



Thermographic Computational Analyses of a 3D Model of a Scanned Breast

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Abstract. Breast cancer is the most common type of cancer among women. Cancer cells are characterized by having a higher metabolic activity and superior vascularization when compared to healthy cells. The internal heat generated by tumors travels to the skin surface where an infrared camera is capable of detecting small temperatures variations on the dermal surface. Breast cancer diagnosis using only thermal images is still not accepted by the medical community which makes necessary another exam to confirm the disease. This work presents a methodology which allows identification of breast cancer using only simulated thermal images. Experiments are performed in a three-dimensional breast geometry obtained with a 3D digital scanning. The procedure starts with the 3D scanning of a model of a real female breast using a “Picza LPX-600RE 3D Laser Scanner” to generate the breast virtual geometry. This virtual 3D model is then used to simulate the heat transfer phenomena using Finite Element Model (FEM). The simulated thermal images of the breast surface are obtained via the FEM model. Based on the temperature difference of a healthy breast and a breast with cancer it is possible to identify the presence of a tumor by analyzing the biggest thermal amplitudes. Results obtained with the FEM model indicate that it is possible to identify breast cancer using only infrared images.

Keywords: Breast cancer · 3D scanning · Thermal images
Numerical simulation · Inverse problem

1 Introduction

Breast cancer and the most common type of cancer among women in the United States and around the world [14]. This disease is characterized by the disordered growth of cells from different parts of the breast, which may invade other tissues, until the appearance of a malignant tumor [15]. Early detection of breast cancer can significantly reduce the mortality rates caused by the disease [16].

There are several medical imaging techniques that are used for the detection of breast cancer. Mammography still is the main exam. However, magnetic resonance imaging and ultrasound are also useful for the evaluation of the disease [13]. Infrared thermography, capable of capture temperature changes in skin surface, has also been explored as a possible screening tool for detection of mammary tumors [11]. Although, the medical authorities in the subject do not yet allow the use of only thermal imaging as a substitute for mammography [7].

As it is generally assumed that tumor tissue has a higher vascularity and metabolism than healthy tissue, the heat produced by the tumor can propagate through the tissues to the surface of the body where it can produce a temperature pattern variation in the skin [8]. Thus, an infrared thermal camera can detect these changes in the surface of the body.

The strategy of using an optimization algorithm together with an infrared camera can be a useful diagnostic tool for characterizing cancer and reducing unnecessary biopsy testing [3]. Computational simulations allow the increase of data processing capacity, it can assist in the numerical modeling of complex geometries, it can facilitate the automatic search by abnormal thermal patterns in thermographic images [10].

Many papers in the literature present several methodologies to aid in the identification of tumors using only surface temperatures of human skin. Most of them deal with heat transfer simulations in simplified breast geometries, and, the calculated temperatures on the surface are used to detect the presence of tumors [1, 2].

The main objective of this work is to detect the presence of breast cancer through the simulation of thermographic images of a three-dimensional model of a breast obtained by digital scanning. Previous works available in the literature simulate temperatures in simplified models of the breast while in this work a real 3D model is used. Temperatures are calculated using the numerical solution of the Pennes equation using the finite element method through commercial software COMSOL. Then, the thermal superficial images of the breast are analyzed using the MATLAB commercial software for the exact identification of the point of greatest temperature increase caused by the presence of the tumor which can be used for the identification of the position of the tumor.

2 Materials and Methods

2.1 Heat Biotransference Equation

The thermal images obtained in the simulations depend on the solution of the Pennes equation by the finite element method using commercial software COMSOL. The pioneering work of Pennes has proposed a quantitative relationship that describes the heat transfer in human tissues and organs, performing the energy balance within the biological tissues through the interaction of blood perfusion and metabolism. Equation 1 represents Pennes' heat biotransference equation [12].

$$\rho c \frac{\partial T}{\partial t} = k \nabla^2 T + w \rho_s c_s (T_a - T) + Q_m \quad (1)$$

where ρ , c , w and k are the specific mass, the specific heat, the blood perfusion rate and the thermal conductivity of the tissue, respectively. ρ_s , c_s and T_a are the specific mass, the specific heat and the temperature of the arterial blood, respectively. Q_m represents the volumetric metabolic heat generation rate of the tissue.

The blood perfusion effect was considered homogeneous and isotropic. It was also considered that thermal equilibrium occurs in the capillaries microcirculatory networks. In these circumstances, the blood enter the capillaries and the difference of temperature due to the arterial blood temperature causes an exchange of temperature with the surrounding tissue until it reaches thermal equilibrium. At this point, there is not heat transfer, either before or after the passage of the blood thorough the capillaries, so that the temperature at which the blood enters the venous circulation is that of the local tissue [5].

2.2 3D Scanned Computational Model and Numerical Solution

Figure 1 shows in schematic form the procedure to obtain the numerical model of the breast used in the simulated thermal analyzes. A real breast model was purchased from the company 3B Scientific and the Picza LPX-600RE 3D Laser Scanner was used to scan the sample, thus obtaining a representative 3D model of the breast. This procedure may be analogous to a possible future capture of the breast geometry of a patient who wishes to be diagnosed.

The numerical solution of the Pennes equation was obtained with the objective of analyzing the thermal behavior of energy transport in the breast. The mesh used in the COMSOL simulations is composed of 66220 tetrahedral elements and 5742 triangular elements.

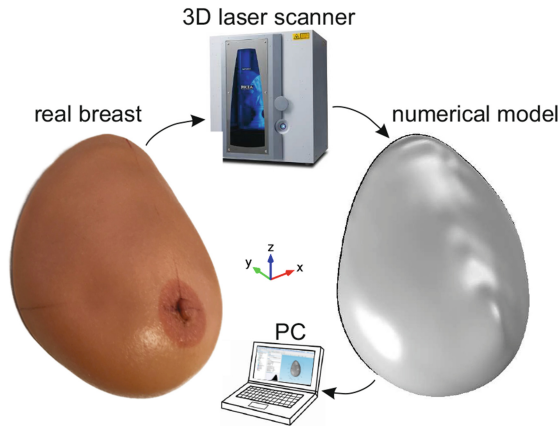


Fig. 1. Procedure for obtaining the 3D geometry of the breast.

2.3 Case of Simulated Breast Cancer

To obtain the simulated thermographic images, only one case of breast cancer was analyzed. This choice was made based on the statistics of breast cancer occurrence found in the literature. Figure 2 shows that most breast cancers are found in the upper right quadrant. Therefore, two simulations were performed. In the first, no tumor was inserted into the breast. In the second, a tumor was inserted in the upper right quadrant. Later the permanent thermal problem will be solved for both cases.

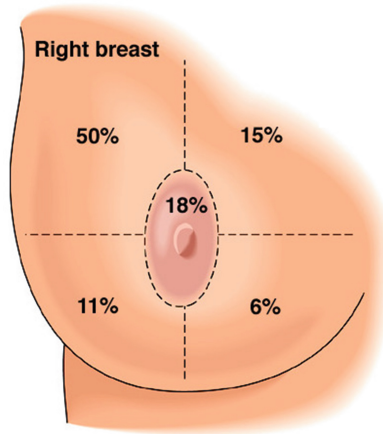


Fig. 2. Breast quadrants and breast cancer occurrence [4].

3 Results and Discussions

At this stage, temperatures on the skin surface of the breast are obtained by solving the Pennes equation in a steady state regime using COMSOL. The tumor inserted has a diameter equal to 1 cm and it was located 10 mm from the skin surface. To solve the equation, in addition to the inclusion of a tumor in the upper right quadrant of the breast, it is necessary to know the bio-thermal properties of the phenomenon. These properties are presented in the Table 1. The boundary conditions considered in the problem are prescribe temperature of $T_a = 37\text{ }^\circ\text{C}$ in the internal surface of the breast, thermal convection in the skin surface with temperature ambient of $25\text{ }^\circ\text{C}$ and convective coefficient of $5\text{ W/m}^2\text{K}$. These conditions were considered to solve the equation.

Figure 3 shows a thermal image of the simulated surface for a healthy breast, i.e., without tumor. The superficial temperatures in the skin of the breast have a normal thermal behavior, where the maximum temperature of $37\text{ }^\circ\text{C}$ observed is still related to the internal surface of the breast that is influenced by the

Table 1. Tissues thermal and biological properties [6,9].

Properties	Value	Layer
Thermal conductivity, k	0.21 W/mK	Healthy tissue
	0.62 W/mK	Tumor
Blood perfusion, w	0.00022 1/s	Healthy tissue
	0.016 1/s	Tumor
Specific mass, ρ	920 kg/m ³	Everywhere
Specific heat, c	3000 J/kgK	Everywhere
Volumetric metabolic heat generation, Q_m	420 W/m ³	Healthy tissue
	300000 W/m ³	Tumor

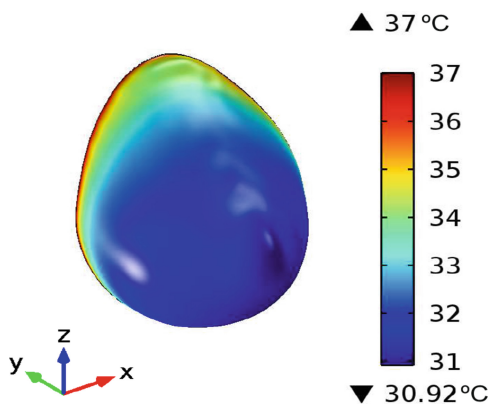


Fig. 3. Thermal image of the surface of a healthy breast.

arterial temperature of the body. The minimum temperature found is in the region of the areola of the breast, because this is the region farthest from the inner part of the body, therefore, being less influenced by the heat transferred from inside the breast, and, more influenced by the thermal convection of the external environment.

The other simulation performed involves a scanned breast with a tumor in the upper right quadrant. The thermal behavior at the skin surface for this particular case of breast cancer is presented in Fig.4. It can be observed in the Figure that there was temperature changes in almost the entire surface of the breast, however, a greater thermal disturbance is found in the upper right quadrant where a tumor was internally inserted.

The values of temperature variations observed only through the thermal images are not accurate, but it can be seen that in the region of the areola there has been a temperature increase of around 2 °C.

After simulating two distinct conditions in the breast, it was possible to observe an alteration in the skin temperature profile. However, for a better con-

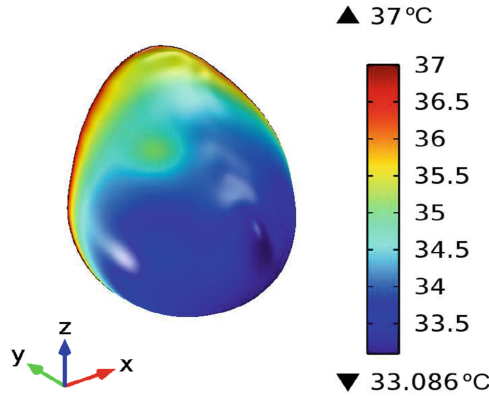


Fig. 4. Surface thermal image of a breast with tumor in the upper right quadrant.

clusion about what occurred in the breast after the appearance of the tumor, the subtraction of the skin surface temperatures between the breast with the tumor and the breast without the tumor is performed. Figure 5a shows only the temperature difference of the skin surface of the breast. Now, one can observe only the temperature variation caused by breast cancer. Thus, it is possible to observe that the maximum temperature variation occurred in the right upper quadrant. The peripheral regions also had a change in their temperature values.

Finally, a temperature curve is obtained by creating a 'cut line' that intercepts the point of greatest thermal variation in the skin caused by the tumor as shown in Fig. 5a. This curve is showed in Fig. 5b which characterizes the ther-

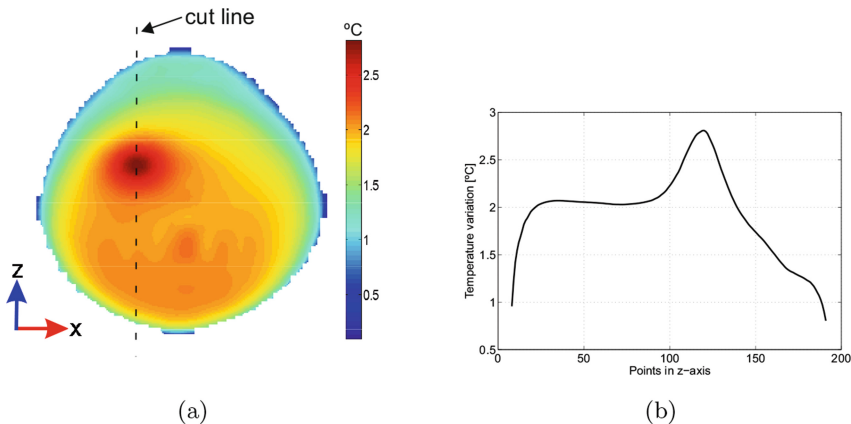


Fig. 5. (a) Skin surface temperature variation caused by the presence of a tumor in the breast right upper quadrant and (b) Temperature profile variation in the breast skin surface caused by the tumor.

mal pattern caused by breast cancer. The idea of this work is that other profiles could be obtained for several other cases of the disease, creating a database that in the future could allow doctors to evaluate patients with and without breast cancer.

4 Conclusions

In this work, the detection of temperature increase caused by the presence of breast cancer was performed using simulated thermographic images.

Unlike other works available in the literature where simplify geometries are considered, in this work, a real breast sample was acquired and a three-dimensional digital scan of the geometry was performed to obtain the 3D computational model. A numerical model of the breast was simulated using COMSOL, and temperatures were calculated for a case without and with tumor using the Pennes equation.

The superficial temperatures in the skin of the breast were obtained for the two studied cases. After, only the difference between the thermal profiles was analyzed. From the obtained temperature changes, it was possible to find the point on the surface where the greatest thermal change occurred and to determined a characteristic thermal profile for the evaluated breast cancer case. In this sense, it is possible to acquire characteristic profiles for several cases making it possible to make a correlation between breast cancers and observed thermal profiles.

Therefore, this work indicates that it is possible to acquire thermal images to identify mammary tumors through the identification of thermal patterns. Experiments are currently being performed to experimentally validate the proposed approach involving thermal images of real breast models acquired by an infrared camera.

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