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Thermal modelling and screening method for skin pathologies using active thermography

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ABSTRACT

This paper presents a novel screening approach of human skin pathologies using *Active IR Thermography*. The input of the proposed algorithm is the values of the physical parameters of the skin. Parameters are estimated based on dynamic thermographic measurements of human skin and the developed thermal model of the tissue. The calculations were based on the inverse thermal modelling. Classification was done using *Support Vector Machine*, *Linear Discriminant Analysis* and *k-Nearest Neighbours* classifiers. As an example, one presented the results of screening for psoriasis.

1. Introduction

Q2 Infrared thermography (IRT) is one of the diagnostic imaging techniques. It is still considered as a supportive to other imaging modalities implemented in medicine. Recently, however, the use of thermography in the various diagnostic applications has been increasing. It is caused not only by its fully non-invasive and contactless character [1] but also by significant progress and quality improvement of IR equipment. Thermal cameras became more sensitive, faster, smaller, lighter and battery-operated. They can be easily installed in clinics and hospitals for daily use [2,3]. A good review of a number of infrared thermography applications in medicine can be found in the literature [4,5]. On the other hand, there is still lack of standardized protocols and methodologies of quantitative use of this high-tech equipment in medicine. The physicians should have an objective technical support in their daily diagnosis while they are using new imaging systems [6]. A special attention should be paid to *Active Thermography* (AT), which consists in temperature measurement in dynamic states as a result of a certain

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thermal provocation [7]. For example, the skin is slightly cooled down and then the temperature recovery to the initial conditions is recorded by a thermal camera. AT is now a new approach. It has already been reported in applications to burns diagnosis, wounds healing and skin cancer screening [1,7]. Lower cooling temperatures increase the temperature contrast (the difference of temperature) between e.g. the healthy skin and pathological changes. Moreover, the AT allows estimating parameters of a tissue using thermal modelling that mathematically describe the properties and heat transfer from highly perfused inner layers of the tissue to the surface of a body. Since tissues affected by some disease represent different thermal characteristics, the values of parameters can be used for detection or differentiation of physiological and pathological states of tissues. It was demonstrated that AT with thermal modelling improves its performance in burns diagnosis, wounds healing [8], cardiosurgery procedures [9] and breast cancer screening [7,10–14]. What is more, the influence of the melanoma lesions on the temperature of the skin was also investigated. The first application of dynamic thermography for melanoma lesion detection was presented in 1995 [15]. It was done using the very old thermographic system without computer analysis. Newer works present the possibility of using lock-in technique and theoretic modelling during melanoma treatment [16]. The preliminary results of healthy skin using lock-in technique was presented in work [17]. The most interesting papers describe the comparison of the model and measurements results [18–20]. The simple temperature difference in time was used to compared the healthy and unhealthy skin [18]. The numerical FEM model is presented in paper [19] and compared with thermographic measurements after cooling. The Pennes model was adjusted to the experiment. As a result the authors concluded that perfusion is five times larger compared to the healthy skin. Modelling was done in 3D space in time domain. However, the results between the model and experiment was not completely converged. The another paper presents numerical model with sensitivity and uncertainty analysis [20]. All above works was based on modelling in time domain using 3D FEM approach.

The contribution of this paper is twofold. Firstly, it presents a new, AT based method for detection of skin pathologies. The method was tested on a group of patients with psoriasis, however it can be extended for screening other pathologies of the skin and the inner tissues. Secondly, a new technique for inverse thermal modelling and parameter estimation of multilayer tissue structure with perfusion was proposed. It is based on inverse thermal modelling and measurement of temperature distribution on the skin surface used for estimation of the value of the unknown model features. This is done by optimization performed in the frequency domain. Such approach simplifies and shortens the calculations (i.e. model parameters estimation) [13]. The thermal modelling leads to the evaluation of the physical parameters of the tissue, that are then used for pathology detection. It was assumed that the human skin tissue has a multilayer structure, which physical parameters depend 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 [1,21–26]. Perfusion of the tissue is one of the most important issues that must be considered in the modelling. Estimated model parameters are finally selected and classified to detect skin tissue abnormalities.

The organization of remaining of the paper is as follows. Q3 Section 2.1 is devoted to the thermal skin modelling, Section 2 describes a method for detection of skin pathologies based on estimated thermal model parameters. Results of method verification are presented in Section 3 and discussed in Section 4. Section 5 concludes the paper.

2. Materials and methods

2.1. Thermal model of the skin

Human skin consists of three main layers: epidermis, dermis and hypodermis. The new, modified type of three-layer thermal model of the skin has been recently developed [25]. The novelty is semi analytical approach of model parameter calculation carried out in Laplace domain. The transformation from time to Laplace domain was made by approximation of temperature rise of the skin by the sum of exponential and erfc function. The model is based on the basic Pennes bioheat transfer in time domain Eq. (1) [24].

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

where $q_b = wc_b(T_b - T)$ – power density associated with the perfusion, 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 [25]. Each layer is described by the physical parameters: λ – thermal conductivity (W/m K), ρ – density (kg/m^3), d – thickness (m), w – blood perfusion coefficient (1/s), c – specific heat of the tissue (J/K kg), c_b – volumetric specific heat of blood (J/K m^3).

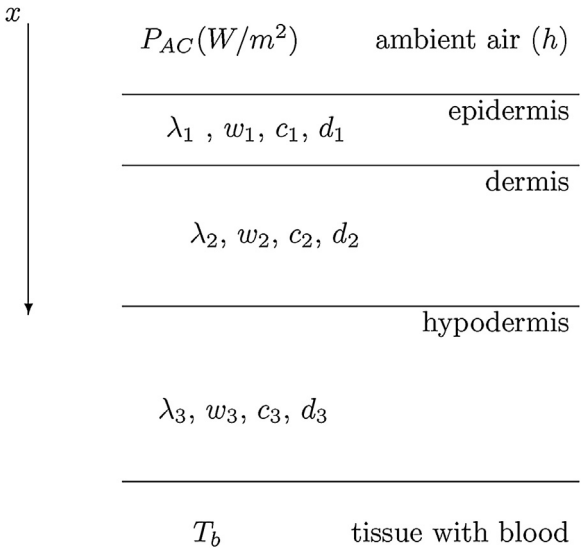

Fig. 1 – Three layer thermal model of the skin.

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