

System and software for thermal image screening in medicine

by M. Strakowska^{*}, A. Kaszuba^{**}, B. Wiecek^{*}, M. Strzelecki^{*}

^{*} Institute of Electronics, Technical University of Lodz, Poland, strakowska.m@gmail.com

^{**} Department of Dermatology, Pediatric Dermatology and Oncology Department of Dermatology, Medical University of Lodz, Poland, andrzej.kaszuba@umed.lodz.pl

Abstract

This paper presents a novel method for the medical screening of the skin pathology such as melanoma, tumors, different inflammations, psoriasis as well as breast cancers. Our approach uses 3-layer Pennes thermal model of a skin including the perfusion in the frequency domain. It simplifies the mathematical calculations of the model and even makes it analytical. The model is tuned by the measured data captured using the thermal camera. Application of the optimization procedure allows the estimation of thermal parameter for each layer. The parameters of the skin is then used for classification of the different tissue's states. System and software are presented as a novel tool which can support medical screening using thermovision camera.

1. Introduction

Thermovision cameras are not often used as a standard equipment in medicine, rather for some experiments and research. The advantage of using thermovision is that this method is contactless, non-invasive and cheap. The aim of our research is to show that some illnesses, especially the skin pathologies can distinguish using thermovision not only qualitatively as it takes place very often but also quantitatively using the real values of tissue's. Such approach will be more objective. Due to this fact the thermal model of human skin was developed and implemented in software which is presented in this paper.

The thermal modeling of the tissue differs from heat transfer in solids and fluids. One has to consider the perfusion and blood flow. The tissue is a non-homogenous, anisotropic medium. It causes the difficulties in solving the model given by the set of differential equations. The attempt of including the perfusion in thermal modeling was presented by Pennes in 1948 [1,6,9,10]. Chen-Holmes (1980) proposed the modeling the heat transfer in a tissue as in the porous material [2]. They divided a tissue into 2 parts: solid-like and fluid-like ones. They introduced the blood (fluid) velocity to model and the additional heat transfer due to the blood movement. They proposed a simple way to split the model into solid and fluid parts using the partitioning factor. The main problem in this approach is to define the velocity of blood and the partitioning factor. Weinbaum-Jiji-Lemons proposed a model including the heat transfer between a tissue, arteries and veins [3,4]. There are many numerical model today for heat transfer in the tissue, but they need to be calibrated with the measuring data, as they use many parameters with explicitly unknown values [6,11].

In this research we use the Pennes model for 3-layer skin tissue structure. In this way we take into account the important parameter of the tissue – the perfusion.

2. Medical screening using IR thermography and inverse thermal modeling

The protocol of medical screening and processing the data starts with the image acquisition from thermovision camera after cold stress – Fig.1. Then the movement correction has to be applied to the sequence of thermal images [8]. Next, the approximation for smoothing and noise reduction is applied. It is done by the combination of exponential and error functions. Next step of the proposed method is the comparing the experimental data with the results obtained from the model. The optimization procedure is applied in order to get the values of tissue parameters. The assumption and scientific hypothesis are that the physiological and pathological tissues have the different values of thermal parameters and perfusion rates.

We propose to use thermal cold provocation to stimulate the transient thermal process in the skin. For such a case, it is easy to define the thermal model in frequency domain for each layer and solved in the analytical way. In order to get a temperature for 3-layer structure, the set of linear equation with continuity conditions at the interfaces, both for the temperature and heat fluxes, have to be solved. Next, one compares the temperature in frequency domain calculated by the model and measured by the thermal camera (after Fourier transform) – Fig. 2. The values of the thermal parameters for each layer are used for the classification of healthy and unhealthy cases using e.g. the neural networks.

The thermal model of the skin takes a form (1).

$$\rho \cdot c \cdot \frac{dT}{dt} = \lambda \cdot \frac{d^2T}{dx^2} + w \cdot c_b \cdot \rho_b (T_B - T) + Q_{met} + Q_{ex} \quad (1)$$

where: Q_b – heat corresponding to blood perfusion, Q_m – heat corresponding to metabolism and Q_{ex} – external heat.

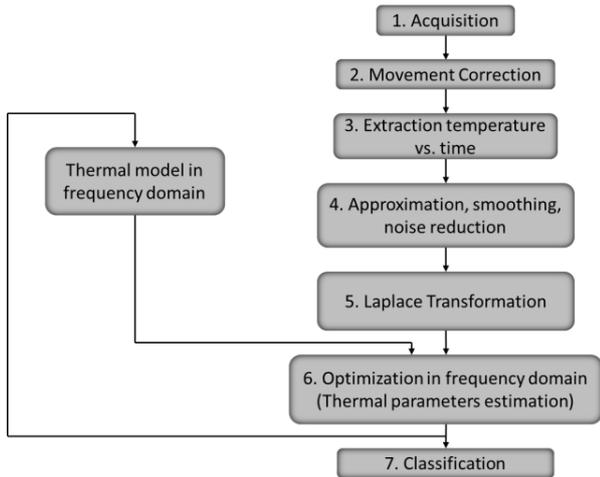


Fig 1. Block scheme of thermovision screening and processing the data procedure

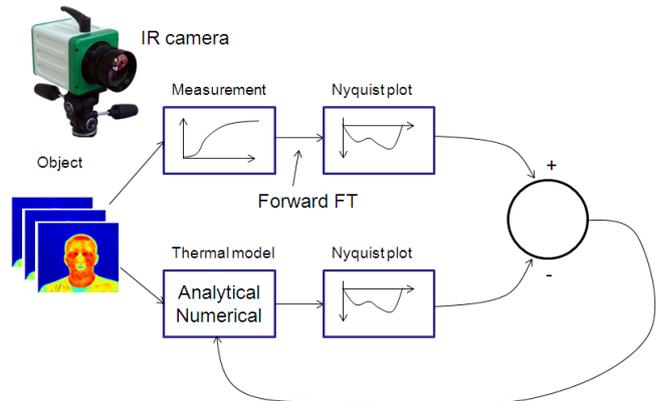


Fig 2. 3-layer thermal model of the human tissue

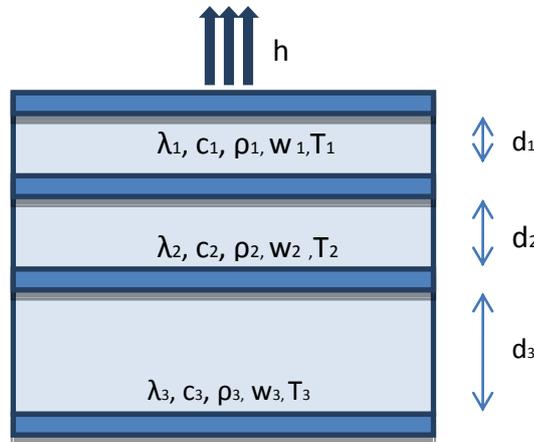


Fig. 3. 1-D 3-layers model of human tissue

3. Software for the medical screening

In this research, a new software for thermal image analysis for medical applications was developed. This program can be useful in dynamic thermal investigations in medicine. Thermal model of human skin is implemented in order to classify human tissue for healthy and unhealthy ones. The transient and frequency analysis is included in the software. For practical screening protocol, we are using the cold provocation. The example for breast cancer screening is presented in Fig. 3 [7].

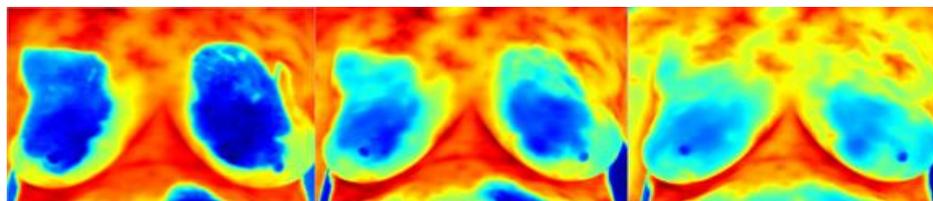


Fig. 3. Example of sequence of thermal images after cold stress provocation using cold gel [7]

Different types of cooling methods were tested in our system: cooling by gel (Fig. 3), compressed air (Fig. 4) and metal blocks (Fig. 5). In this paper preliminary results for patient with psoriasis are presented. Our approach assumes that the healthy and unhealthy skin was compared for the same or opposite part of the body. Because the psoriasis are spread over the body it is hard to cool down two regions of interest equally using cooling gel or compressed air. For such cases the cooling was done using the metal blocks (Fig. 5,6,10).

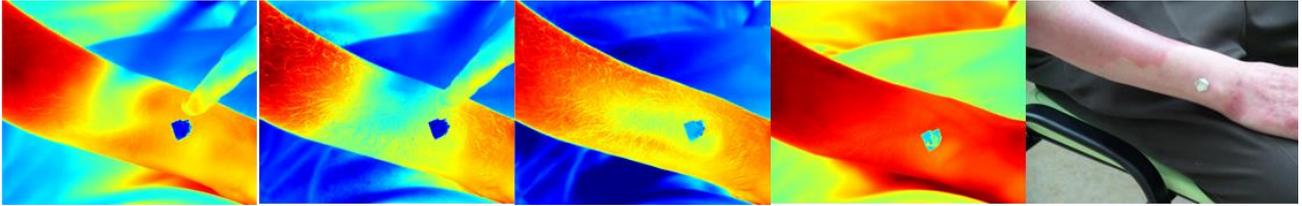


Fig. 4. The sequence of thermal images during and after cooling using compressed air

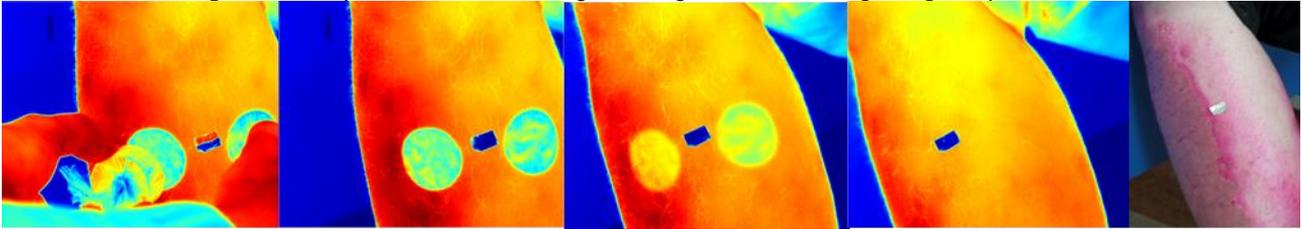


Fig. 5. The sequence of thermal images during and after cooling using metal blocks

At first, the sequence of thermal images is registered after the thermal provocation. Next the movement correction is applied. This is very important in the measurement of a patient's skin temperature, as the recording lasts several minutes sometimes. All movements like heart beating or breathing disturb the measurement. The movement correction is based on cross-correlation method [8]. In order to improve tracking the region of interest, some characteristic points have to be defined on the skin. Figure 6 shows two regions of interest (ROIs) (healthy and unhealthy) of patient's skin with psoriasis cooled down by the metal blocks and aluminum foil placed in between ROIs.

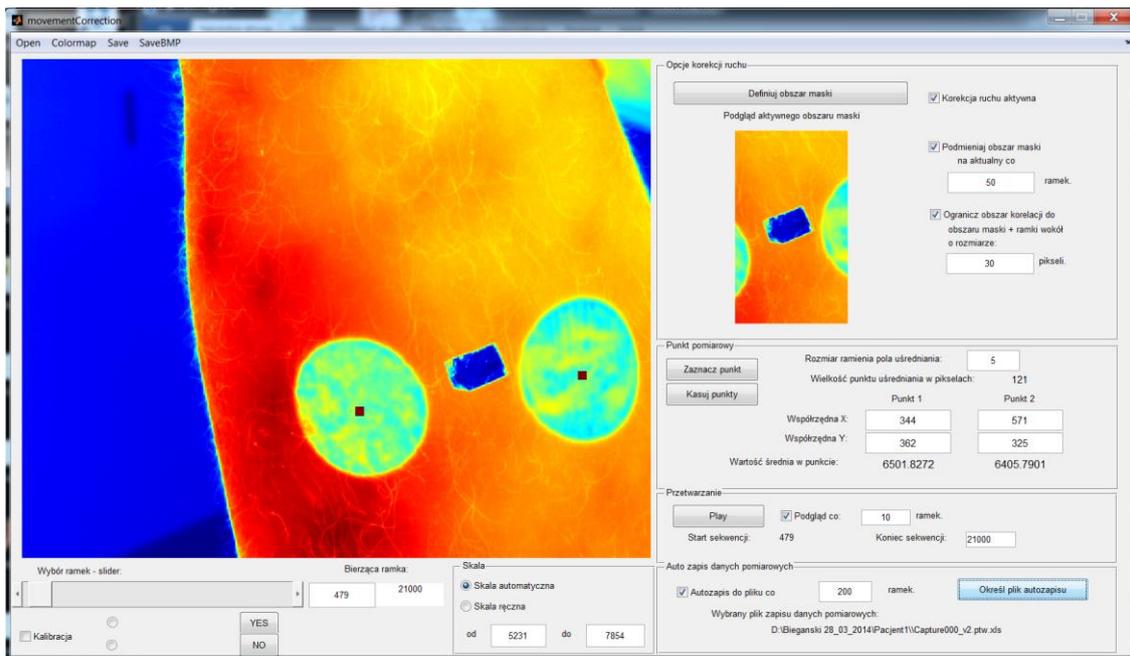


Fig. 6. Screen of the module for movement correction

The program allows to define manually the image part (mask) which is correlated with every next image in the sequence. The constrains of region where the motion is corrected can be specified in details in order to speed up the operation of the program. In this module motion correction of two ROIs marked in the image is possible. There is also the possibility of viewing the process of the movement correction for every few frames. When the correction stops, the data is written to the Excel[®] format file. The operator can apply the correction for all pixels on the thermal image.

Next module implemented in the software is time (Fig. 7) and frequency analysis and approximation the temperature evolution in time. The temperature surplus above the ambient (ΔT) is approximated by the exponential and error functions. Such approximation gives the good results and can be easily transformed into the frequency domain. The curves of temperature in frequency domain are represented by the Nyquist plot given by eqn. (2).

$$\Delta T = \frac{A}{1 + j\omega/\omega_0} + \frac{B}{1 + \sqrt{j\omega/\omega_1}} \quad (2)$$

Then the optimization is performed using the *fminsearch* function in Matlab® which uses the Nelder-Mead simplex method. This is the multidimensional unconstrained nonlinear minimization, and using *patternsearch* function, in which we can set up the limits of the parameters manually. If the function cannot be fitted automatically because of e.g. the noise, there is possible to find parameters of the model manually finding appropriate values of A , B , ω_0, ω_1 .

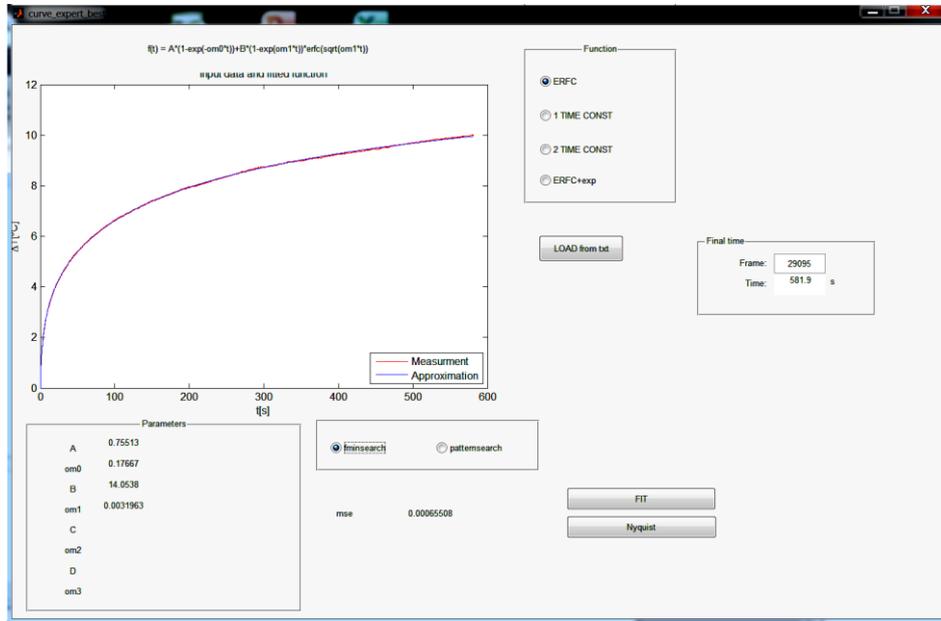


Fig. 7. Screen of the module for curve fitting in time domain

The optimization procedure in frequency domain is main part of the software. The thermal parameters of skin are estimated in order to fit the temperature curves from the model and measurement. The operator can choose the set of parameters for tuning. Few methods of optimization are implemented in this software – pattern search method, genetic algorithm, constrained nonlinear optimization and the Nelder-Mead simplex method. Figure 8 presents a screen of two function: one got from the model for the values of parameters from the literature, second – the example of function after approximation of the measured data for patient with psoriasis.

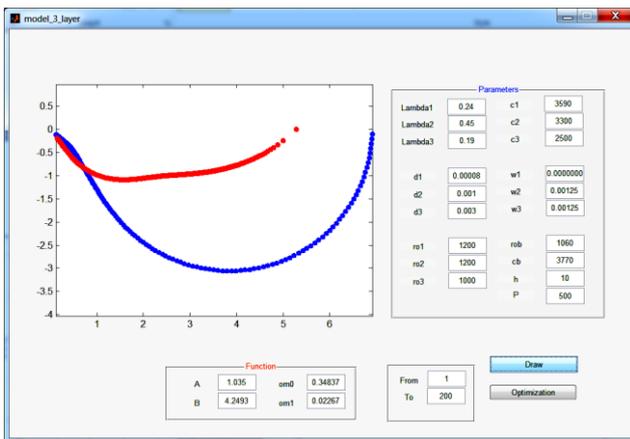


Fig. 8. Screen of the program for manual curve fitting in frequency domain

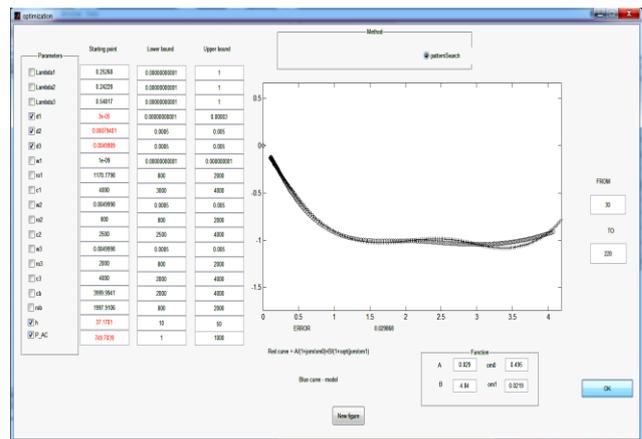


Fig. 9. Main window of the program with fitted Nyquist plots

The result of fitting the Nyquist plots of temperature for the model and thermographic measurement is presented in Fig. 9. It has to be pointed out that using such optimization the depth of penetration of heat inside the body can also be estimated. It can be seen that it is rather difficult to fit the Nyquist plots for the very low frequencies. The best fitting is always for higher frequency range. It is because of the depth of the heat penetration in the tissue. The model has a limited depth, and the low frequency part of Nyquist plot corresponds to the deeper parts of the tissue.

4. Preliminary results

Few patient with psoriasis was examined in order to check if the illnesses tissue gives different thermal response then healthy one. Measurement was done using the metal blocks. Both blocks were put on the skin for 10 seconds in the same moment. Then the sequence of images was registered for 6 minutes using Cedip Titanium InSB 640x512 MWIR thermovision camera which can record images at high frame rate. After that the curve of temperature vs. time was extracted for two chosen areas.



Fig. 10. System of thermovision measurement in hospital and metal blocks using for cooling the skin

Table 1 shows the result of fitting in frequency domain, both for healthy and unhealthy parts of the skin.

Table 1. Values of the fit function for examined patients

	A		ω_0		B		ω_1	
	healthy	unhealthy	healthy	unhealthy	healthy	unhealthy	healthy	unhealthy
Patient 1	1,5349	0,9241	0,25587	0,35328	3,0457	2,4792	0,021913	0,014551
Patient 2	1,7508	0,82935	0,31961	0,49474	4,9875	4,8438	0,022066	0,021875
Patient 3	1,0576	1,7579	0,063837	0,26663	4,3701	3,055	0,075433	0,0023438
Patient 4	1,0823	1,035	0,027692	0,34837	5,4975	4,2493	0,028668	0,022676
Patient 5	1,6851	2,3336	0,018442	0,21059	3,8919	4,7295	0,027292	0,0074936

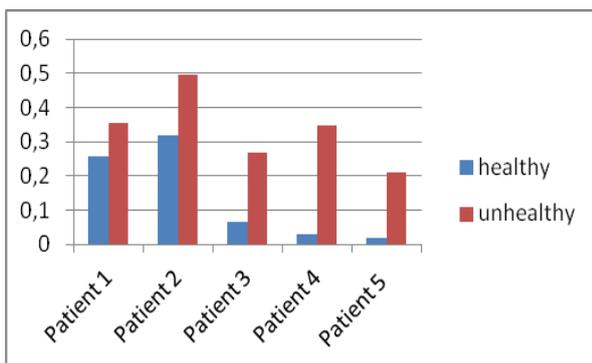


Fig. 11. Value of ω_0 for healthy and unhealthy skin for each patient

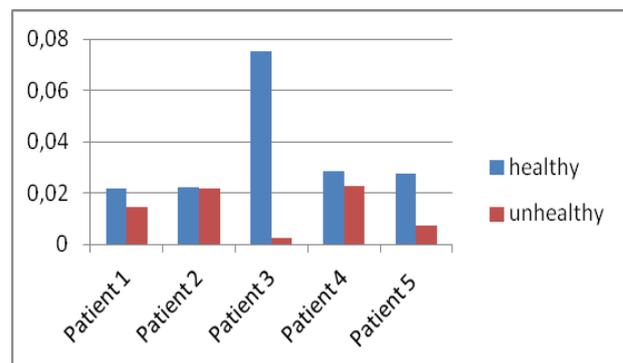


Fig. 12. Value of ω_1 for healthy and unhealthy skin for each patient

The first results shows that ω_0 have higher values for unhealthy tissue while the value of ω_1 has higher value for healthy tissue. It means that unhealthy tissue reacts faster than the healthy one. It is due to the higher perfusion the skin with the high inflammation caused by the psoriasis.

5. Conclusions

Developed system and software can be easily used in medicine to support the diagnosis using standard method. Thermovision as a noninvasive and relatively cheap method of measurement can be using in the hospitals. First study is promising and shows that thermal parameters and perfusion rate is different for healthy and unhealthy parts of the skin and agree with the data published in the literature. There is an idea to use this approach to estimate the stage of different skin diseases, e.g. psoriasis. This system can be also used in other diseases of the skin. There is a hypothesis that this approach can be also helpful in skin cancer screening, especially to distinguish the benign and malignant melanoma.

REFERENCES

- [1] Pennes, H. H., "Analysis of Tissue and Arterial Blood Temperatures in the Resting Human Forearm", *Journal of Applied Physiology*, Vol. I, Number 2, 1948.
- [2] Chen, M.M. & Holmes, K. R., *Microvascular Contributions in Tissue Heat Transfer*, *Annals of the New York Academy of Sciences*, Vol. 335, 1980, pp. 137–150, ISSN 0077-8923.
- [3] Weinbaum, S., Jiji, L.M. & Lemons, D.E., Theory and experiment for the effect of vascular microstructure on surface tissue heat transfer. Part I. Anatomical foundation and model conceptualization. *ASME Journal of Biomechanical Engineering*, Vol. 106, 1984, pp. 321-330, ISSN 0148-0731.
- [4] Weinbaum, S. & Jiji, L.M., A new simplified bioheat equation for the effect of blood flow on local average tissue temperature. *ASME Journal of Biomechanical Engineering*, Vol. 107, 1985, pp. 131-139, ISSN 0148-0731.
- [5] Thorsten M. Buzug, Steffen Schumann, Lucas Pfaffmann, Uwe Reinhold and Jürgen Ruhlmann, *Functional Infrared Imaging for Skin-Cancer Screening*, *EMBS Annual International Conference*, New York City, USA, Aug 30-Sept 3, 2006.
- [6] Alireza Zolfaghari and Mehdi Maerefat, *Bioheat Transfer, Developments in Heat Transfer*, Dr. Marco Aurelio Dos Santos Bernardes (Ed.), 2011, ISBN: 978-953-307-569-3, InTech, Available from: <http://www.intechopen.com/books/developments-in-heat-transfer/bioheat-transfer>.
- [7] E. Laaperi, A-L. Laaperi, M. Strąkowska, B. Więcek, P. Przymusiła, "Cold provocation improves breast cancer detection with IR thermography - A pilot study", *Thermology International*, ISSN-1560-604X, Volume 22, Number 4 (October), s. 152-156, 2012
- [8] M. Strakowska, R. Strakowski, B. Wiecek and M. Strzelecki „Cross-correlation based movement correction method for biomedical dynamic infrared imaging”, *11th International Conference on Quantitative InfraRed Thermography, QIRT2012*, 11-14 June 2012, Naples-Italy, ISBN 9788890648441
- [9] Jonathan W. Valvano, "Bioheat transfer", Wiley "Encyclopedia of Medical Devices and Instrumentation", Second Edition 2005, The University of Texas Austin, Texas
- [10] Jasiński M., *Modelling of 1D Bioheat Transfer with Perfusion Coefficient Dependent on Tissue Necrosis*, *Scientific Research of the Institute of Mathematics and Computer Science, Czestochowa University of Technology*, Vol. 7, 2008
- [11] Khanafer, K., Vafai, K., *Synthesis of Mathematical Models Representing Bioheat Transport*, *Advances in Numerical Heat Transfer*, Vol III, Chap. 1, pp. 1- 28, CRC Press, New York, (2009)