parts (e.g. eyes, mouth), so that the specific area on face can be tracked with high precision. Regarding the evaluation of thermal sensation and comfort, we seek to obtain a more steady data basis. This can be achieved by improving the feedback reminder UI and by adjusting the feedback frequency. Most notably, to draw well-founded conclusions, a quantitative analysis on a bigger sample of tests is necessary.

With future enhancements, potential practical applications of the approach can be found in the area of building automation and control. To adjust local thermal conditions according to individual needs, currently individuals have to operate controls directly or provide individual feedback to an automated control. Thermal stress detection based on IR sensing could replace or assist the individual feedback and thus provide customized conditions while maintaining an uninterrupted work environment. With IR-sensing, the impact of thermal stress on productivity could be investigated in future studies by monitoring skin temperature and work performance. Another area of research is the use of IR sensing to detect cognitive or emotional stress which is related to a change in skin temperature.

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