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Simulating external compressions of the breast with the Surface Evolver

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Abstract. In this paper we introduce a computational modelling that reproduces the breast compression processes used to obtain the mammogram. The main result is a programme in which one can track the first steps of virtual mammography. On the one hand, our modelling enables addition of structures that represent different tissues, muscles and glands in the breast. On the other hand, we shall validate and implement it by means of laboratory tests with phantoms. To the best of our knowledge, these two characteristics do confer originality to our research. This is because their interrelation seems not to be properly established elsewhere yet. We conclude that our model reproduces the same shapes and measurements really taken by the volunteer’s breasts.

The 2nd author dedicates this work to his wife Clarice.

1. Introduction

The obit rate caused by cancer around the globe is tracked by the World Health Organization. Their statistics indicate that 7.6 million of the obits in 2008 were due to cancer. This ratio has been increasing and some estimates show that it can reach 13.1 million cases until 2030. Lung cancer in women is still the leading obituary kind, and breast cancer follows right next. See http://www.who.int/mediacentre/factsheets/fs297/en for details.

Medical imaging methods help detect breast cancer. The most used are resonance, ultrasonography and mammography. However, screen/film mammography is the primary imaging modality due to low cost and accessibility. It has proved to be an effective aid in the early detection, and most of the restraint in obit rate is solely thanks to this method. But it shares a disadvantage with the others: in the imaging procedure, forces applied to the breast change its shape considerable. For the surgery, tumour location is highly uncertain, and so a great portion of the breast has to be removed [1].

Along the past decade there has been an effort to develop softwares devoted to anatomic modelling of the breast and of deformations by mammography procedures. Among others, we cite [1, 2, 3, 4, 5] and [6]. Some are aesthetically impressive, like [7]. For a model at rest, this latter is indeed very complete, but its functionality has not been presented yet. The problem will reside in the excessive computational complexity at managing all different elements that take part in the model. The source codes tend to be untreatable in such cases.

In order to bypass these difficulties, perhaps a simpler approach like the ITK software of [1] turns out to be more accessible. However, the human breast is composed by different tissues, muscles and glands, as highly taken into account in [7]. Since ITK works with three dimensional meshes, it is a hard task to separate all those components into specific clusters. Moreover, this produces a “Lego effect” that demands too much orchestration to control the belonging of each mesh element to each tissue, muscle or gland.

Which simplifications can be made without going into considerable errors? Regarding numeric modelling of the breast deformation during mammography, we still do not have enough satisfactory answers. In this case, the dilemma between complexity and simplification motivated us to work with the Surface Evolver [8]. Its computational representation of any element is made by surface layers that enclose it. Evolver allows to add as
many elements as needed, together with their individual attributes like mass, geometric restrictions, contact and elastic bending energies, etc. See http://www.susqu.edu/brakke for details.

Figure 1: Side view of the breast.

In the long-term, our research aims at a full and detailed reproduction of the mammography procedure with Evolver. By starting with the mammographies that show tumour nodules, we rewind the virtual procedure. This way, nodules will be located with precision for the surgery. For the time being, our work is devoted to simulations of external compressions of the breast. In order to track tumour nodules, we shall either consider the complexity of internal parts, or equate their trajectory by performing experiments with transparent breast phantoms.

2. Methodology

In order to take mammographies in our virtual environment, we have subdivided the whole process in 6 main steps for each breast. We call them SRG (surgery), STU (stand-up), LAT (lay-on-table), CRC (cranio-caudal), LET (lean-on-table) and MLO (medio-lateral-oblique).

Of course, at each step the mass of the breast remains constant, while its shape changes drastically. Except for CRC and MLO, changes in the volume and average density are much slighter than in the area. There is enough literature with average values, but for our purposes they are inadequate, because measurements vary a lot from woman to woman.

It is possible to apply electrodes to draw a computer model and then get magnitudes numerically. However, this procedure is not practical and requires expensive equipment.

But we check our data in Evolver by means of a virtual tape-measure that we call TMR. Our procedure is to enter the initial values and then use the TMR to fine-tune them. For the time being, the fine-tuning is still interactive. We shall make it automatic in future.

Figure 3 left shows a standing woman with her spine straight. The dotted line indicates a tape measure that passes under her breast. With the open right hand upon her belly we locate our coordinates: Ox points as the thumb, Oy points as the other fingers, and the palm is raised along Oz. Figure 3 right shows the oval curve obtained after having taken the volunteer’s measurements. Important values are indicated there, and we have fixed all magnitudes in the cgs-system. Notice that the overall perimeter is 86cm.

1 Taken from http://en.wikipedia.org/wiki/Portal:Medicine/Selected_picture/26
See the link *Slides-ICMSQUARE* of our home page [http://www.facom.ufu.br/~nascimento](http://www.facom.ufu.br/~nascimento) for other important measurements. There you will also find a detailed description of the methods and the modelling used in our work.

Regarding CRC and MLO measurements, they are taken directly from the mammographies. Our simulations with Evolver always start at SRG, because it is the most symmetric position. In practice, not only a surgical drape holds the base of the breast, but also an auxiliary surgeon and sometimes an extra support fitted under the woman’s armpit.

Our Evolver datafiles follow the sequence SRG → STU and then either LAT → CRC or LET → MLO. From STU to LAT, early simulations showed that the virtual breast does not necessarily reach a symmetric configuration. This is because Evolver seeks to attain some pre-defined values and stabilises right thereafter. The authors believe that the breasts’ shape naturally minimises a certain energy whenever they rest at a given position. In the case of cell membranes, this energy is related to the Willmore Functional (for instance, see [9]). This functional is defined as $\int_M H^2 dS$, where $M$, $H$ and $dS$ stand for the surface of the body, its mean curvature and the area element of integration, respectively. By asking Evolver to minimise this integral, we have obtained more symmetric answers. That is why the Willmore Functional is included in our datafiles. We conjecture that this energy is minimised whenever the breast accommodates in a rest position.

### 3. Results

The main result is our programme, in which the user can track the first steps of the virtual mammography, as depicted in Figures 4 and 5.

![Figure 4: STU enhanced with Geomview.](image)

In order to run our programme, we recommend Linux Operating System Ubuntu 11.10 or later, Evolver 2.50 and Geomview 1.9.4. For the time being, we have implemented SRG, STU and LAT, all of them for the left breast only. You can either run it in our Virtual Machine, available on our home page in the link *Softwares*, or access our link *Slides-ICMSQUARE* for an overview. The Virtual Machine contains all source codes, and therefore all details of our modelling.
Regarding its validation, the link Softwares also contains three sample Videos of tests with a transparent phantom. The phantom dimensions are compatible with the volunteer’s, and addition of virtual nodules to our model will be implemented in a forthcoming work.

It is important to notice that the breast volume decreases from SRG to STU, and again from STU to LAT. Indeed, when the woman is lain down on the operating table, the breast structure is uniformly distributed on its base. This is when we have the least pressure due to gravity.

The breast mass is constant and mean density = mass/volume. When the woman stands up, the breast mass concentrates at the bottom. Pressure due to gravity gets higher, and the same happens to the mean density. This makes the breast volume smaller. In the volunteer’s case, our simulations with Evolver indicate that it decreases from 700cm$^3$ to 680cm$^3$ approximately.

Further on, when the woman lays her breast on the table, not only gravity by also the contact force acts. The volume decreases again. In the volunteer’s case, it drops from 680cm$^3$ to nearly 660cm$^3$. Because of that, in this paper we have used the word compression as the action of pressing something into a smaller space, rather than pressing or squeezing together. This second meaning applies to our next paper, devoted to simulating the virtual CC and MLO mammographies.

4. Conclusions
Our model reproduces the same shapes and measurements really taken by the volunteer’s breasts. We have just presented the first results of a long-term research. These initial results are already of high complexity. For instance, nipple location, changes in shape, values and dimensions follow many geometric and physical laws. There are equated and implemented in the programmes, but technical details will be postponed to future publications.

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