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Modelling of skin tissue thermal phenomena to support the diagnosis of pathological changes

PHD THESIS

ABSTRACT

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Contents

1. Introduction

The aim the thesis was to elaborate the new screening method for skin pathologies. The proposed screening method consists of two main steps: thermal modelling of the tissue and classification of the pathologies. The thermal modelling leads to the evaluation of the physical parameters of the tissue, that are then used in the classification process. It was assumed that the human skin tissue as a multilayer structure, has physical parameters dependent on the pathology presence and its severity. In this research the thermal parameters of the skin including perfusion were used. There are at least a few thermal models of the skin presented in the literature, both analytical and numerical ones. Among them, the Pennes model is still in use, although it is one of the first published and considered as a simplified one [1, 4, 5, 7, 8, 9, 13]. Perfusion of the tissue is one of the most important issue and has to be applied in the modelling In order to get the thermal parameters of the skin, the inverse thermal problem has to be solved. It is done by the optimization in the frequency domain. It simplified and shortened the calculations [10].

Classification is now used in many practical applications, i.e.: image recognition and signal processing [2, 3, 6, 12]. There are a few well-known methods of object classification such as *Support Vector Machine* or *k-Nearest Neighbours*. Chosen algorithms of classification were tested in this research.

Two theses were formulated. The proof of these theses allows to confirm the correctness of the scientific hypothesis and usefulness of the new screening method using thermal cameras for differentiation of the pathological and physiological states of the skin.

1. The approximation of the skin temperature rise curve by the linear combination of the exponential function and the error function makes it possible to use the proposed model to estimate the thermal parameters of the skin and the perfusion.
2. It is possible to develop a method of medical screening which use active infrared thermography and the thermal modelling of skin to detect pathological conditions.

2. Thermal model of the skin

As the human skin consists of three main layers: epidermis, dermis and hypodermis, the three layer thermal model of the skin has been recently developed [9]. The model is based on the Pennes bioheat transfer Eq. (1) [8].

$$\rho c \frac{\partial T}{\partial t} = \lambda \nabla^2 T + q_b + q_m + q_z \tag{1}$$

where $q_b = wc_b(T_b - T)$ - power density associated with the blood flow, T_b - blood temperature, q_m - metabolic power density, q_z - power density supplied from outside. All power densities are in W/m^3.

The model is shown in Fig. 1 [9]. Each layer is described by the physical parameters: λ - thermal conductivity $(W/m \cdot K)$, ρ - density (kg/m^3), d - thickness (m), w - blood perfusion coefficient $(1/s)$, c - specific heat of the tissue $(J/K \cdot kg)$, c_b - volumetric specific heat of blood $(J/K \cdot m^3)$.

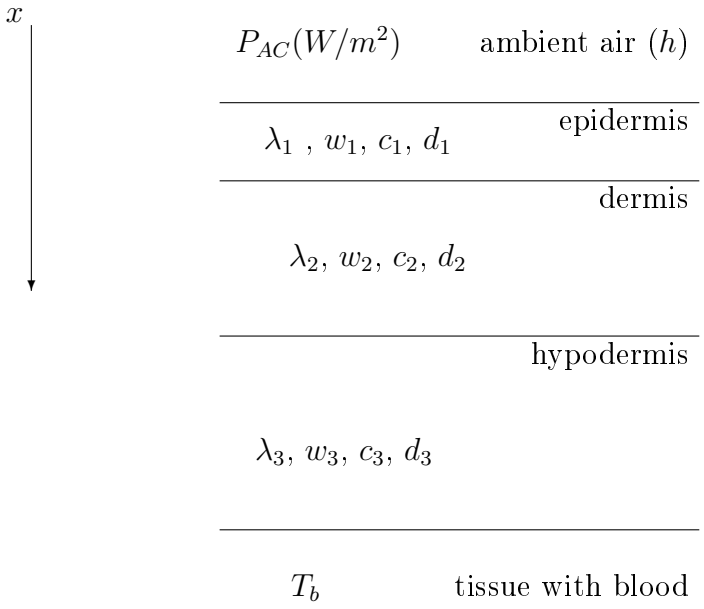

Figure 1: Three layer thermal model of the skin

One assumes that temperature of the blood (inner temperature of the body, body core temperature) is the reference value and is equal to 0^oC. To verify the model, the measurements using thermovision camera were done. The skin was cooled down, and then the temperature rise in time was registered till the temperature came back to its initial value. Thermal excitation can be defined as a unit step. It was assumed that heat is transferred in one direction through the skin. At the borders between the layers, the continuity of heat flux and the temperature were assumed.

Developed thermal model of the skin is solved partially analytically in frequency domain. This simplifies the calculation and speeds up the analysis as compared to numerical methods used usually for thermal modeling of biomedical object [4, 5, 7, 13].

Mathematical thermal model of the skin for one dimension can be expressed by the Eq. (2).

$$\lambda \frac{\partial^2 T}{\partial x^2} = \rho c \frac{\partial T}{\partial t} + w c_b \rho_b T - q_m \tag{2}$$

Parameters of the thermal model were extracted by fitting the Nyquist plots of temperature: calculated using the presented model and measured by the thermographic

camera. The curve of temperature rise after cooling down the skin was approximated by the sum of exponential and error functions (3) in time domain. Such equation can be analytically transform to the Laplace domain. It was confirmed that such approximation gives better result then the sum of a few exponential functions [9].

$$f(t) = A(1 - e^{-\omega_0 t}) + B(1 - e^{\omega_1 t}\mathrm{erfc}\sqrt{\omega_1 t}) \tag{3}$$

where ω_1 and ω_2 are the angular frequencies. Based on the function (3) the Laplace transformation were applied for every measurement. Next, the parameters of the model were extracted by the optimization (using *Patternsearch method*) in order to fit the model (presented in frequency domain) to the results of the experiment using Laplace transformation of the function (3) for $s = j\omega$.

Calculated thermal parameters were used for classification of healthy and unhealthy skin cases. Different classifiers were used in this research including *Neural Networks*, *Decision Trees*, *Support Vector Machine* and *k-Nearest Neighbours* approaches [2, 3, 12].

The block diagram of the developed screening protocol is presented in Fig. 2.

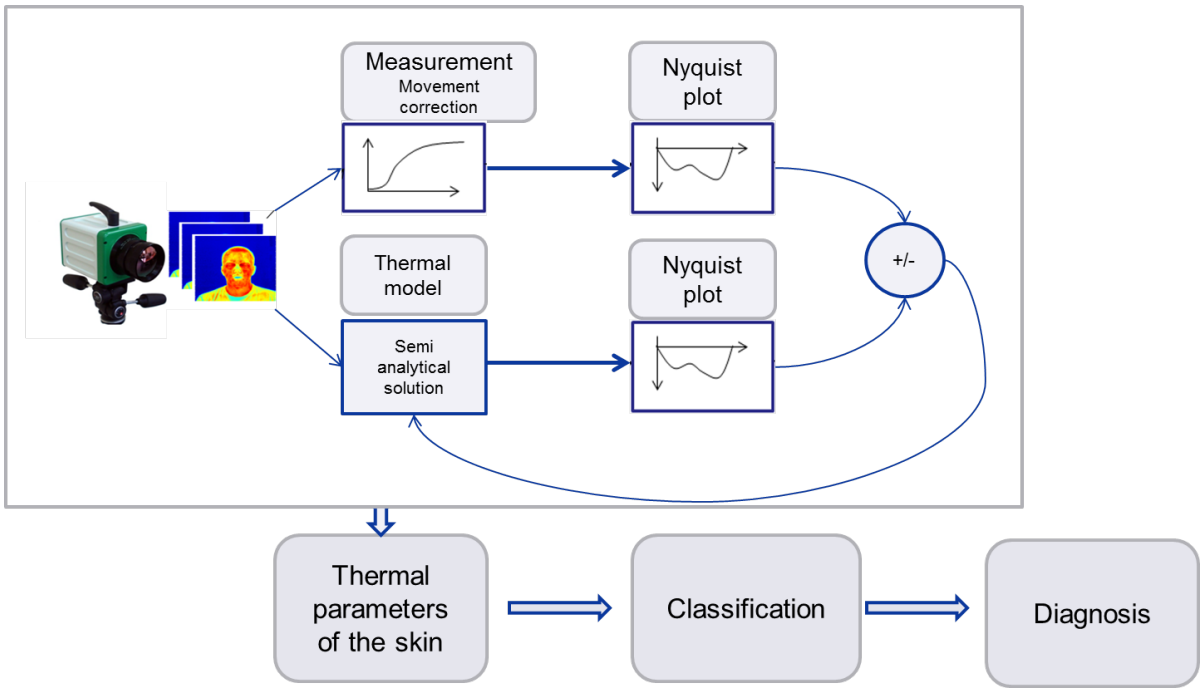

Figure 2: The block diagram of operations in developed thermographic screening method

3. Experiment

The experiment was done with 25 patients suffering from psoriasis. During the examination, a thermal response of the skin was registered by a thermographic camera after thermal excitation (cooling down by cold metal blocks for 7 seconds [10]) in two region of interest: healthy (reference) and unhealthy part of the skin (with psoriasis) - Fig. 3. Two round areas in thermal image presented in Fig. 3b are due to the cold provocation and denote the cooled regions. The visible metal foil is used for movement correction [11].

The total number of 50 samples were taken during the test, 25 for healthy and 25 for unhealthy part of the skin. Then, one performed the analysis in time and frequency domains to extract the model's parameters.

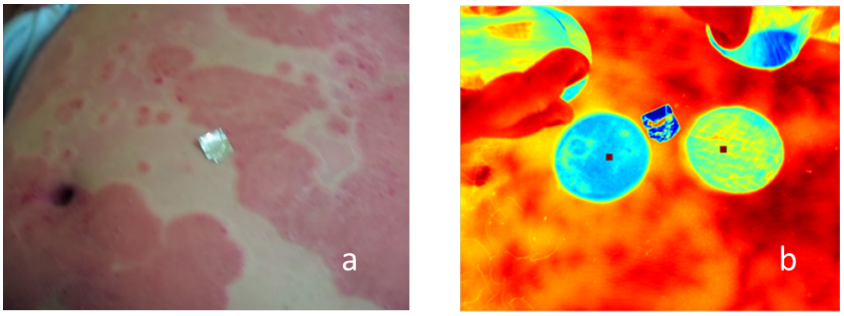

Figure 3: The example of visible (a) and thermovision (b) images of the patient with psoriasis during the examination

4. Classification of the healthy and unhealthy parts of the skin

The aim of the classification task was to distinguish the healthy and unhealthy skin tissues. Every tests were performed using cross-validation method with one patient rejected and used for the validation of classification [2, 3, 12].

Simple classification test was done 25 times (because of 25 patient in the database). During each simulation two samples of one patient (2 regions of interest, healthy and unhealthy skin) were rejected. Learning the classifiers was done using the data set of the remaining 24 patients - 48 samples. The parameters extracted from the rejected patient was taken as the input data for classification validation. The procedure was repeated for every patient. Finally, 50 regions of IR images were classified. Based on the real state of the skin, confirmed by the physician, the effectiveness of classifier used was described.

Few classifiers were tested: DT (*Decision Trees*), LDA (*Linear Discriminant Analysis*), SVM (*Support Vector Machine*) and k-NN (*k-Nearest Neighbors*).

5. Conclusions

In order to prove first thesis, a three-layer model of skin was developed. It was used to estimate thermal parameters of the skin and blood's perfusion value by the solution of the inverse thermal problem in frequency domain. It has been proven that parameters derived from the model can be used to determine the condition of the skin. The tests were carried out in which different methods of feature selection and classification were examined. The best detection accuracy of 96% was achieved. To conclude, a screening method was developed using the active thermovision method.

The skin temperature rise curve approximated by the weighted sum of exponential function and error function, used in the developed screening method, allows the thermal characterization of biomedical structure in the frequency domain. The above statement proves the second thesis of the work.

Based on what have been presented, the thesis has clearly a positive influence on the development of the biomedical engineering in the field of tissue thermal modeling and the use of dynamic infrared imaging.

Acknowledgments

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