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Thermal-time constant imaging in cold-stress screening

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***Abstract*— This paper presents the use of active thermography as the tool of medical imaging technique. The cold stress method is used to stimulate human skin and measure its temperature change in time. Image and data processing techniques are applied to calculate response parameters and plot theirs spatial distribution. The preliminary results are presented which reveal different vascularization under the skin.**

Keywords-active thermography; cold stress; temperature response; medical imaging.

I. INTRODUCTION

The aim of this study was to characterize the key image processing techniques and to develop the software for the use of active thermography as the medical imaging technique for screening. The thermography is the passive technique that measures temperature distribution on the surface of the skin. The advantage of using thermovision is that this method is contactless, non-invasive and it becomes significantly cheaper now. However, the temperature distribution on the skin's surface results from individual thermal characteristics of human body. In particular, the skin temperature depends on the energy balance inside the tissue, where the perfusion and small and large vessel blood flow takes place. Therefore, a more complex technique such as active thermography is used in order to evaluate thermal parameters in quantitative way [1]. The thermal parameters characterizing the tissue are calculated from recorded temperature change in time after thermal stimulation (cooling or warming) of the skin. The most popular approach is to fit the exponential curve to the recorded temperature [1]. The calculated time constants are then used to characterize the tissue. In order to approximate skin response more precise the linear combination of exponential functions is also used [2-4]. Combination of exponential and error functions was used in this research. It was verified that such approach approximates the temperature change better with the lower error [5]. Moreover, it results from the physical multilayer structure of skin and heat flow [6]. It is assumed that estimated thermal parameters can be used to differentiate the state of the skin and inner tissue because the possible diseases e.g. breast cancer, inflammation, melanoma and other pathologies influence the vascularization of the tissue [7-9].

Many of today's medical diagnosis techniques use imaging as the method to present the results of measurements of the human body. It is one of the most convenient approach to identify areas of interest where a further analysis should be undertaken. The results of active thermography in medical applications can also be presented in form of image that show spatial distribution of measured parameters' values. The paper presents an exemplary software for such applications. The main elements of the algorithm and the result of imaging are shown. The example of examination was performed on the skin in the area with blood vessels beneath it.

II. THERMOGRAPHIC MEASUREMENT

The thermographic measurement was done using MWIR (3-5 μm) Cedip-Titanium camera with InSb cooled detector of 640 x 512 pixels resolution and the NETD = 17mK. The selected frame rate is important to measure precisely the skin's fast thermal response starting just after the end of the thermal stimulation. It is caused by the reaction of thin, top layer of the skin called epidermis. Due to this fact, the frame rate of 50 FPS was chosen. Thermal stimulation of the skin was performed using two metal blocks at room temperature, approximately 25°C [6]. Applying them to the skin for 6 seconds allowed to cool by about 7°C below the normal temperature. The sequences of the thermal images have been recorded for 5 minutes. Such time was sufficient for skin to reach the initial steady-state temperature. The examination was performed according to the guidelines for thermovision measurements in medicine [10,11]. After acquisition the sequence of infrared images, they were processed and analyzed using the software developed for this research.

III. DEVELOPED SOFTWARE

A few steps should be performed to visualize the distribution of calculated parameters from the skin thermal response. At first, the movement correction has to be applied. This is a very important step in the measurement of a patient's skin temperature, as the recording lasts several minutes and the patients breathe and slightly moves. Temperature change is examined for every point of the area under the thermal stimulation. All movements disturb the measurement and can cause wrong function approximation, and in consequence wrong parameters calculation. The movement correction is based on the cross-correlation method [12]. The method localizes the template image in the base image. The image position, which is the most similar to the template, is indicated by the highest absolute value of the calculated cross-correlation coefficient. The output matrix of correlation coefficients, which size is the same as the size of the base image, is calculated with the formula:

$$\gamma(u,v) = \frac{\sum_{x,y}[f(x,y)-\bar{f}_{u,v}][t(x-u,y-v)-\bar{t}]}{\{\sum_{x,y}[f(x,y)-\bar{f}_{u,v}]^2[t(x-u.y-v)-\bar{t}]^2\}^{0.5}} \quad (1)$$

where:

f is an image,

t is a template image,

$\bar{t}$ is the mean of template,

$\bar{f}_{u,v}$ is the mean of $f(x,y)$ in the region under template.

This method is sensitive for the intensity gradient in the image. In order to improve movement correction the aluminum foil, which has different emissivity than human skin, is placed on the body as a marker. The algorithm tracks this marker and calculates its new position for every frame. The stabilized image size is specified as the recorded frame size is reduced by the maximum dislocation in every direction. Based on the calculated data, the stabilized images in time are extracted from the recorded sequence. Briefly speaking, the algorithm works as the digital image stabilization technique performed after recording process. Next, the Region Of Interest (ROI) is determined where the temperature difference between first and last frame of the stabilized images are detected. Afterwards, temperature change in time is extracted from the sequence of stabilized images. Not all pixels in detected ROI are further processed because the final approximation of data curves is very time consuming. For example, the approximation of 4800 temperature curves, in used MATLAB programming environment, takes around 50 minutes on Intel i7 processor class computer. The whole size of ROI contains 19000 pixels. Therefore, the measured temperature is calculated as the mean value of 3x3 pixels area for the pixels (centers of averaged area) that have coordinates with even columns and rows. In result, only ~17% of points from the region of interest are processed in next steps, what allows to speed up the calculations. The extracted data often contain noise. It can be caused by incorrect movement correction or simply measurement noise. This noise is reduced with the use of median filter followed by mean filter. The filtration is done for the data in time of every selected pixel – it is one-dimensional filtration. The size of filters' mask was respectively 25 samples (1 second) for median and 200 samples (8 seconds) for mean filter. Finally, the approximation by the linear combination of exponential and error function (2) is applied.

$$f(t) = A(1-e^{-\omega_0 t}) + B(1-e^{\omega_1 t}\cdot erfc(\sqrt{\omega_1 \cdot t})) \quad (2)$$

The approximation is done with Pattern Search method built in MATLAB environment [13]. The final result is a set of 4 parameters: A, B, ω_0, ω_1 which are the parameters adjusted by the used optimization procedure. Coefficients A, B are the amplitudes and ω_0, ω_1 are the pulsations of curve components. The last step is to calculate parameters values for the pixels that were omitted during data extraction from the stabilized image. These points' parameters values are interpolated as the mean values of the calculated ones in the direct neighborhood.

To sum up, the presented algorithm of data extraction is divided into 6 main steps.

- Stabilized frames extraction from recorded infrared sequence.
- Region of interest detection (region where thermal stimulation was applied).
- Measured temperature in time curves extraction.
- Smoothing the data curves.
- Time graphs approximation with the proposed function.
- Omitted pixels data interpolation.

IV. PRELIMINARY RESULTS

The preliminary tests were carried out on the forearm. The area where thermal stimulation was applied was carefully chosen. On the static infrared image no veins were seen on the surface of the skin – Figure 1. However, the veins are located on the forearm close to the skin based on the anatomical structure of this part of the human body. Blood flow underneath the skin surface, where one measure the temperature, should vary the thermal time constants. This assumption is confirmed in Figure 2. One can notice the difference of time constants for the skin with and without blood vessels. As the result of performed calculations, the spatial distribution of the values of four parameters are visualized. All parameters are normalized and their values are coded with false colors. Prepared data are blended with the background image of recorded part of the human body to visualize the final effect more clearly. The blood vessels are seen in Figure 3. Unfortunately, some artifacts are also seen on the periphery of the selected ROI. With high probability it is an effect of not precise movement correction. It is clearly seen that more information are carried by ω_0 (Fig. 3) and ω_1 (Fig. 4). Visualization of A (Fig. 5) and B (Fig. 6) parameters are rather noisy but blood vessels areas can be localized in these images as well.

V. CONCLUSION

The article presents the preliminary results of the imaging technique based on active thermography and the linear combination of exponential and error functions. Spatial distributions of calculated curve parameters are presented. The example confirms that this method is suitable for characterization skin areas with different vascularization. Based on this approach it can be assumed that the active

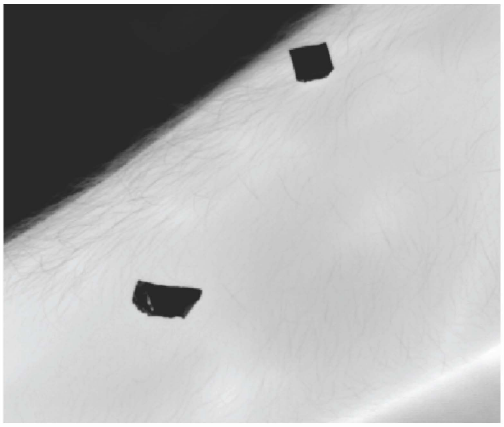

Figure 1. Area under test before the examination

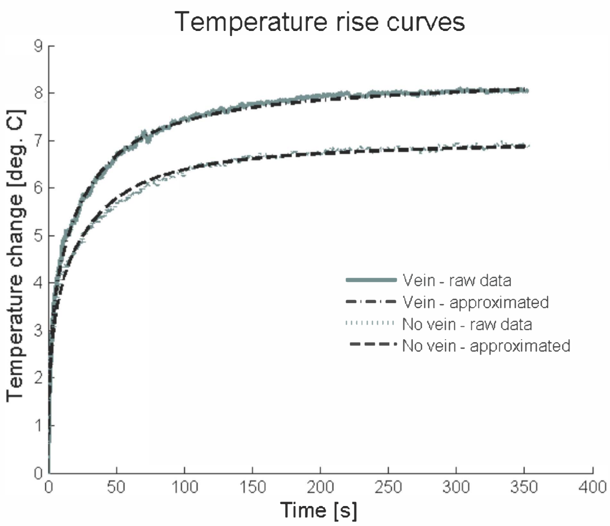

Figure 2. Time graphs of temperature rise after thermal stimulation, where: raw data are values of temperature rise in time measured in point of interest, approximated data are curves ploted with the described linear combination and its calculated parameters.

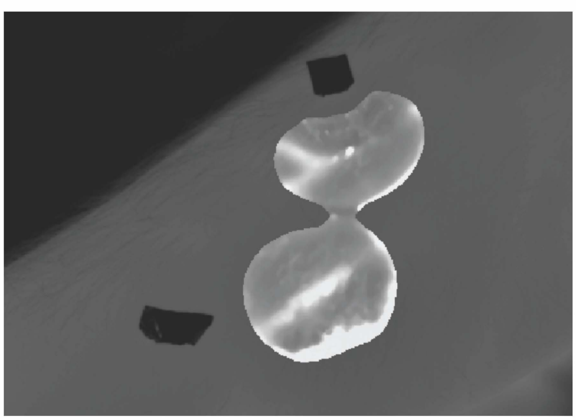

Figure 3. Spatial distribution of parameter ω_0 with detected veins.

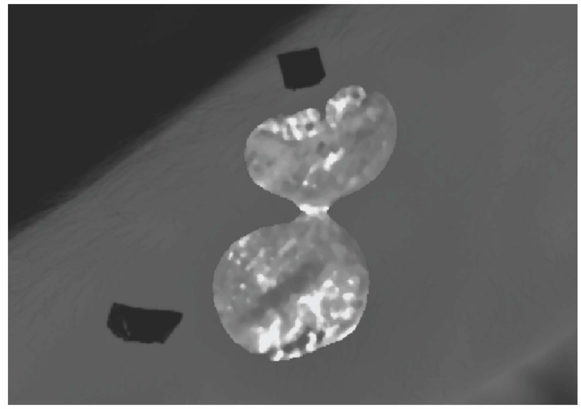

Figure 4. Spatial distribution of parameter ω_1.

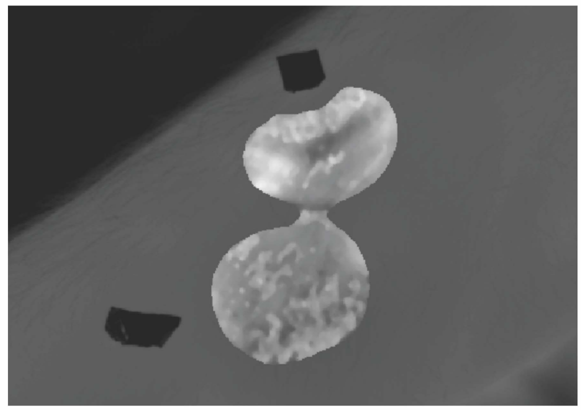

Figure 5. Spatial distribution of parameter A.

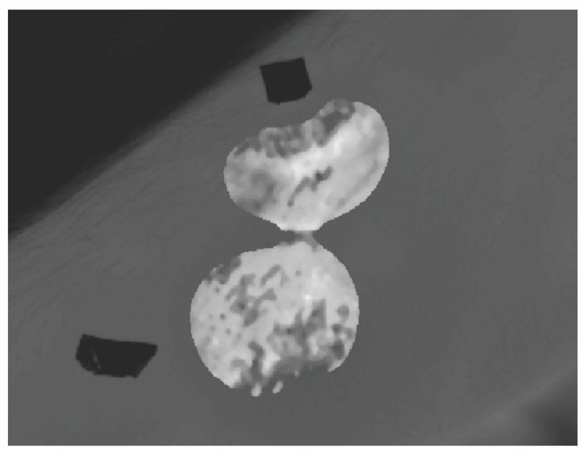

Figure 6. Spatial distribution of parameter B.

thermography imaging can be useful tool in the diagnosis of diseases that change the blood flow in affected areas. One should remember that active thermography as the noninvasive technique is very attractive for practical diagnosis.

Further work on the development of the presented software will be continued. At first, the movement correction module should be improved to eliminate artifacts on the periphery of the ROI. The approximation method of measured temperature rise should also be improved to remove noise in the visualization of spatial distribution of the selected parameters.

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