Simulating Breast Temperature Profiles Through Substitute Geometries from Breast Prostheses

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Abstract— Breast cancer may cause changes on the breast surface temperature. Some of these changes can be seen in infrared images. Temperatures obtained through these images can be used to validate the numerical simulations. In order to proceed to such simulations, we need to use a 3D geometry of the breast but this can not be directly obtained. Surrogate geometries can be used for this purpose. They were obtained from external prostheses for patients submitted to complete mamma surgical removal. The purpose of this work is to simulate the temperature profile of the breast using such geometry and compare these with patients' infrared image. Prostheses measurements were performed by a coordinate measuring machine (CMM). Seven different models of prostheses were processed; each model has weight, mobility and consistency similar to that of a breast. From the patient infrared image, points of two curves representing the contour of the base of the breast and the contour of the lateral of the breast are obtained. Results were compared that is coordinates obtained from the thermogram and those of the surrogate geometries of the external breast prostheses. Least-squares method was used to obtain the coefficients of the curves for the base and lateral contour and to choose the surrogate geometry that fits better the patient.

Keywords: **image analysis, thermal image, numerical simulation**

I. INTRODUCTION

The breast cancer is the most frequent type of tumor in women and the second cause of their deaths in Brazil (the first one is the arterial hypertension). Early diagnosis can provide higher chances of cure [1].

Nowadays, the mammogram is the 'gold-standard' in breast cancer detection. It is a anatomic test which the interpretation depends on the physician's experience. On the other hand, thermogram has no radiation risk and is totally painless [3].

Although, thermograph does not detect all tumors and there are no current regulations to obtain the infrared (IR) images, it can represent an important tool when used together with the mammography to detect early abnormal condition [4].

References [5] and [6] dealt with the simulation of breast diseases. The breast tumor parameters (depth, size and heat generation) were estimated by [5] using artificial neural network, genetic algorithm and finite element method (FEM) by a use of a two-dimensional geometry of an idealized breast model (a circle). FEM and a tridimensional geometry of a simplified breast (hemisphere) and cancerous tumor (sphere) were used in [6] to make parametrical analyze to simulate temperature changes in the breast surface due to the tumors. Reference [5] suggested that their results may be compared with the temperatures obtained from thermography.

In our research group, reference [1] simulated breast temperatures with an approximated geometry, a spherical one, and compared the maximum temperatures with the breast thermography of the patient. Now, she is undergoing a research that uses optimization techniques to estimate thermophysical properties of a breast. Reference [13] estimated depth and flow through parametric analysis and the finite-volume method in a three-dimensional geometry. Some results of the simulations were compared with thermography.

The present work considers the acquisition of temperature profiles in breast through substitute geometry determined from breast external prostheses. The development of this work is divided into three parts: the acquirement of the surrogate geometry; the choice of the surrogate geometry that best fits the real breast in study; and the achievement of the temperature profiles with numerical simulation.

These efforts are part of the research project "Processing of digital images applied to mastology" developed by UFF and UFPE granted by CAPES (Project PE021/2008). Further information regarding to the goals already achieved by the project can be found at http://200.20.11.171/proeng/.

II. METHODOLOGY

A. Acquirement of the surrogate geometry

The scanning process of the breast external prostheses was done in the Laboratory of Coordinate Measuring of the UFPE. We used the Coordinate Measuring Machine (CMM) CRYSTA 547 manufactured by Mitutoyo.

Seven different breast external prostheses were scanned: models SG-419 and SG-420, with sizes 1, 2, 4, 6, 8, 10 and 12, manufactured by Orto Pauher that donated all prostheses. These models (Fig. 1) are the

same models provided by the Brazilian Health Security (Sistema Único de Saúde – SUS) to the patients that were submitted to total mastectomy.
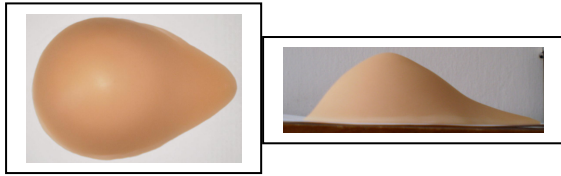

Figure 1. An external breast prostheses manufactured by Ortho Pauher.

Taking the nipple as the origin point of the coordinate system, the CMM machine scans the prosthesis in longitudinal and latitudinal directions obtaining four lists of points. The last curve was obtained from the points that form the base of the prosthesis.

The points acquired by the CMM are used as input to the commercial program Gambit, in order to generate the breast volume. They are properly connected together as lines to form the upper and lower surfaces of the scanned prosthesis and the volume is build up. Meshes are then generated for further use.

The surrogate geometries are stored without the meshes in order to simplify the representation of the tumor to be simulated. Fig. 2 shows this.
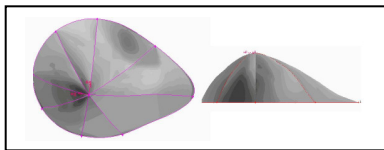

Figure 2. Surrogate geometry of one of the breast external prostheses.

B. Finding the surrogate geometry that best fits the real breast in study

Three patients from the Hospital das Clínicas (HC-UFPE) were chosen. All of them have the clinical diagnosis and the most complete set of examinations with the right location of the nodule. One of them is shown in this work.

The protocol to obtain the patient thermograms (or IR images) is described in [4]. The IR images were manipulated with a computational program developed at UFF. The software reads two thermograms for each patient: the frontal image with lifted arms and one of the lateral images, the external one. The program detects automatically the points of the base of the two breasts and the points of the contour of the body, writing separated lists of coordinates. As the thermogram is a two-dimensional IR image, the coordinate Z is set to be zero. So, one text file is prepared for each breast by writing together the points of the contour of the breast (obtained from the points of the contour of the body) and the points of the base of the breast. The program output supplies these two text file per breast: one file contains the points that form the base contour and another file with the coordinates of the external lateral contour.

These two lists are in the format that the commercial program Gambit can use as input.

To allow comparisons, the curves obtained from thermography and the curves obtained from the surrogate geometries must have the same orientation and the origin of their coordinate system must be placed at the same point. To do so, a numerical program in the C++ language was developed for this. Its steps are shown in Fig. 3.

To allow these comparisons, the curves of the prostheses were translated and rotated so that their origins coincide with the midpoint of the breast base curve. The rotation was performed with the calculation of the angle between the symmetry axis of the object and the vertical axis. To determine the rotation angle, it was used the concept of the moment of inertia [8] in digital formulation [7]. At this point, the coordinates are referred to the same origin, which is the middle point of the curves and have the same orientation.
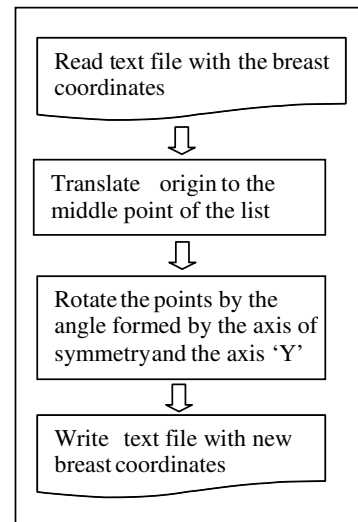

Figure 3. Steps to move the middle point of the curve to the origin of the system.

Finally, the best surrogate geometry can be chosen. For this, another numerical program in the C++ language was written to choose the surrogate geometry that best fits the patient geometry. The developed software uses the least-square method (LSM) and the Gauss method with pivoting strategy [9] and [10].Its steps are depicted in Fig. 4.

Additional informations regarding to Gambit and Fluent can be found at [11] and [12].

III. RESULTS

In order to calculate the breast temperatures the nodules are set inside the breast volume using the data of the patient exams. The nodules and the normal tissue have specific thermophysical properties equal to that used by [13]. The tumor can be considered as a heat source inside the breast. The tumor can cause the elevation of the temperature because of the angiogenesis. It is an earlier event in the development of breast cancer and can occur before the tumor cells acquire the ability to invade the surrounding stroma. The angiogenesis can occur even before there is a morphologic evidence of an

in-situ carcinoma [14]. The new arteries and the circulating blood cause the increase in the temperature that can be viewed by the infrared images.

Once the surrogate geometry is selected, the volume is imported by the Gambit software to allocate the nodule with the size and the location described by the examinations of the patient as transcript in Table I.

TABLE I.   TRANSCRIPTION OF PART OF THE PATIENT EXAMS

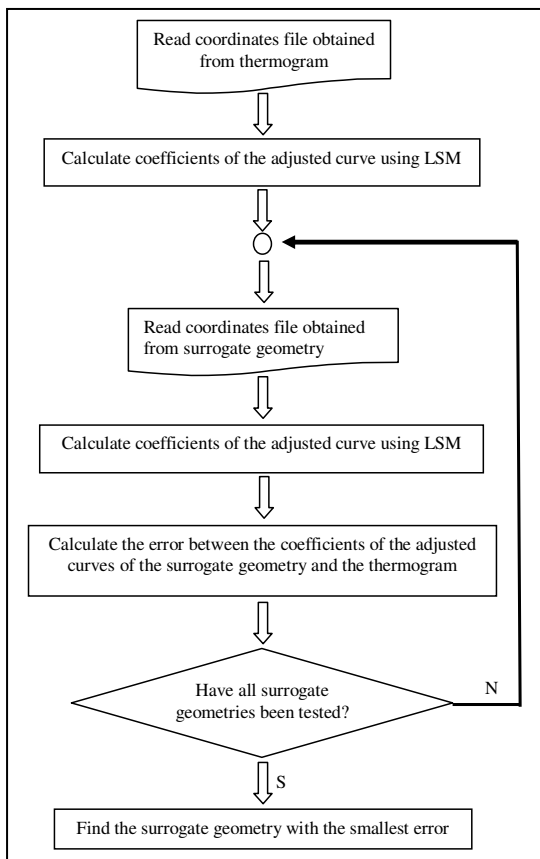|	Nodule #1	Nodule #2
Type	cyst	cyst
Size	0.4x0.2 cm	0.2x0.1 cm
Format	cylinder	cylinder
Position	8-9h	~9h

Figure 4.   Steps to choose the surrogate geometry that best fits the patient geometry.

Numerical grids with tetrahedral elements are generated in the whole computational domain. Their characteristics are associated to it and the mesh is exported. The result is shown in Fig. 5.
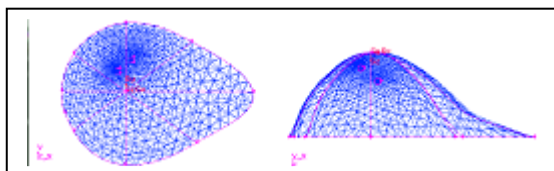

Figure 5.   The meshed surrogate geometry with inner nodules.

The commercial software Fluent is used to perform the temperature simulation of the meshed surrogate geometry. The thermophysical properties are set to the normal and cyst tissues. The cyst properties were considered the same of the saturated water at 300K and they are shown in [15]. The data used for the boundary conditions were taken from the data of the patient profiles and are shown bellow:

- There is a convective heat exchange with a coefficient equal to 13.5W/m²°C [9] between the breast surface and the external environment at 27.5ºC.

- The temperature of the breast base was considered to be equal to 37°C.

- The breast tissue was considered to be the glandular one.

A study of mesh stability was made, with the use of three different meshes. They used 6100, 13056 and 13748 nodes. The cysts appear at the temperature's profile of the surrogate breast and at the thermogram of the patient.

The cysts temperatures measured on the thermograms are approximately 31°C and they are depicted at Fig. 6.
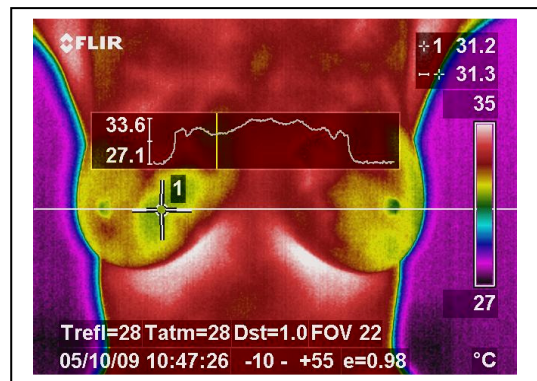

Figure 6.   Thermogram of the patient . The curve above represents the temperatures over the white line.

The surrogate geometry with the first mesh is shown in Fig. 7, where at the temperature of the nodule #1 is around 28°C and the nodule #2 one is around 31°C. Fig. 8 shows the second mesh. The nodule#1 temperature is about 29ºC and the nodule#2 temperatures is around 31°C. Fig. 9 shows the temperature profile of the surrogate geometry with the third mesh. The nodule#1 appears in the image with temperatures around 29°C and the temperature of nodule#2 is around 31°C.

Because of the small differences in the calculated temperatures, the second mesh was chosen in order to improve the computational time.
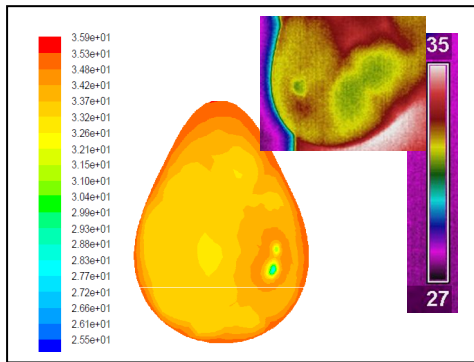
Figure 7.   The result of temperature simulation to the surrogate geometry meshed with 6109 nodes (on the left side) compared with the patient's thermogram (on the right side).
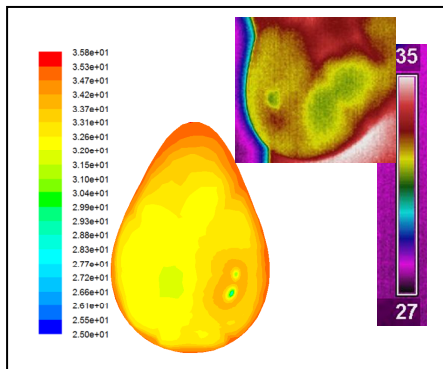

Figure 8.   The result of temperature simulation to the surrogate geometry meshed with 13056 nodes (on the left side) compared with the patient's thermogram(on the right side).
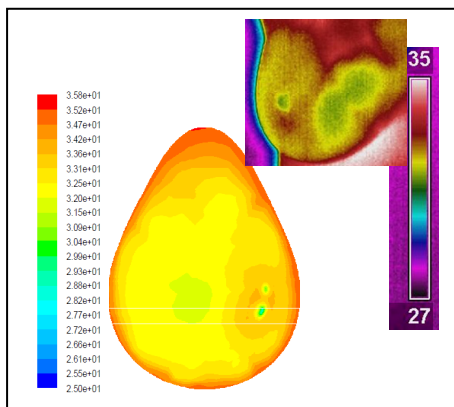

Figure 9.   The result of temperature simulation to the surrogate geometry meshed with 13748 nodes (on the left side) compared with the patient's thermogram (on the right side).

IV.   CONCLUSIONS

The nodules can be viewed at the temperature profile obtained by the simulation on the surrogate geometry as well as in the infrared images. It suggests that the thermography shows the nodules found on previous exams. The visualization of the simulation of the temperature profile depends on the refinement of the mesh. The preliminary results are good in the qualitative way and approximate if we consider the quantitative one. In a qualitative way, the shape of the temperature profile obtained by Fluent is quite similar that viewed by thermography. In a quantitative way, as cited before,

only the lowest temperature of the region of the cyst was compared. The error was about -6.45%.

The continuity of this work, which analyzes a breast with one solid nodule, one lymph node and one cyst, is measured nearing its completion. In this case, the biggest error made between the temperatures in regions with abnormalities was about 1.16%.

The most important contribution of this paper was the use of a tridimensional geometry closer to a real female breast, and the fact that the points used in the surrogate geometry choice were taken from the patient's termography.

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