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Unambiguous Analysis of Woman Breast Shape for Plastic Surgery Outcome Evaluation

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Abstract

This paper reports a multidisciplinary research between computer science and plastic and reconstructive surgery. In particular, a new method is proposed to unambiguously define a geometric partitioning of a large thoracic area including the breast mound. The new technique uses only well-defined anatomical points, defined and selected by surgeons. A simple sequence of geometric operations is performed to partition the breast surface into four anatomic subunits, according to clinically derived breast meridian and equator lines. Using this breast shape partition, useful measurement can be extrapolated on 3D model data set. Our method has been validated on a number of breast 3D models acquired by means of a commercial scanner on real clinical cases collected by Istituto Nazionale dei Tumori in Milan (INT).

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [**Computer Graphics**]: Applications; **General Terms**: Biomedical 3D Scanning and Modeling

1. Introduction

Breast shape assessment in aesthetic and reconstructive surgery is a crucial step to evaluate the final outcome. Up today, visual assessment is the common practice among surgeons, since no universally accepted breast shape analysis techniques are currently available. Devising reliable methodologies to objectively analyse natural and reconstructed breast shape is an important research issue in plastic and reconstructive surgery and in computer graphics. Several reproducible measurement methodologies have been proposed in the literature but none of them reached clinical practice. Some authors propose to analyse breast shape either by using anatomic reference points and manual linear measurements, or by measuring the volume by means of water displacement, MRI, X-rays, or thermoplastic moulding [SPKB86, BRH*99, BBS01, Teb02, DMGL02, GNCMM02, NG03, LH04, LSD*05].

3D scanning technologies can be exploited to acquire useful data for accurate and reproducible analysis of breast surface. In this paper, we define a non-ambiguous segmentation of the thoraco-mammary surface, starting from the informal specifications suggested by the surgeons of INT in Milan. We also indicate a set of geometric measurements and computer graphics techniques for 3D visualisation allowing an objective evaluation of the outcome of cosmetic and reconstructive surgery. The clinical evaluation of the proposed methodology benefited from the feedback of surgeons and has been clinically assessed.

We first conducted a series of preliminary studies aimed at analysing 3D data sets acquired using a Konica Minolta 3D laser scanner [KM04] on real clinical cases. The analysis of the raw data has been carried out using an open source 3D modelling tool (Blender 2.40 [BF05]). Breast analysis according to the constraints suggested by surgeons led to the definition of an algorithm that subdivides the breast surface model into four sub-units, using a few anatomical landmarks manually placed by the user. The proposed algorithm has been implemented in a custom tool named Breast Shape Analyzer 0.1 (BSA 0.1), aimed at automating the breast partitioning operations. The tool is also capable of extrapolating useful measurements from the model. Experiments conducted on real data by surgeons confirm the usefulness of

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such a tool in surgical planning applications. In particular, BSA 0.1 enabled the surgeons to compute objective parameters for outcome evaluation of cosmetic and reconstructive surgery.

The remainder of this paper is organised as follows. In Section 2, we report some motivation and medical requirements. In Section 3, we discuss a formal definition of the proposed breast surface partitioning methodology, quantitative parameters, and visualisation techniques for objective outcome evaluation. In Section 4, implementation details of BSA 0.1 are presented, while clinical validation are discussed in Section 5. Finally, conclusion are drawn in Section 6.

2. Surgeon's Desiderata

The surgeon possesses the ability, from his experience, to recognise several anatomical points and structures of interest, in the analysis of the specific patients. However the instruments used to gather measurements (e.g., area of breast surface, length of the path over the breast surface, and so on) are inaccurate or do not exists at all. Moreover, manual measurements heavily depend on experimental settings, such as posture of the subject and the like.

Recently, computer scientist from Catania University and surgeons from INT joined in a multidisciplinary effort to find a viable solution and explore the new technological perspective for the analysis of breast shape [CGF*05]. Analysis and definition of the breast shape based on clinical semantics can help plastic surgeons to objectively evaluate the outcome of reconstructive plastic operations.

The team singled out, as a starting point for this research, the following objectives that are especially relevant for common clinical practice:

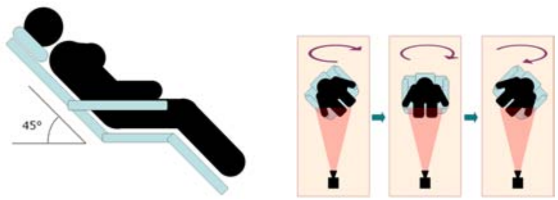
1. Characterisation and segmentation of breast subunits;
2. Measure of distances between landmark points over the female thorax: these measures may be obtained as line distances in the 3D space or may be obtained as path length over the body surface;
3. Measure of areas, volumes, percentage of area subunit over the total area;
4. Angles between landmark planes.

The relevance of these measures is evident if one considers that the area ratio between lower and upper pole of the breast and between other clinically-meaningful surfaces, and distances between anatomical landmark are widely used parameters in reconstructive surgery. One important issue raised by the surgeons has been to provide a sound and objective meaning for the vague but universally used terms, such as *sweet slope*, *well defined inferior pole* and similar. To this aim visualisation in false colours of curvature and convexity resulted in a effective tool.

The analysis of curvature and convexity can help surgeons to achieve symmetry and the desired breast shape i.e., the main goals of breast reconstructive surgery.

3. Breast Surface Analysis

The analysis presented here has been carried out on a set of breast models related to clinical cases collected in Plastic and Reconstructive Surgery Department at Istituto Nazionale Tumori in Milan, according to common cosmetic and reconstructive criteria (e.g., age, menopausal status, ptosis classification).

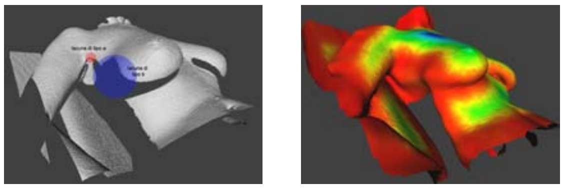


(a) Patients' posture at 45 degrees.

(b) Rotation of the chair with respect to the camera.

Figure 1: *Patient positioning.*

The recruited volunteers were seated on a chair with their back at 45 degrees, as to simulate theatre evaluation position (Figure 1). Three scans of the same volunteer were acquired: facing the camera and rotating the chair at 45 degrees to the left and to the right. Moreover, three more acquisitions were taken in the same positioning, but suspending the breast with a large adhesive bandage, in order to evaluate the infra-mammary fold shape. We choose not to merge the different scans because of uncontrollable physiological movements (e.g., breathing and imperceptible body torsions) during the scanning process. Although extremely precise, laser scanning requires a time lag that is not compatible with the patient breathing. This difficulty may be overcome either accelerating laser scanning, or adopting faster but less accurate shape from video methodologies [Pol05].



(a) Original data.

(b) Filled model.

Figure 2: *Gap filling by volumetric diffusion.*

Therefore, the analysis has been performed on partial views. Unsampled areas has been filled using volumetric diffusion [DMGL02] (Figure 2). These methodology is compatible with precision requirements of surgeons when it

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deals with small gaps (below 0.8 cm of diameter). Filling gaps of larger size has been done only for visualisation purposes and the reconstructed areas in these cases are not been used in landmark positioning.

3.1. Anatomical Landmarks

In order to unambiguously define breast sub-units, we exploited the following anatomical landmarks, suggested by surgeons because of their easy reproducibility (Figure 3):

1. *Sternal Notch* or *Jugulum* (p_j)
2. *Xiphoid* (p_x)
3. *Nipple* (p_c)
4. *Pectoralis insertion in the arm* (p_{aa})
5. *Acromial extremity of clavicle* (p_s)
6. *Mid-axillary point* (p_{pa})
7. *Lowest breast point with respect to the vertical body axis* (p_d)

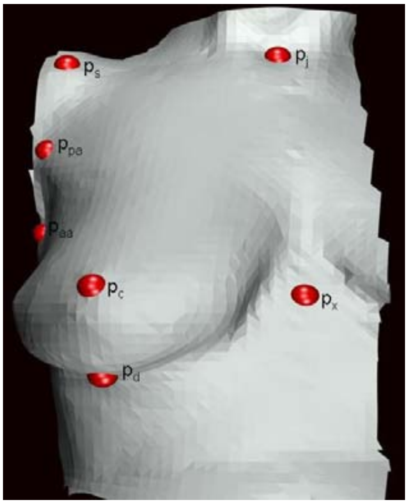

Figure 3: *Anatomical landmarks.*

Accurate positioning of these landmarks is crucial for the quality of the outcome and it is difficult to automatise because the landmarks have clinical meaning. Hence, these points are interactively placed by surgeons on the model using the BSA 0.1 tool described in Section 4.

3.2. Anatomical Sub-Units

In clinical practice, breast sub-units are manually traced and the outcome strongly depends on the experience and ability of surgeons. We aimed at defining a tracing scheme that is less dependent on the ability of the user. The proposed scheme employs simple geometric primitives such as planes, lines, and geodesics. Geometrically-defined breast partitioning guarantees a more objective and reproducible subdivision procedure and opens the way to objective quantitative measuring methods.

The proposed subdivision algorithm defines four elements:

1. *Thoraco-mammary bilateral symmetry plane* (π_s);
2. *Breast meridian plane* ($\pi_{m,l}$ and $\pi_{m,r}$ for left and right breast, respectively);
3. *Breast equatorial plane* ($\pi_{e,l}$ and $\pi_{e,r}$ for left and right breast, respectively);
4. *Breast box hull.*

First, we define the *bilateral symmetry plane* as the axial plane through p_j (*jugulum*), p_x (*xiphoid*) and the derived point M_{gx}. M_{gx} is the middle point of the geodesic between p_j and p_x. Notice that these three points are not collinear due to the natural curvature of the thorax (Figure 4(a)).

The *breast meridian plane* is defined by three points (see Figure 4(b)): the nipple, the midpoint, M_{js}, of the straight line between p_g (sternal notch) and p_s (acromial extremity of the clavicle), and the midpoint M_{px} of the straight line between p_{pa} (pectoralis insertion in the arm) and p_x (xiphoid). This plane intersects the model subdividing the surface in lateral and medial aspects. The curve produced on the model is usually referred to as *breast meridian* (Figure 4(b) and Figure 4(c)).

In order to define the *equatorial plane*, we imitate a very common device used by plastic surgeons to mark the nipple-areola complex. The *nipple-areola plane* is defined as the tangent plane at the nipple, p_c (Figure 4(d)). The equatorial plane is orthogonal to the nipple-areola plane and to the line defined by the intersection of this plane and the meridian plane (Figure 4(e)). The intersection between the equatorial plane and the breast surface is called *breast equator*. It separates the upper and lower halves of the breast (Figure 4(f)).

In order to analyse breast surface properties in compliance to surgeon specifications, an enlarged thoraco-mammary surface from the breast model has been selected as a region of interest to produce a *breast box hull*. This box is made up of six surfaces detected in sequence as follows:

- *Breast surface* (Figure 5(a))
- *Back plane*, π_b, orthogonal to the bilateral symmetry plane containing p_s (acromial extremity of clavicle) and p_{aa} (pectoralis insertion in the arm) Figure 5(b))
- *Thoraco-mammary bilateral symmetry plane* π_s (Figure 4(a))
- *Lateral plane*, $\pi_{l,i}$, orthogonal to the back plane and containing p_{aa} (axillary apex) and p_{pa} (pectoralis insertion) (Figure 5(c))
- *Lower plane*, π_L, orthogonal to the bilateral symmetry plane passing through p_d (Figure 5(d))
- *Upper plane*, π_U, orthogonal to the bilateral symmetry plane, to back plane and including p_g (sternal notch) and p_s (acromial border of the clavicle) (Figure 5(e))

3.3. Measurements

Given the partition defined in Section 3.2 a number of relevant measurements can be computed:

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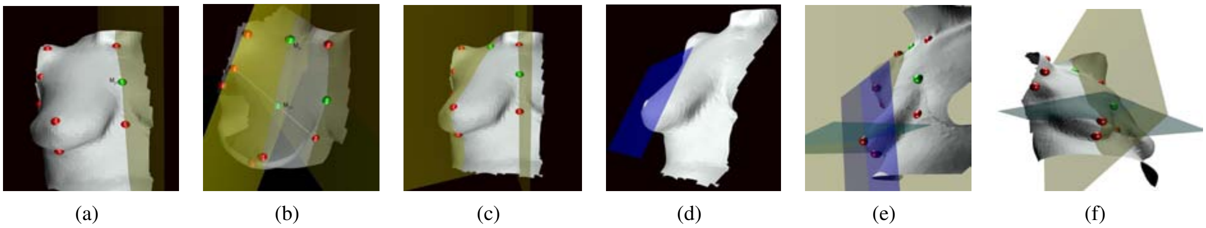

Figure 4: *Planes used for breast segmentation. (a) Thoraco-mammary bilateral symmetry plane. (b) Breast meridian plane (c) Breast meridian curve obtained by intersecting the 3D model and the meridian plane. (d)Nipple-areola plane. (e) Construction of the equatorial plane. (f) Breast equatorial curve.*

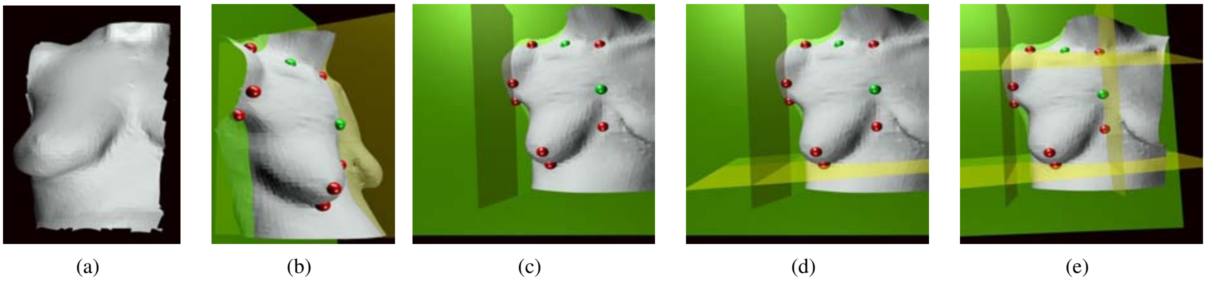

Figure 5: *Surfaces involved in the Breast Box Hull. (a) Front surface. (b) Back plane,* π_b*. (c) Lateral plane,* $\pi_{l,r}$*. (d) Lower plane,* π_L*. (e) Upper plane,* π_U*.*

Line Measurements Distances between all the landmark pairs and distances between p_c and the bilateral symmetry plane, and between the nipple, p_c, and the back plane, π_b (Figure 6).

Area measurements We computed the area of some relevant surfaces: the front box hull, the upper pole, the lower pole, and the sub-units defined by the intersection of the meridian plane, $\pi_{m,i}$, and the equator plane, $\pi_{e,i}$. Knowing the relationship between these areas can help the surgeons to understand breast shape features.

Angles Let us define $O_i x_i y_i z_i$ the (generally non-orthogonal) coordinate system induced by the intersection of the planes π_s, $\pi_{m,i}$, $\pi_{e,i}$ (refer to Section 3.2 and Figure 7), where i stands for l (left) or r (right). We compute the angles $\widehat{x_i y_i}$ and $\widehat{x_i z_i}$, where x_i is the axis including the nipple, p_c. The former gives a measure of the symmetry of the nipples with respect to the bilateral symmetry plane. The latter quantifies the breast *ptosis*.

Curvature and convexity Visualising the mean curvature and convexity of the breast surface is useful to capture the concept of widely used clinical terms, such as “sweet slope” and “well defined inferior pole”. Since no unambiguous definition of breast shape features is available, surgeons found false-colour visualisation more useful than any attempt to make accurate measurements of data.

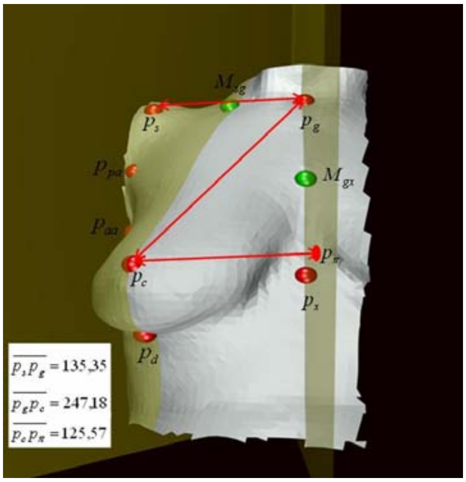

Figure 6: *Some useful linear measurements.*

4. The *Breast Shape Analyzer* Tool

The Breast Shape Anayzer tool (BSA 0.1) includes a mesh visualiser, supporting the STL file format. The visualiser gives the possibility to the user to render the model in wireframe, flat or Gouraud shading. The mesh can be rotated, translated or scaled via the interface controls. BSA 0.1 al-

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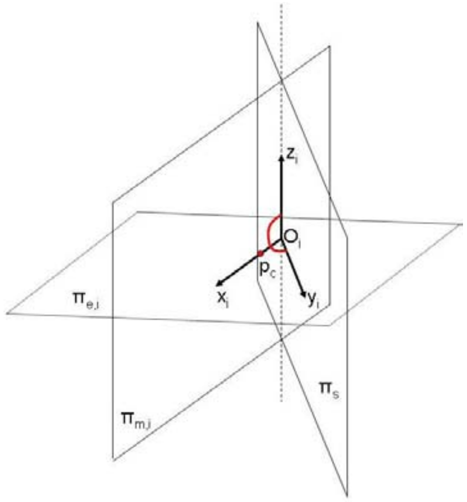

Figure 7: *The Angle Reference System.*

lows the positioning of landmarks directly on the mesh. When a point in screen space is acquired, a ray is casted from the near plane to the far plane, in the OpenGL contest, and the closest vertex to this ray is automatically selected as a landmark point. Every landmark shift on the mesh is interactively shown and the coordinates values are visualised in a separate text area of the interface for feedback (Figure 8(a)). The tool automatically computes and shows all the relevant planes as soon as all the needed landmarks are positioned. The rendering of the plane is transparent to allow simple interpretation and the interactive correction of its position (Figure 8(b)). One delicate issue is the computation of the tangent plane at the nipple, p_c. This is done using an approximation of the normal to the surface (Figure 8(c)). The segmented subunits may be visualised in different contrasted colours (Figure 9). All the measures that have been listed in the previous section are calculated and visualised on the interface, and stored in a file for a successive processing.

Finally, the mean curvature and convexity of the breast are computed and the model is painted in false colours accordingly. Two colouring modes are allowed: curvature and convexity. When displaying curvature, a colour ramp is used, ranging from blue to red in increasing order of curvature. Convexity is encoded using two colours, representing concave and convex regions. Surface colouring significantly captures breast shape features, thus guiding surgeons in post-operative outcome evaluation. Figure 10(a) and Figure 10(b) shows an example of curvature and convexity colouring. Clearly, colouring does not fulfill our expectations. This depends on the sampling noise of the surface. This effect can be partially reduced by smoothing the surface, while preserving significant details (i.e., high curvature regions). Edge-preserving smoothing can be implemented using many different filters, such as Bilateral filter [TM98]. Alternatively, curvature can be computed on a simplified mesh and then mapped back to the original model e.g., using a point-surface distance. We are currently evaluating the quality and time efficiency of both solutions.

5. Clinical Validation

Most of the published medical studies on breast shape evaluation focus on reconstruction using volume estimation or simple linear measures [SPKB86, BRH*99, BBS01, Teb02, DMGL02, GNCMM02, NG03, LH04, LSD*05]. None of them has reached clinical practice. In most of these studies either the landmarks are ambiguously and arbitrarily placed, or their definition is hard to reproduce in complex cases.

In this work, we suggest to place landmarks on bony extremities, since they are more reproducible. Building on these points, the resulting unambiguous geometric partitioning of the breast shape has been found very useful by surgeons to develop a reliable breast topography and a proper outcome evaluation protocol.

The clinical experimentation technique reported here is at its beginning: the data obtained with the volunteers have been processed and the qualitative and quantitative measures obtained seem to be in accordance with common breast surgical practice. However, a more complete set of experiments is in planning to better clinically evaluate the proposed measurements scheme.

6. Conclusions

Evaluating the post-operative outcome of breast plastic surgery is currently a little more than craftsmanship and intuition, strongly relying on the professional skills of surgeons. Clinical capabilities and personal experience of plastic surgeons cannot be embedded into a standard clinical procedure, unless a new theoretical background in anatomical shape analysis is established.

A series of feature points uniquely characterizing woman breast surface was fixed in compliance with surgeon's suggestions and requirements. Building on these landmarks, we devised a simple and reproducible breast partitioning scheme employing only geometric primitives as simple as planes, lines, and geodesics. We came out with a simple and intuitive description of breast surface that has been appreciated by the plastic surgery community and is being clinically validated. Our unambiguous geometric breast partitioning is a first step towards the definition of a portable and reproducible analysis scheme, and opens the path to the definition of objective breast biometrics that, in turn, can lead to the definition of a standard clinical evaluation protocol.

A prototype software, *Breast Shape Analyzer* (BSA 0.1), based on our novel methodology has been produced, empower surgeons with useful measuring and visualisation tools. BSA will be soon available in our website

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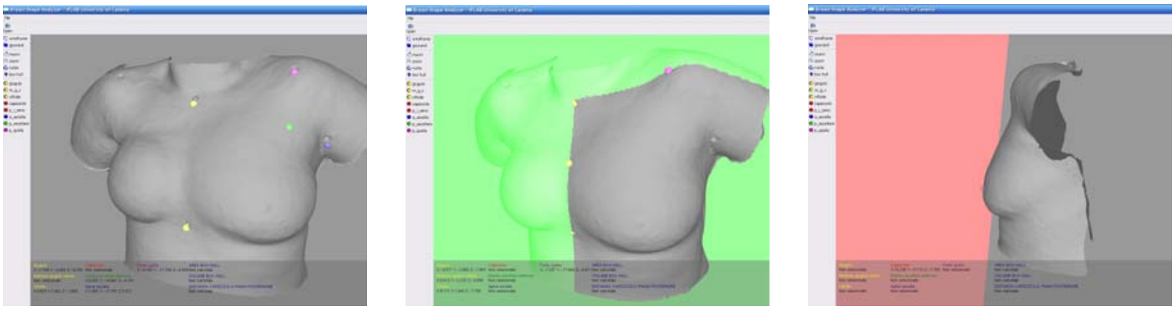

(a) Landmark positioning on the mesh. Notice the numerical coordinates values displayed below the viewport.

(b) Transparency of landmark planes in the case of plane π_s.

(c) The nipple tangent plane is showed in red.

Figure 8: *Breast partitioning using the BSA tool.*

http://www.dmi.unict.it/~iplab. Many challenging issues are left open by this work:

a) use of faster (and/or cheaper) scanning techniques;
b) modeling of the elastic and structural deformation of the breast shape;
c) parametric fitting of a standard breast model from few 3D anatomical landmark and/or a low resolution scan of the body.

Future works will be focalized on above issues.

Acknowledgements

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References

[BBS01] BULSTRODE N., BELLAMY E., SHROTRIA S.: Breast volume assessment: comparing five different techniques. In *Breast* (Apr. 2001), vol. 10, pp. 117–123.

[BF05] BLENDER FOUNDATION: Blender 2.40. `http://www.blender.org/`, 2005.

[BRH*99] BROWN T. P., RINGROSE C., HYLAND R. E., COLE A. A., M. B. T.: A method of assessing female breast morphometry and its clinical application. *British Journal of Plastic Surgery 52*, 5 (1999), 355–359.

[CGF*05] CATANUTO G., GALLO G., FARINELLA G. M., IMPOCO G., NAVA M. B., PENNATI A., SPANO A.: Breast shape analysis on three-dimensional models. In *Third European Conference on Plastic and Reconstructive Surgery of the Breast* (Dec. 2005).

[DMGL02] DAVIS J., MARSHNER S., GARR M., LEVOY M.: Filling holes in complex surfaces using volumetric diffusion. In *First Int. Symp. on 3D Data Processing, Visualization and Transmission (3DPVT'02)* (2002), IEEE Comp. Soc., pp. 428–438.

[GNCMM02] GALDINO G. M., NAHABEDIAN M., CHIARAMONTE M. GENG J. Z. K. S., MANSON P.: Clinical applications of three-dimensional photography in breast surgery. *Plastic and Reconstructive Surgery 110*, 1 (2002), 58–70.

[KM04] KONICA MINOLTA: Minolta VI 900/910 high resolution laser scanners. `http://www.minolta-3d.com/`, 2004.

[LH04] LEE H.-Y., HONG K. KIM E. A.: Measurement protocol of women's nude breasts using a 3d scanning technique. 353–360.

[LSD*05] LOSKEN A., SEIFY H., DENSON D. D., PAREDES A. A. J., CARLSON G. W.: Validating three-dimensional imaging of the breast. 695–696.

[NG03] NAHABEDIAN M. Y., GALDINO G.: Symmetrical breast reconstruction: is there a role for three-dimensional digital photography?

[Pol05] POLLEFEYS M.: 3D from image sequences: Calibration, motion and shape recovery. In *Mathematical Models in Computer Vision: The Handbook*, Paragios N., Chen Y.,, Faugeras O., (Eds.). Springer, 2005.

[SPKB86] SMITH D. J. J., PALIN W. E. J., KATCH V. L., BENNETT J. E.: Breast volume and anthropomorphic measurements: normal values. 331–335.

[Teb02] TEBBETTS J. B.: A system for breast implant selection based on patient tissue characteristics and implant-soft tissue dynamics.

[TM98] TOMASI C., MANDUCHI R.: Bilateral filtering for gray and color images. In *ICCV '98: Proceedings of the Sixth International Conference on Computer Vision* (Washington, DC, USA, 1998), IEEE Computer Society.

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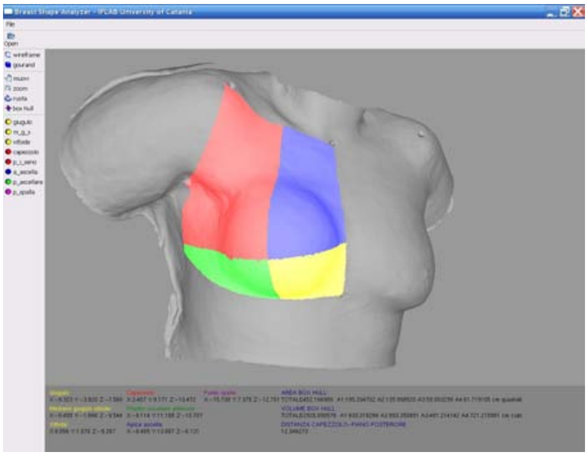
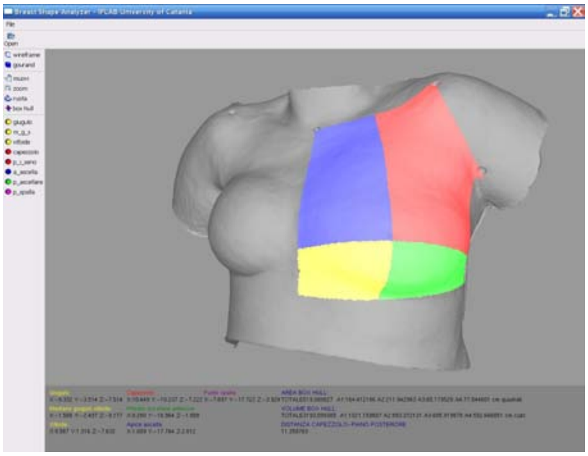
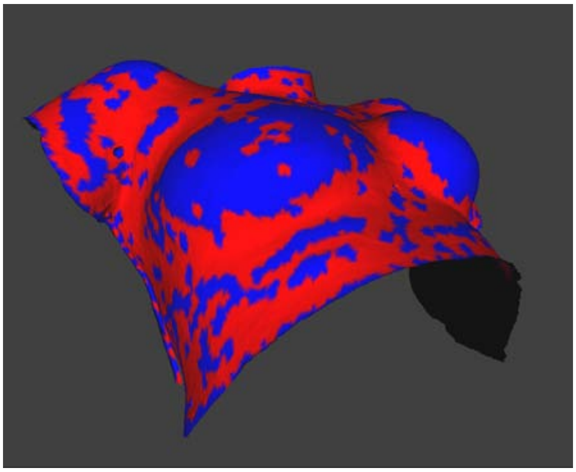


(a) Right breast.

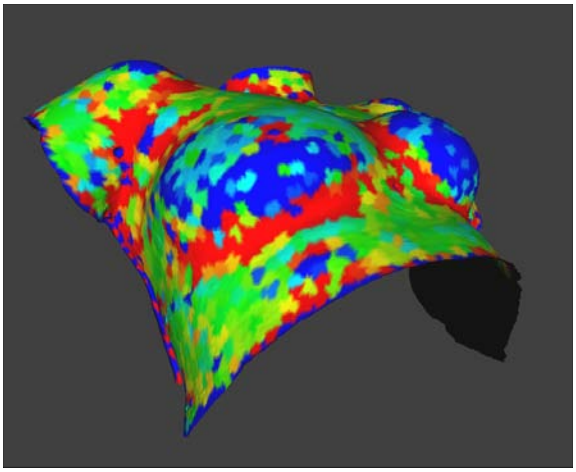


(b) Left breast.

Figure 9: *Breast subunits evidenced with different colours using the BSA tool. The values of the computed measures are displayed on the bottom.*



(a) Concavity and convexity. The red is associated to regions showing an intruding curvature, while blue encodes extruding areas.



(b) Curvature. A wide area is lightly coloured since it is almost flat, while highly curved regions, such as the infra-mammary fold, are coloured using darker colours.

Figure 10: *Convexity and curvature of the 3D model of a volunteer's breast.*

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