

Simulating CC and MLO compressions with the Surface Evolver

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Abstract. Mammographies are X-ray images of the breast under external compressions called Craniocaudal (CC) and Mediolateral Oblique (MLO). Together they increase the chances of detecting cancer but the breast is shown in strongly deformed shapes. Cancer location is highly uncertain for the surgery and so the breast is commonly taken out entirely, a serious trauma for the patient. In this paper we present a fully virtual mammography procedure that faithfully reproduces all shapes of the breast and in its inside tracks the cancer at any step. The cancer is then precisely located for the surgery and can be removed through a small incision. So the whole structure is preserved and cured as an integral benefit to the patient.

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

1. Introduction

The mammography procedure consists of taking X-ray images of the breast. They can reveal the presence of nodules of tissues. Certain nodules appear as a reaction of the body against instability in health. They are called tumours, which can either stall and be harmless or spread and attack other cells. The first case is called benign and the second malignant, namely *cancer*.

Nodules have a hard consistency but can be pretty small. An X-ray image should capture them with the best distinctness, which also helps classify them as Normal, Benign and Malignant. Because of that the breast is submitted to external compressions of the mammographer called Craniocaudal (CC) and Mediolateral Oblique (MLO).

These two different views increase the chances of detecting and classifying such nodules, but the breast is shown in strongly deformed shapes. Cancer location is highly uncertain for the surgery, and so the breast is commonly taken out entirely, a serious trauma for the patient.

If cancer were located precisely, it could be removed through a small incision. After some slight corrections by plastic surgery the whole breast would remain preserved. As a matter of fact, this is already possible through cutting-edge technologies like tomosynthesis [1, 2] and high-tech goggles for cancer detection [3].

There are many articles about these modern techniques but we cited just three for the sake of brevity. However, such techniques are quite expensive and still under improvement. Hence very few women can afford them in developing countries. Magnetic resonance could be a less dear alternative, but unfortunately not in poor countries yet.

The cheapest techniques are ultrasound and mammography. Both deform the shape of the breast considerably, but the latter has an advantage: not only the breast structure but also the mammography procedure can be modelled and simulated together in a totally virtual environment. Some related softwares have been developed exactly with the purpose of locating nodules for the surgery. We cite [4–9] and [10].

Unfortunately, they still present relevant limitations already discussed in [11]. To the best of our knowledge, until now, not one of them has been officially approved by a Medical Council as a reliable nodule locator permitting it to become part of surgical preparations.



In [11] we introduced the first part of a long-term research that aims at a full and detailed reproduction of the mammography procedure with the Surface Evolver [12]. Differently from previous works, our approach is to implement nodule trajectories under CC and MLO compressions in our model. These trajectories are studied by means of transparent breast phantoms. See www.cirsinc.com/products/all/44 for a picture. This present article is a continuation of [11]. Herewith we include the CC and MLO compressions and give some technical details omitted in that first paper.

2. Methodology

As explained in [11], our simulation has 6 main steps: SRG (*surgery*), STU (*stand-up*), LAT (*lay-on-table*), CRC (*cranio-caudal*), LET (*lean-on-table*) and MLO (*medio-lateral-oblique*). Figure 1 shows important measurements of the initial positions. We *always* use the cgs-system. For CRC and MLO, measurements are taken directly from the X-ray images.

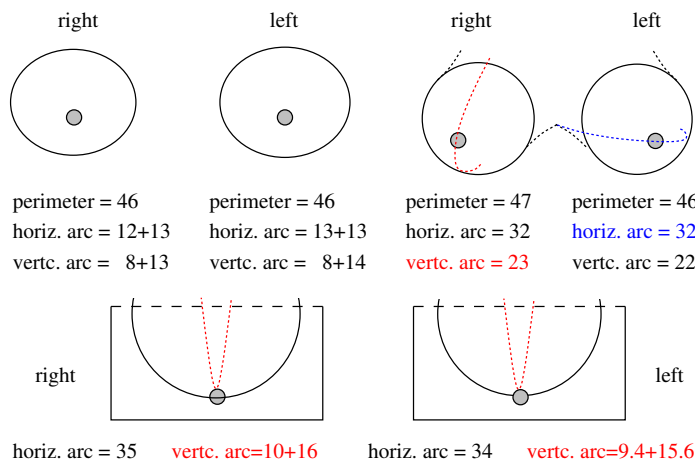


Figure 1: Measurements of SRG, STU and LAT.

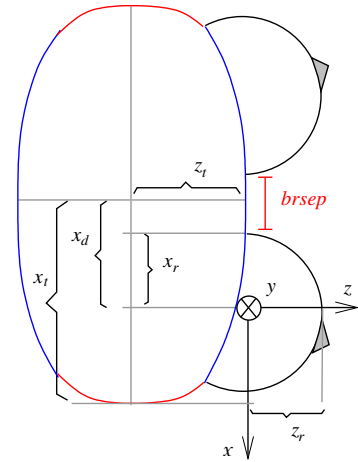


Figure 2: Deduced *unsigned* values.

Now we focus on SRG. Figure 2 is deduced from Figure 1. Empirically, the breasts are within a range of the thorax that can be equated as a cylindrical surface called *bbase*, whose generatrix is a *cubic ellipse* given by $|1 + z/z_t|^3 + |(x + x_d)/x_t|^3 = 1$.

Here the subscript *t* means “thorax”, whereas *d* stands for “detachment”. Namely, the generatrix of *bbase* has a centre with *x*-coordinate detached from the portion of *bbase* that is actually under the breast. More precisely, $x_d = x_r + brsep/2$.

The breast surface is typically modelled as the upper hemisphere of an ellipsoid with the following radii: x_r , y_r and z_r . It lies on *bbase* and z_r is also the 3rd coordinate of the nipple. In our case measurements indicate that $y_r = z_r = vtarc/\pi$, where *vtarc* stands for “vert. arc” in Figure 1. As depicted in Figure 2, the upper blue arc that we call *fthrx* is almost straight. Therefore we take $x_r = (fthrx - bsep)/4$.

Although we use the half-ellipsoid approach to compute initial values of area and volume, breast and thorax meet at a contour that cannot be an ellipse. Empirically, it is also a cubic ellipse called *bbsrc* in our programmes and equated as $(|x|/x_r)^3 + (|y|/y_r)^3 = 1$. We take $x_t = fthrx/1.7$ and $z_t = lthrx/1.7$, where the factor 1.7 is a rescaling of $\pi/2$. This one would be the factor if the generatrix of *bbase* were a circumference.

Figure 3 shows how we locate the nipple and place the lower plate for CC compressions. The woman places her breast on the lower plate in such a way that most of it will lie thereon. We have observed it as a quite intuitive action. Figure 3 shows the point of contact between the breast and the edge of the plate: it is at the origin of *Oxz*.

Of course, the edge of the lower plate is tangent to the thorax. In Figure 3 we drew a red vector that is normal to the point of tangency. Let θ be the angle that this vector *N* makes with *Ox*. An easy computation gives $\theta = \arccos((x_d/x_t)^{3/2})$, whence

$$N = \left(z_t \cos^{\frac{4}{3}} \theta, 0, x_t \sin^{\frac{4}{3}} \theta \right). \quad (1)$$

Of course, the corresponding unitary normal is $n = N/||N||$. Now an important remark: *bbsrc* is used as a reference to obtain the values in Figure 1. Namely, the tape-measure has to contour arcs of the breast with endpoints on *bbsrc*. Its considered to be fixed to the woman’s thorax. This contour is easily recognised when the woman is lain down. When she stands up, you can use the jugular notch to locate it again.

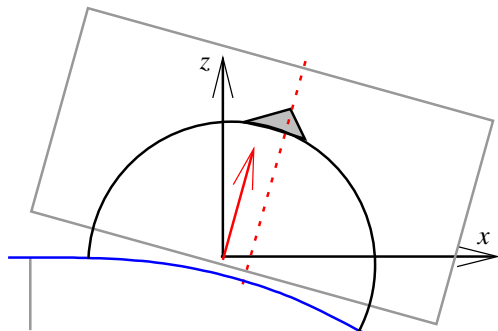


Figure 3: Nipple and plate for CC.

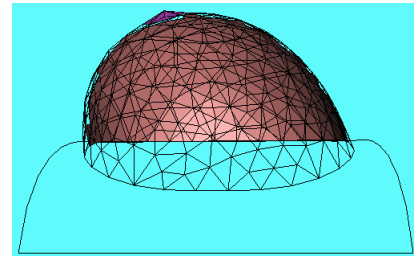


Figure 4: Profile curve.

Figure 3 indicates the nipple at a point of the breast where the unitary normal η to the surface has the following property: its projection onto Oxz is parallel to n . This observation is empirical. Curiously, it holds for *any* of the 6 steps described above (from SRG to MLO).

Now we recall Figure 1. For the left breast at SRG notice that $vtarc = 8 + 14$ from bottom to top. Let $n = (n_1, n_2, n_3)$, where in fact $n_2 = 0$. By taking this example our programme will comb the breast surface until it finds the normal vector

$$\eta = \left(n_1, -n_3 \cos\left(\frac{8+11}{44} \cdot \pi\right), n_3 \sin\left(\frac{8+11}{44} \cdot \pi\right) \right). \quad (2)$$

The factor $(8+11)/44$ in (2) is not $8/22$ because the profile of the breast is not quite an upper circumference (see Figure 4), whence the average between $8\pi/22$ and the right angle $11\pi/22$.

We locate our coordinate system by opening the back of the right hand upon the woman's sternum. Technical details can be found in [11, 13].

As Evolver works with surface layers, our first approach is to mark a virtual nodule on a layer inside our model and track its trajectory. In Evolver we represent it by a black triangle. Our programme makes all steps and compressions gradually, and the user can follow the graphical output in real time. Figures 5 and 6 show only the beginning and the end of $SRG \rightarrow STU \rightarrow LET \rightarrow MLO$.

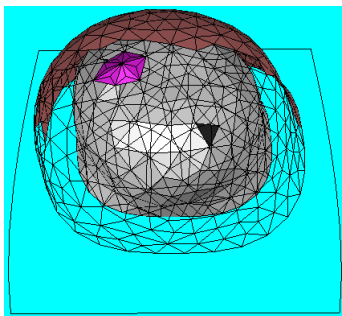


Figure 5: Marking a nodule at SRG.

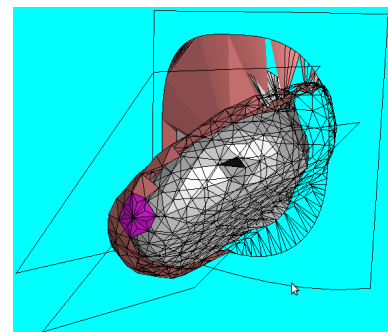


Figure 6: Its position at MLO.

There are many kinds of breast tumours: lipoma (in the fat), carcinoma (in the glands), papilloma (inside the nipple), etc. In all cases they represent an abnormal group of cells of the corresponding component: fat, gland, lactiferous duct, etc. Therefore, a tumour cannot move about as if it were detached from its component. That is why we consider the layers as a reasonable approach.

Although inexact, it is worthwhile to study this approach before adding further complexity to our model. In Section 3 we compare Evolver's virtual displacement with actual displacements inside the phantom when it is compressed by a mammographer. Tests are still at the beginning but we have not found any inconsistency yet.

3. Results

The link *Softwares* of our home page

<http://www.facom.ufu.br/~nascimento>

contains five sample videos of tests with a transparent phantom. A thorough inspection of the videos enabled us to plot the nodule trajectories as shown in Figures 11 and 12 of [13].

Our simulator tracks any chosen virtual nodule as depicted in Figures 5 and 6. Its coordinates are saved in a file named `<patient's number>Xtrj.st`, where X=L,R indicates either the left or the right breast, respectively. As an example, we have chosen a virtual nodule at SRG that lead to the following table:

coord.	SRG	STU	LAT	CRC	LET	MLO
x	4.25	3.48	3.37	3.45	5.19	6.15
y	2.74	1.16	0.48	-1.31	1.15	0.65
z	3.12	2.53	2.70	5.00	3.82	4.63

(3)

In Section 5 of [13] we inspect a nodule of the phantom that is the closest to the one of Table 3. In its case, the CC compression gives

$$(4.90, 0.41, 3.67) + \Delta_{\text{phantom}} = (5.71, -0.49, 4.89). \quad (4)$$

Our example in [11] is a breast that weighs 350. Its volume varies from 700 (SRG) to 660 (LAT). But the density of the phantom is nearly the double. Adjustments must be taken into account (see [13] for details). Going back to Table 3, the transition from LAT to CRC gives

$$(3.37, 0.48, 2.70) + \Delta_{\text{breast}} = (3.45, -1.31, 5.00). \quad (5)$$

In practice the x -coordinate of (5) has not changed. Thus we shall not use it for comparisons. But both the y and z coordinates of the displacements Δ in (4) and (5) have grown consistently. Of course, in (5) they are the double of (4) but we recall that the phantom is 1.75 times denser than the breast.

4. Conclusions

This work has many progresses compared with [11]. We have been dealing with the direct virtual mammography. However, the most important is the reverse procedure. In future our software will work as follows: starting from CC and MLO images that show a cancer, it will be located at SRG through the layer-approach. See Section 6 of [13] for details.

5. Acknowledgements

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