Thermography-based remote detection of psycho-emotional states

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Abstract

We study the possibilities and limitations of infrared thermography to remotely control and characterize human functional states. The work is focused on estimating the relationship between the dynamics of heat fluxes from a human face and fingers captured by a thermal camera, and the physiological response of the autonomic nervous system registered by contact methods. The purpose of this work is to develop the technology to remotely control psycho-emotional conditions of the person (quiet wakefulness, emotions, a stress) on the basis of infrared imaging of: the expansion of the cutaneous blood vessels; the dynamics of respiratory flows; the sweating gland activity. The results are then compared to the data on the activity mimic muscles and skin galvanic response of the fingers registered by contact methods.

1. Introduction

Over the last few years, there has been a growing interest in the development of new techniques for remote non-invasive control of human psychological markers. The reliable detection of functional states of a person involved in hazard-related activity has become also socially important.

One of the significant applications of thermography is noncontact registration of psychophysiological parameters through systems of distant detection and identification of human appearance and behaviour features in situations of anxiety, increased emotional excitement, and stress. Human skin has high emissivity, close to a perfect blackbody. Therefore, a change in its temperature leads to a significant change in the power of emitted infrared (IR) radiation. Low reflectance of skin minimizes the environmental influence on the detection of skin temperature. In thermographic imaging low reflectance allows accurate capturing of local temperature changes. Cardone et al [1] review the main achievements of thermography in monitoring the human functional states (FS). They also provide strong evidence of the ability to use infrared images as the basis for a quantitative estimate of autonomic-nervous-system activity parameters, such as local blood perfusion, heart rate, and respiratory rate. Pavlidis & Levine [2] show that the level of perfusion in the eye-socket region allows the registration of small temperature changes associated with human FS. Puri, et al [3] discovered that the rectangular forehead area containing central vessels is the most informative for stress diagnostics.

A number of studies suggest that one of the most informative methods for human FS evaluation is remote thermographic analysis of breathing flows. For example, Lewis et al [4] provide experimental data showing that infrared thermography allows sufficiently accurate evaluation of breathing rhythm and relative tidal volume. Study of facial thermal radiation by infrared cameras (thermal imagers) is a new and actively developing area at the intersection of fundamental science and practice (Jarlier et al. [5]; Kong et al [6]). This method is the most promising and rapidly developing technique for the distant detection of emotions. Temperature mapping has now a high temporal resolution and allows identification of face features and expressions in low-light conditions.

Generally, a thermography is used in combination with a regular video camera. The software module is developed for comparison of the image from the video camera and the thermal imaging camera. The facial image in the visible range has more pronounced details that allow more accurate determination of the areas of interest on the face; it compensates for possible distortions, such as head rotation and mimic distortions, and allows more accurate estimation of the distortion parameters. In Ekman et al. [7], the comparison was based on the analysis of 13 facial regions of interest (ROIs) that are critically important for the recognition of basic emotions. For each ROI the average value of the parameters was extracted, and then principal-component analysis was used to identify the degree of deviation of each of the 13 regions from neutral facial expression. It turned out that under different levels of illumination but constant temperature the thermal method was better than the visual method, as was expected. Under conditions of constant illumination and variable temperature (a fan with heated air of varying intensity was directed on the face of the subject) the visual method showed greater efficacy, whereas the performance of the thermal method, contrary to expectations, remained virtually unchanged.

The most available to thermal measurements is a human face and the area around it. Under constant external conditions, the temperature map of human face is non-uniform and is determined by the individual physiological features of a body. Local changes in skin temperature can be related to:

1) the activity of mimic muscles;
2) the expansion of cutaneous blood vessels;
3) the dynamics of respiratory flows;
4) the sweating gland activity.

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2. Experimental procedure

The main condition for formation of an IR image is the temperature contrast between an object and a background. Features of radiation of a skin of the person defined wide use of a thermography in physiological and biomedical diagnostics [8 -10]. The skin has high emissivity in the IR spectra close to that of a perfect black body; therefore, the change of its temperature leads to a substantial change in the emitted IR of radiation. Besides, the low reflection of the skin minimizes the influence of the environment on the captured radiation.

Certain areas on a human face have the largest thermal response to various internal and external stimuli (regions of interest, ROI [11]. One of the biggest challenges in the infrared-based FS control is the correction of ROI locations for body movements.

In experiments, a FLIR SC7700 camera was used for IR imaging. The camera has an operating range of 3.7-4.8 μm (MWIR) and allows capturing thermal images with a frequency up to 115 Hz with the spatial resolution of 640x512 pixels and up to 400 Hz with limited resolution. The control of the camera and the image post-processing are carried out by the camera software: Altair and FLIR ResearchIRMax.

A number of experiments were performed using a second IR camera - COX CX640. This camera operates in a wavelength range of 8-14 μm (LWIR) and produces thermal images with a frequency of up to 50 Hz with a spatial resolution of 640x480 pixels. LWIR camera belongs to the class of uncooled thermal receivers of a microbolometric type, has a thermal inertia and lower temperature sensitivity compared to the MWIR camera. Thermal Imaging Analyzer software is used to obtain and analyze the thermal images.

Recordings within the visible range was carried out at the same time using an Olymus OM-D E5 digital camera.

About 25 healthy examinees (men and women) aged from 18 to 55 years participated in the experiments. All measurements were taken while the examinees were sitting, after their adaptation to laboratory conditions. The thermal imager and the video camera located at distance about 1 m from the examinee. The recording duration varied from 20 up to 15 min. The recording frequency was 5-25 Hz. The fixed indoor temperature (20-22 °C) was maintained.

The skin galvanic response (SGR) on the fingers was also controlled. SGR is a bioelectric response widely applied in psychophysiological researches as a highly sensitive index of the activity of the sympathetic nervous system and also of the neuromental tension of a person. A multi-channel encephalograph analyzer Entsefalan was used simultaneously with thermal imaging for the contact control of physiological responses. The part of experimental installation is presented in Figure 1.

Fig. 1. *Part of the experimental installation*

A series of experiments was conducted using the prepared scenarios containing intervals in which examinees were in a quiet status, and intervals in which stressful conditions were modelled.

3. Results and discussion

Full-face and profile facial thermal images were obtained for the study of human breathing. It was found that the periodic change in the temperature of the areas of interest is consistently observed in the registration of IR radiation from the surface of the skin of the full-face both in the medium-wave and long-wave IR range (Fig. 2).

Fig. 3 shows changes in a thermal signal detected from three ROIs under a person's nasal area while breathing. Temperature evolution at selected points was studied. The power spectra of the signals of a resting person typically show a single peak frequency that corresponds to a normal human breathing rate. The spectra of the signals recorded during a stress test, however, do not allow extraction of a single peak frequency (Fig. 3, right). Thus, the developed methodology allows for detecting atypical or irregular breathing patterns, which can be considered as markers for psychological or physiological distress.

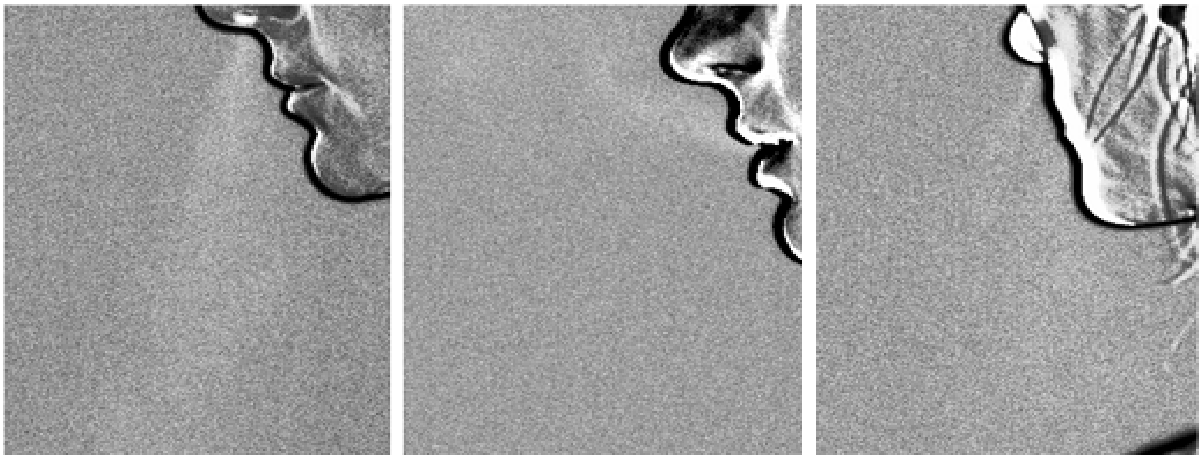

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Fig. 2. *IR images of breathing: 1. 90° angle, through nose and mouth; 2. 120° angle*

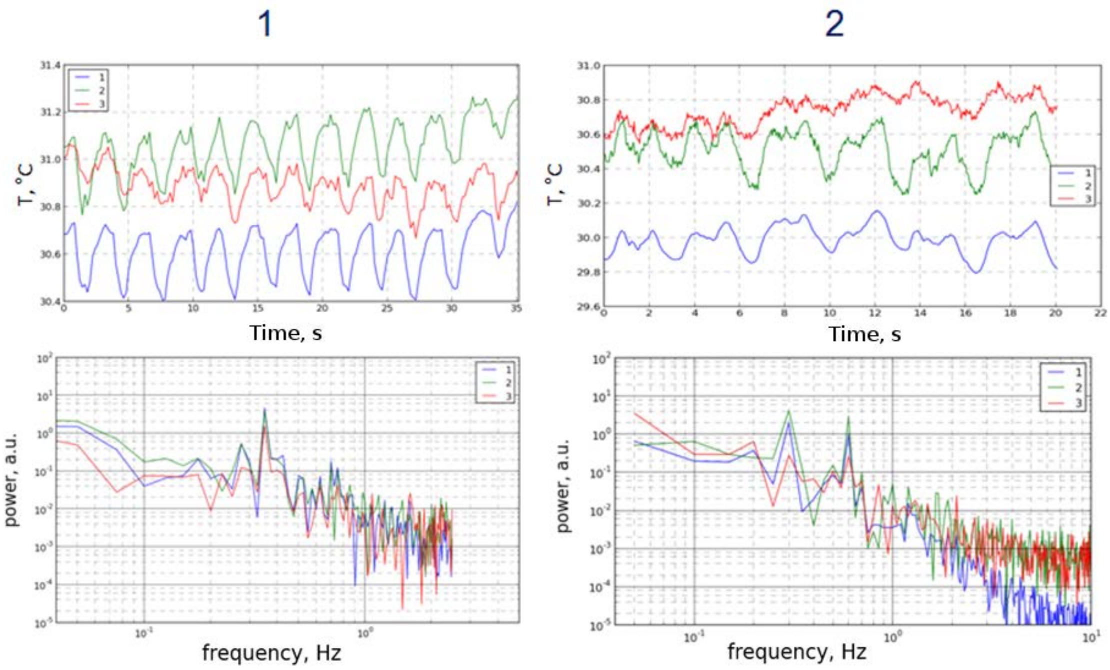


Fig. 3. *Time-series and spectral characteristics of human breathing dynamics: 1. in normal resting conditions; 2. under stress*

In Fig. 4 the example of comparison of dynamics of a heat flux from area of interest (a nose tip) on a human face with results of record of the skin galvanic response (SGR) is provided. In Fig. 4 it is visible that stressful response to a sharp sound leads to local increase, and intensive mental loading - to local lowering of temperature in the field of interest (most possibly, connected to its cooling due to increased activity of the sweat glands).

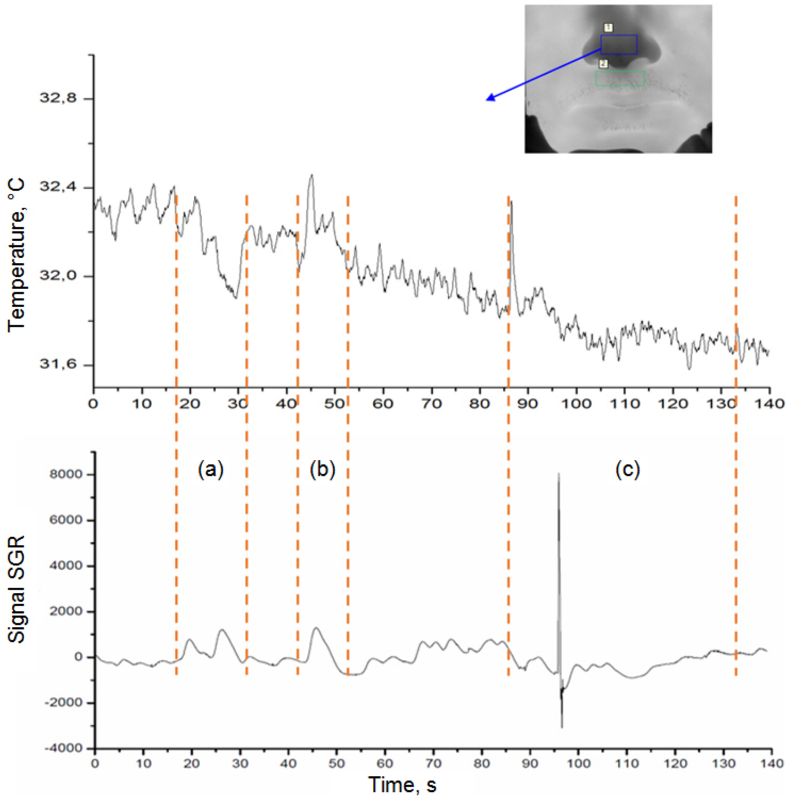


Fig. 4. *Comparison of dynamics of an average temperature signal in the field of interest (it is allocated on the thermogram) and SGR signal during passing of the test: (a) deep breath; (b) sharp sound; (c) mental load*

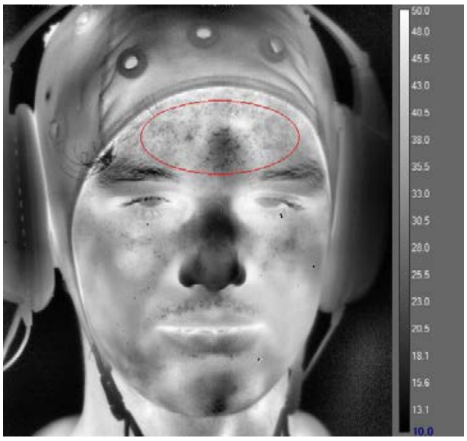


Fig. 5. *Perspiration visualization during an intense mental activity*

Detailed process of perspiration from the pores was tested using micro and macro recording of POIs on the face (Fig.5) as well as on the fingertips (Fig.6 a). Micro drops of perspiration were visualized and their dynamics was studied with the FLIR SC7700 camera. Especially sweating from the pores on the fingers were in focus. Their size evolution was recorded with high spatial and temporal resolution (the smallest recorded spots had a diameter of 0,2 mm). It was shown that perspiration drops on IR images may appear and disappear in time less than 1 second (Fig 6 b).

The comparison of the fingertips dynamics to the SGR signal showed good agreement – the galvanic signal gives the instant response to psycho-emotional states changing as well as thermographic images.

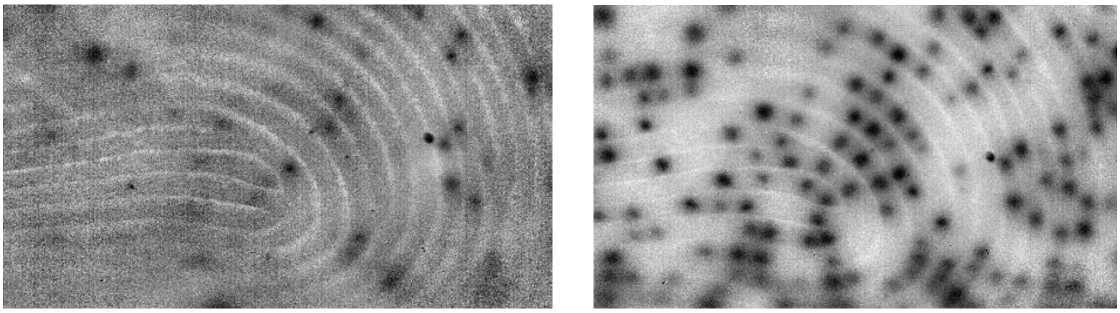
4. Conclusions

The possibilities and limitations of infrared thermography to control heat fluxes from human face area and fingers in order to characterize human functional states were studied. The work is focused on estimating the relationship between the dynamics of heat fluxes from a human face and fingers captured by a thermal camera, and the physiological response of the autonomic nervous system registered by contact methods.

The dynamics of respiratory flows and the sweating gland activity was studied using two infrared cameras with different parameters. The expansion of cutaneous blood vessels was not detected. Changes in a thermal signal were detected from different ROIs under a person's nasal area while breathing. Temperature evolution at selected POIs was studied. The power spectra of the signals of a resting person typically show a single peak frequency that corresponds to a normal human breathing rate; the spectra of the signals recorded during a stress test, however, do not allow extraction of a single peak frequency. The developed methodology allows detecting atypical or irregular breathing patterns, which can be considered as markers for psychological or physiological distress.

Perspiration from the pores was tested using micro and micro recording of the face and fingertips. Sweating from the pores on the fingers was recorded with high spatial and temporal resolution. It was shown that the perspiration drops on IR images may appear and disappear in time less than 1 s. Their dynamics well correlates with the SGR signal.

The analysis of the revealed psychophysical response in the form of a local change in emitted IR radiation from the facial area for different tests was carried out. The results suggest that dynamics of thermal fields in a human facial area can serve as the indicators of changes in a human psycho-emotional state. The developed complex method was demonstrated to be rather promising.



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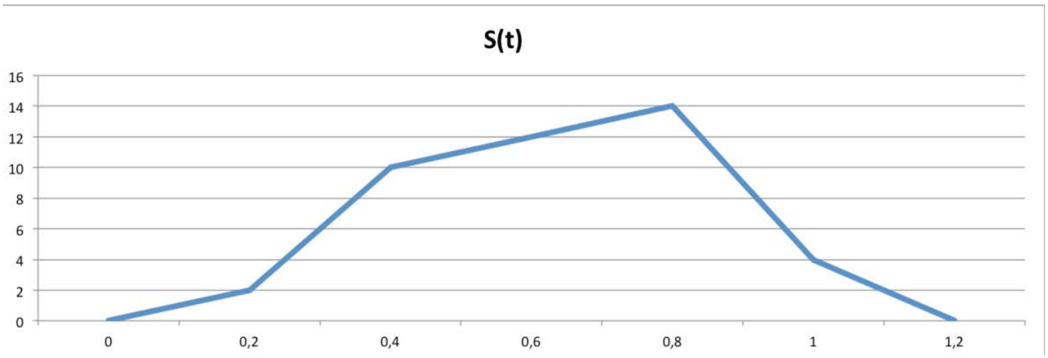

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Fig. 6. *Dynamics of the perspiration drops on the fingers at sharp sound. Time interval between two upper images is 1 s*

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