Development of a BCCT Quantitative 3D Evaluation System through Low-Cost Solutions

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Abstract

Breast cancer is one of the most mediated malignant diseases, because of its high incidence and prevalence, but principally because of its physical and psychological invasivity. Breast Cancer Conservative Treatments (BCCT) allows a local control of the disease, with a survival similar to that obtained with a mastectomy, but with a better aesthetic result: the tumor is excised together with a small healthy tissue layer. In BCCT the surgical outcome depends on several factors, many of them difficult to assess, thus leading to a significantly heterogeneous results. For this reason, it is fundamental to evaluate specific surgical procedures on the basis of their aesthetic outcome through specific quantitative tools.

The *Breast Cancer Conservative Treatment.cosmetic results* (BCCT.core), is a software recently developed with the objective to overcome the limitations of reproducibility and objectivity of the methods currently used to evaluate the aesthetic result of BCCT. This software is based on the comparison between the treated and non-treated breast in frontal photographs from the patients. Several indices related to the surgical aesthetic result are automatically obtained from the image, making the evaluation fast, easy and reproducible.

Although the BCCT.core system presents satisfactory results, presents a significant limitation. The female breast is a complex three dimensional (3D) object and its boundaries are rather fuzzily defined in two dimensional (2D) pictures, thus making difficult the body landmarks identification. On the contrary, the use of a 3D model would allow the comparison between real geometrical characteristics of the breasts including the possibility of estimating volume and 3D surface differences, in order to plan future surgical interventions.

The goal of this work is the development of a simple 3D model of a female torso, using low-cost solutions, namely: a reconstruction algorithm from two uncalibrated views, through epipolar geometry approach and making use of a Kinect sensor device. The created model will be used in an updated version of a BCCT.core to obtain a full 3D aesthetic assessment of the surgical outcome. With the inclusion of measurements extracted from the 3D model, aiming to improve the global assessment result, without increasing its complexity, as the pictures are acquired with a single camera without requiring any calibration procedure.

Keywords: 3d models, uncalibrated views, kinect sensor device, low-cost solutions, breast cancer conservative treatment, aesthetic evaluation, BCCT.core

1. Introduction

Nowadays breast cancer is considered a public health problem, and it is currently the most common tumour found in women. One in ten women will develop breast cancer at some point in their life. It is a very frequent disease and remains one of the most publicized malignancies not only because of its high incidence and prevalence, but also because of the impact that the breast has on women's body, sexual and maternal images.

As far as treatment is concerned, progress has been made and BCCT has been established as an alternative to the classic invasive surgical treatment. Contrary to a mastectomy, where the entire breast is removed, in conservative treatment the tumour is removed macroscopically together with a small amount of cancer free breast tissue. The patient then undergoes radiotherapy on the remainder of the breast. This conservative approach, in its various forms, has made it possible to locally control the disease and it has a similar survival rate to that obtained with the mastectomy, but with better cosmetic results [1,2].

Approximately 90% of breast cancers are curable if detected in their initial phase and treated properly. This means that many women are expected to live with the aesthetic results of their local breast cancer treatment for a longer period of time. This fact increases the importance of a good aesthetic outcome,

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which has been acknowledged by experts in this field. However, it is known that auditing this problem and developing techniques to improve aesthetic results is a difficult task due to the absence of a standard method to measure the aesthetic outcome [3,4].

Until recently, the most common technique used to assess the aesthetic results was the subjective assessment by one or more observers, who focus directly on the patients or on photographic representations of them. The opinion on the final aesthetic result is graded using one of several existing scales that rank the results, usually by comparing the operated breast with the untreated breast. The most frequently used evaluation scale was introduced by Harris in 1979 [5]. However, there are some problems regarding the interpretation of the results of the studies which use this type of assessment: for example, exemption is not always guaranteed since it is often performed by professionals who are involved in the treatment. Therefore, its reproducibility is not usually high [6] and when measured, the level of agreement between observers is low or moderate [7].

In an attempt to overcome the lack of objectivity and reproducibility, objective methods were introduced. These methods consisted of comparing the two breasts with simple measurements marked directly on patients or on photographs of them [3,8]. Almost all of the measurements suggested in the literature capture the breast's asymmetry and were subject to significant intra-observer and inter-observer variability, as is the case of Breast Retraction Assessment (BRA) proposed by Pezner et al. [9] or the Breast Compliance Evaluation (BCE) introduced by Tsouskas and Fentiman [10]. In addition to attempting to evaluate the aesthetic result from the measurements, they also attempted to correlate measurements with the subjective evaluation.

The current methodologies in studies that evaluate the cosmetic outcome of BCCT continue to show a significant lack of standardization, not only in the type of assessment used, but also in the factors included in this evaluation and the instruments used for this analysis. There was a need to replace or enhance the expert human evaluation of the aesthetic results of BCCT, with a validated objective tool. This tool should be easy to use and highly reproducible and acceptable to those who would be evaluated. One of those cases is the Breast Analysing Tool (BAT) that was very recently introduced by Fitzal et al. [11], which uses a very recent measure named Breast Symmetry Index (BSI).

Although, the most prominent tool to objectively and automatically perform the aesthetic evaluation of BCCT was recently introduce by Cardoso and Cardoso [12]. This computer-aided medical system, called Breast Cancer *Conservative Treatment.cosmetic results* (BCCT.core), aims to overcome the acute shortage of such software systems and exploit the unique ability of computational methods to provide an effective and easy to use tool to improve the outcome of breast cancer patient care. BCCT.core is an automatic system capable of objectively evaluating the overall aesthetic results of BCCT. The development of BCCT.core consisted of automatically extracting several features from frontal patient's photographs (see Fig. 1), capturing some of the factors that are considered to have an impact on the overall cosmetic results: breast asymmetry, skin colour changes due to the radiotherapy treatment and the appearance of the surgical scar [12]. In a second phase, a Machine Learning algorithm is applied to predict the overall cosmetic result using the recorded features [13].

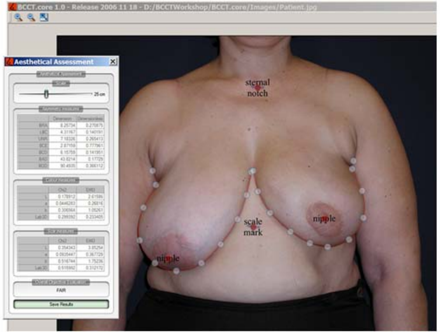
BCCT.core 1.0 - Release 2006 11 18 - D:/BCCTWorkshop/BCCT.core/Images/Patient.jpg

Fig. 1. BCCT.core interface.

The objective overall classification outputted by this module constitutes a valuable summary of the aesthetical result, enabling an effective comparison between different medical teams and centers all over the world. BCCT.core is currently being used by many international groups in prospective studies: Nottingham Breast Institute, UK; Leiden University Medical Centre, The Netherlands; Cancer Care Center, Sydney, Australia; University of Heidelberg, Breast Center, Heidelberg, Germany; Medical University, Vienna, Austria; etc. The approach of this tool, while innovative and reproducible, has several points that need to be addressed as is often suggested by the users. The first case is the interpretability of the model that relates the aesthetical result with the input measures; and the second, the only use of face-view of the patients not including the information from side or oblique views. These drawbacks were very recently subject of study [14,15]. However, one of the setbacks of these methods is then the lack of the third dimension.

Now, more than ever, it is important not only to compare results after treatment, but also to predict cosmetic results before the procedure has taken place. There is therefore a need for a tool capable of simulating surgical options and outcomes in terms of volume, gain or loss, and of better educating patients on a more informed choice of breast surgery procedures. A more accurate and objective tool to predict surgical outcomes to guide the patient and surgeon in the decision-making or planning process is feasible using 3D imaging and surgical simulation. A simulation model also allows patients to visualise the possible outcomes of different surgical options. It is generally accepted that 3D imaging has great potential in a clinical environment, although there are factors that may influence its use in the near future. The high cost of the equipment and the need of specialized people to operate are undesirable circumstances. Consequently, the search for low cost equipments and easy to perform is highly desirable.

2. Surface modeling for aesthetical outcome assessment

The potential advantages of using 3D imaging as a tool for objective cosmetic evaluation include the ability to view the breast from a significant number of angles, to estimate volume/volume deficit and to plan future surgeries. There are several variations of this tool that range from a relatively simple volumetric analysis to more sophisticated programmes, which provide quantitative measurements, or software that makes it possible to simulate the most likely post-operative outcome. With the development of the new oncoplastic techniques in breast conservation it is even more important to be able to compare cosmetic results, helping to tailor the spectrum of techniques available to individual cases, without compromising either the oncologic or the cosmetic results [16].

Several research groups have more or less recently made attempts with 3D approaches [17,18,19]. Probably the more interesting and consistent attempts have been made by Losken and colleagues [20,21,22] and Catanuto joint with Politecnico di Milano Bioengineering group [23,24,25,26]. The first group developed an objective technique based on a 3D camera and software to quantify the cosmetic results of BCCT. This software package makes it possible to establish a comparison between the treated and untreated breast by analyzing the surface area and volume differences. The camera includes 12 individual digital lenses arranged in 3 planes with a single focal point at the manubrium. Images were captured with the patients' arms in two different positions: at their sides and with on their hips. The software was afterwards used to determine the level of asymmetry between the breasts using a root mean square (RMS) calculation, bisecting the thorax down the midline, selecting the left side, and creating a mirror image. Then the original image was superimposed on the mirrored image to create a perfectly synchronization between the two sides of the thorax.

The second group used 3D laser scanning combined with anatomical landmarks identified by surgeons and developed the Breast Shape Analyzer 0.1 (BSA 0.1) software, thus providing useful objective quantitative measurements to surgeons [23]. This technique uses only well-defined anatomical points, identified and selected by surgeons. A simple sequence of geometric operations is performed to divide the breast surface into four anatomic subunits, according to clinically derived breast meridian and equator lines, in order to perform several measures that can be extrapolated on a 3D model data set. The acquisition was made using a commercial laser scanner, applied on volunteers sitting on a chair with their back at 45 degrees. Each volunteer was scanned three times: facing the camera and rotating the chair at 45 degrees to the left and to the right. This system presents an important drawback related with patients' uncontrollable physiological movements, which enable the merge the different scans.

In another work Catanuto et al. [24,25] presents a set of parameters to unambiguously estimate the shape of the natural and the reconstructed breast, using an optoelectronic tracking system in seven female volunteers, and allows a real-time breathing artifact correction [26] and a surface patch fusion with no intervention by the operator. With those parameters it is possible to describe several anatomical geometrical properties. With this technique, they obtained a graphic depiction of the curvature of the thoracic surface as the most interesting result. The breast surface was segmented into four quadrants using reproducible landmarks. The main drawback of these 3D techniques stands on the demand for specialized hardware, software and personnel. The high cost and the difficulty of using these methods on a daily basis prevent their widespread use in the near future. Moreover, almost all currently used techniques based on 3D models do not try to predict the aesthetic result for a more informed choice of treatment, neither are suitable for the automatic evaluation of the aesthetic result after the surgery [18, 21, 24]. More recently Tepper et al. [19] tried to overcome this drawback. In their work, they provide an overview of 3D breast photography, with emphasis on its potential role to establish a standardized system for breast analysis, by introducing a new concept entitled "mammometrics", in which 3D-based breast measurements can be used to help guide operative planning and objectively analyze surgical results.

2.1. Methodology implemented

The aim of this project was to obtain simple 3D models or volumetric information from the data, and compare this information with reference models previous obtained using a robust system. These reference models were obtained by projecting laser spots on the object and using a stereo acquisition system [25,26]. In this work we study two different methodologies based on low-cost solutions to extract 3D information from patients or a female phantom torso. The first approach was based on an uncalibrated environment from two different views using epipolar geometry [27], while the second was conducted making use of a disparity map from the scene using a Kinect sensor device. The 3D information acquired will be used in the future to support the aesthetic evaluation of BCCT. We expected, in a recent future, to incorporate this kind of information in the BCCT.core [12] model, in order to obtain a full 3D aesthetic assessment of the surgical outcome. With the inclusion of measurements extracted from the 3D model, aiming to improve the global assessment result, without increasing its complexity, as the photographs are acquired with a single camera or a low-cost commercial system without requiring any calibration procedure.

3. Reference model acquisition

As stated before, our methodologies were tested both with a phantom and in real female patients. For the real acquisitions we only have reference measures manually performed. On the other hand for the female phantom torso we made manually measures, but also with equipments based on active stereoscopy techniques (see Fig. 2).

Fig. 2. Female phantom torso (left – real photo; right – 3D surface model).

This reference model was acquired by Computer Aided Radiation Therapy group of the Politecnico di Milano, which developed in the last years, specific instrumentations and algorithms aiming to create a tool to acquire and analyze patients' surface in order to quantitatively assess surgical outcome in breast plastic and reconstructive surgery [28]. The acquisition system is based in a programmable laser pattern static projector and an optical tracking system [29] (see Fig. 3). The surface is obtained using a "row-wise" scanning projected into the object that we want to acquire, and the scanning can be repeated as many times as desired to obtain a more dense point cloud. The tracking system used to localize the laser spot projected in the surface is based in a stereo vision system.

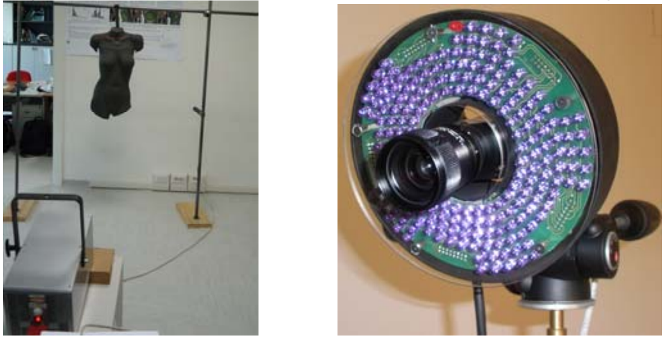

Fig. 3. Acquisition system (left – laser scanner and the female phantom torso; right – one of the cameras from the tracking system).

4. Uncalibrated environment using epipolar geometry

Part of the problem that is addressed in this work is that of binocular disparity, namely the different displacement objects undergo when seen through different viewpoints. The human brain uses this process to identify distances to objects. The same process is used in computer vision, where similar features are matched and their disparity is calculated. Then, with some computation and provided that there exist some knowledge between the cameras it is possible to reconstruct the scene up to a metric reconstruction, where the lengths and distances of that reconstruction have a direct relation to real world measures. If such knowledge is unknown, every reconstruction is relative to a trivial projective transformation, thus the measures of that projection might have no direct relation to real world measures.

4.1. Stereo vision and epipolar restrictions

Based on Hartley and Zisserman [27] and Szeliski [30], it is possible to build a mathematical model in order to relate two views (see Fig. 4).

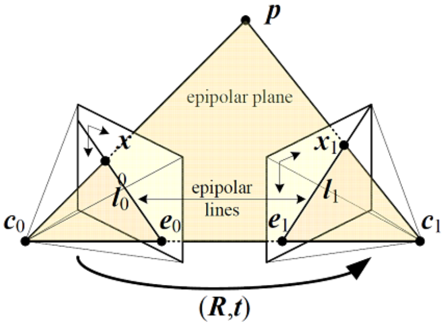

Fig. 4. Geometric model for two-view geometry based on the pinhole camera model. The projection of point p is, respectively, x and x1 in the left and right view, c0 and c1 are the camera centers, and e0 and e1 the epipoles, finally l0 and l1 are the epipolar lines that pass through x and x1, respectively, and are contained in the epipolar plane for point p. Note that all epipolar lines and planes go through the epipoles. Also note that, between the two cameras, it is assumed that exist a rotation and translation associated, (R; t). Taken from [30].

Although we do not know the exact position of point ***p***, we know that it must be located somewhere in the ray cast between the camera centres and that point, that pass through the image plane in each one of the points ***x*** and $\boldsymbol{x_l}$. After some geometrical relations and based on the camera model [30,31], it is possible to define a matrix ***E***, ***3x3*** of ***rank-2***, that relates every corresponding point as such:

$$\hat{x}_l^T \cdot E \cdot \hat{x} = 0 \qquad (1)$$

where ***E*** is defined as:

$$E = [t]_\times \cdot R \qquad (2)$$

This is, of course, if both ***R*** and ***t*** are known. In this work's case of study, those are not known, as it deals with free-moving hand-held cameras. Also, as it is an uncalibrated environment, there is no easy access to camera parameters and the cameras' calibration matrix. In such situation, it is possible to define a new matrix ***F***, the fundamental matrix, which still respects the epipolar constraint, as follows:

$$\hat{x}_l^T \cdot E \cdot \hat{x} = \hat{x}_l^T \cdot K_r^{-T} \cdot E \cdot \hat{x} = \hat{x}_l^T \cdot F \cdot \hat{x} = 0 \qquad (3)$$

The matrix defined in equation 3 [27] has many applications, and it is of utter importance. ***F*** is normally found using, at least, 8 matches in both images, solving a system of equations using Singular Value Decomposition (SVD). It can, anyway, be estimated using only 7 correspondences solving for a system of non-linear equations, as this matrix has only seven degrees of freedom. If more than eight points are available, then it is possible to minimise the noise that can be introduce while estimating ***F***. If using automatic established correspondences, then there might exist some outliers (wrongly-matched points) that must be addressed.

The process of stereo matching consists on finding correspondences for the maximum number of pixels in each image. Assuming a low baseline (the displacement, or disparity, between the two views is much smaller than the distance to the objects on the scene), it is possible to assume that most of the pixels from either images will match, in other words, almost all scene points are visible in both views. It is possible to ease the correspondence problem and the computation of correspondent distances by pre-aligning the views, a process called rectification, so that corresponding epipolar lines are horizontally aligned. That way, the stereo matching problem is reduced to a one-dimension search and the math is reduced to what is summarised in Fig. 5.

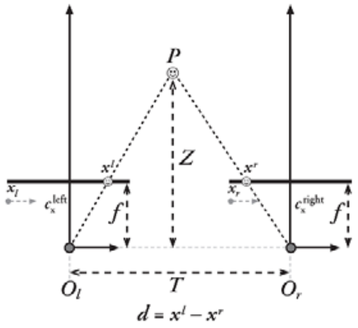

Fig. 5. Disparity search summary assuming a low baseline (T << Z). The search space for correspondences is limited to the x-dimension and the disparity value is very simple to compute. Taken from [31].

From there it is possible to note that the problem, as it is posed here, assumes that the focal length ***f*** is the same for both views. That is common, as even with autofocus, in low baseline problems that value tends to be the same [31], even though the state-of-the-art methods do try to transform that (and other) intrinsic parameter, assuming it is not shared by both the views, so that our model holds. By simple triangle similarity, it is possible to verify that:

$$\frac{T-(x_l-x_r)}{Z-f}=\frac{T}{Z}\Rightarrow Z=\frac{f\cdot T}{x_l-x_r}\Rightarrow Z=\frac{fT}{d} \tag{4}$$

4.2. Rectification

From the previous section it is noted that rectification is a very important and necessary step in the reconstruction process. This step is highly based on the epipolar geometry, where the main goal is to find a way to alight horizontally corresponding epipolar lines. The relation between the fundamental matrix ***F*** and the rectification process is that of finding a pair of homografies that will transform the images so that they become rectified [30,31]. In the rectified case, the ***F*** has the form [32]:

$$F=H_r^T\cdot[u_1]_\times\cdot H_l \tag{5}$$

where, $[u_1]_x$ is the skew-symmetric matrix.

In order to rectify a pair of images it is necessary to search for a pair of homographies so that the epipolar constraint (equation 3) of a rectified pair is verified. If H_r and H_l are such homographies, then it is defined as such:

$$(H_r\cdot x_r)^T\cdot[u_1]_\times\cdot(H_l\cdot x_l)=0 \tag{6}$$

So, the process of planar rectification is to find a pair of homografies that will align the epipolar lines. Thus, it is possible to establish these assumptions:

1. All epipolar lines are parallel to the ***x*** axis;
2. All image features and points have the same corresponding ***y*** coordinate.

Hartley and Zisserman [27] created a method that is based on the process of relocating the epipoles in both images. So, the algorithm attempts to transform the epipoles so that their location is set at infinity (with the last coordinate as 0, in homogeneous coordinates). Starting from a set of matches $x_i \leftrightarrow x'_i$, more than seven, compute the fundamental matrix ***F*** from those matches and find the epipoles ***e*** and ***e'*** so that ***e'F = 0*** and ***Fe = 0***. Then, compute the projective transformation ***H'*** that maps the epipole ***e'*** to infinity, $(1;0;0)^T$. With that, find the matching projective transformation ***H*** that minimizes the least-squares distance:

$$\sum_i d(H\cdot x_i, H'\cdot x'_i) \tag{7}$$

Fusiello and Irsara [32] developed recently a new rectification algorithm that attempts to get close to that of the euclidean rectification. This method attempts to use some notions of autocalibration for trying and estimating the camera parameters (that are assumed to be equal for both views, as it is the case for the images used). From a set of correspondences $x_i \leftrightarrow x'_i$ it defines a Sampson error function for each correspondence:

$$E_j^2 = \frac{(x'^T \cdot F \cdot x)^2}{(F \cdot x)_1^2 + (F \cdot x)_2^2 + (x'^T \cdot F)_1^2 + (x'^T \cdot F)_2^2} \tag{8}$$

where **$(\bullet)_i$** is the **i^{th}** component of the normalized vector. The homographies are then obtained by creating a system of non-linear equations to every correspondence (***E = 0***).

4.3. Experimental results

In this methodology a simplified approach was implemented. Basically, the depth, in each point, is computed using only the difference in the ***x-axis***, assuming a correct image rectification. Using a laser scanner, was projected in the female phantom several light spots to make easier the detection and matching of pixels. Several pairs of two photographs were acquired, from two different points of view, using a single camera without any calibration procedure. The two views present some rotation and/or translation between them, assuming a low baseline between acquisitions.

4.3.1. Identification and matching of points

Initially, the points are indentified and correctly matched, using a semi-automatic approach, from the light spots projected on the female phantom. The detection of the light spots is made automatically, then the user match the corresponding points manually (see Fig. 6).

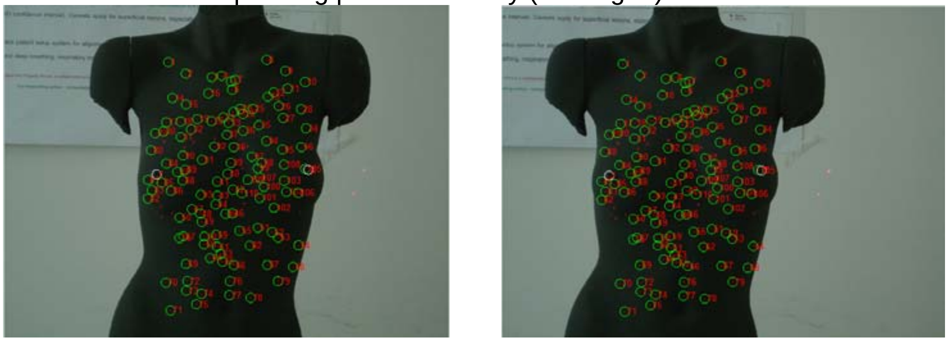

Fig. 6. Identification of corresponding points (The nipples are also identified by the user (white circles).

4.3.2. Rectification of the two views

In this step, the points correctly previous identified are used to rectify the images using epipolar geometry with the Fusiello and Irsara [32] algorithm (see Fig. 7).

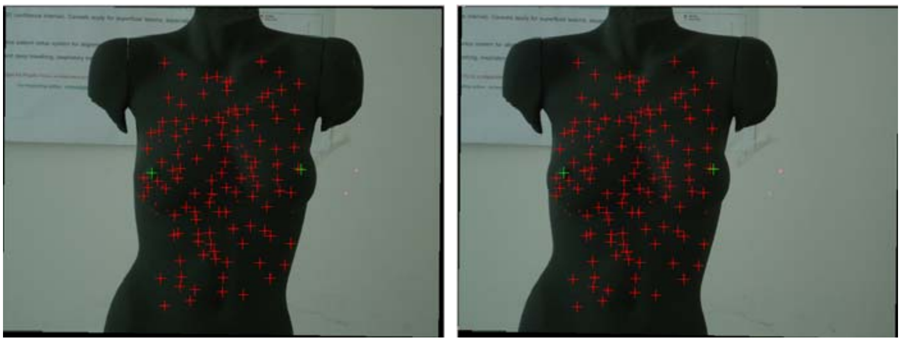

Fig. 7. Rectified images.

The rectification algorithm used was the introduced by Fusiello and Irsara [32], because achieved the best results, with the lowest error, in a previous work [33]. However, it is also the slower to run and sometimes it might not end successfully, due to the random characteristics of the Non-linear Least Squares method, which initializes the focal length with a random value and then iteratively tries to improve that value. As stated before various pairs of photographs were acquired, and were subject to the steps previous presented. The quality of rectification is measure by evaluating the difference, in pixels, between each pair of matched pixels and the corresponding epipolar line using the equation 8. In this part, we obtained an average error of 0.2399 pixels with a Standard Deviation of 0.0171.

4.3.4. Depth information

After the rectification step, all the corresponding points in the images present the same ***y*** coordinate, and now it is possible to compute the disparity between each point. From the equation 4 we can see that the depth information, of each point, is found using the focal distance, the baseline of the cameras and the disparity information. As we are working in an uncalibrated environment, the focal distance and the baseline information are unknown. For that reason we cannot work with real metric values. In the other hand, we can work with relative distances and work with ratio values in both scenarios: real phantom and the computation uncalibrated approach. In this scenario the equation 4 is simplified to:

$$Z = \frac{1}{d} \qquad (9)$$

4.3.5. Torso surface fitting

In this part, the matched points in the chest and abdomen zone are used to fit to a 3D surface. The generated models can be used to take measures and compare with the reference model. Several models were tested from a simple plane to a surface with a higher level. The tested models are presented in Table 1, which shows the Mean Square Error (MSE) of the points used to the surface created using them:

Table 1. Mean square error of 3D fitting models.

Model No.	Model Equation	MSE
Model 1	Z = a0 x + a1 y + a2	5.96 E-10
Model 2	Z = a0 x^2 + a1 y^2 + a2 x + a3 y + a4	2.27 E-10
Model 3	Z = a0 x^2 + a1 y^2 + a2 x + a3 y + a4 x y + a5	1.72 E-10
Model 4	Z = a0 x^3 + a1 y^3 + a2	6.53 E-10
Model 5	Z = a0 x^2 - a1 y^2 + a2	6.37 E-10
Model 6	Z = -a0 x^2 + a1 y^2 + a2	6.37 E-10

These results were obtained considering all the pair of images. The MSE values obtained is an average of all the tests. As we can observe from the table, the Model 3 obtained better results. The obtained surface is presented in Fig. 8. The nipples were also modelled and are identified with red circles.

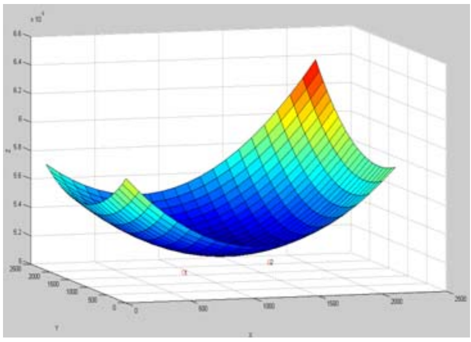

Fig. 8. Surface fitting model.

4.3.5. Results

A surface fitting model was generated for all pair of images. The nipples were also modelled using the equation 9. From this information, relative distances of the nipples to the surface can be computed. The same procedure was conducted for the 3D reference model presented in section 3. The distance between each nipple and the chest are presented in Table 2.

Table 2. Nipples measures taken from 3D reference model.

Real Measures	
Right nipple	4.3 cm
Left Nipple	3.7 cm
Ratio	1.1622

As we are working with relative measures, we have to use ratio values to compare the model achieved in our approach with the 3D reference model. The ratio showed in Table 2 represents one of the features that we can extract from the patient and use to improve the BCCT.core model. For the models generated with our approach, and making an average of the ratios obtained, for all pair of images, we had an average ratio of 1.1184 and a standard deviation of 0.0973.

The value obtained is not far from the real one, but there is some variation in the results. We also have to test this approach in different phantoms and of course with real persons. A great variability of the rotation, translation and baseline of the camera should be performed to improve the quality of this approach and evaluate its quality and performance.

5. Kinect based method

The Kinect is hardware developed for the X-BOX console. This device has one RGB camera and a depth sensor based on an infrared laser projector combined with a monochrome CMOS sensor. This sensor captures video data in 3D under any ambient lighting conditions. It was developed for a Windows platform, an open source software for the everyday user. It is a very recent low-cost platform and its utilization is increasing as an alternative to other more expensive 3D technologies.

From this device we can obtain a disparity map in colour or gray scale. The pixel colour or gray scale represented specific depth information, but the conversion to metric distances is not proportional. Calibration equations must be used to perform to convert the raw data generated by Kinect, which is represented on 2048 levels. There are few different equations to calibrate Kinect, which were tested, but the one that presents better results was the following:

$$d_m = \left(\frac{d_r}{2048} \right)^3 \cdot 9216 \qquad (10)$$

where d_r is the raw data from Kinect and d_m represents the real distance.

We start to apply this approach to the female phantom torso, in order to obtain a real 3D model. The calibration equation gives us the real depth but do not changes the values of ***x*** and ***y***, that obviously are not real. For that reason we cannot compare the results of Kinect with others reference models, such as, that one's obtained with laser scanner, we need a different calibration function to perform this. However, some results were obtained from the data acquired. The phantom was acquired with Kinect device in three different occasions. In these three acquisitions there is some difference, such as: some rotation of the phantom, translation of the Kinect device and also different distance between Kinect and the object (see Fig. 9).

Fig. 9. Different acquisition of phantom with kinect.

To evaluate the quality of the disparity map, we try to compare this depth information with measures taken from 3D model generated with laser scanner, the same as presented in the previous section (see Table 2). Those measures represent the height of each breast by measuring the distance between the nipple and the cheat. In the disparity map we used two different approaches, one that we manually identify the fiducial points, and other where those points are found automatically in specific zones indentified by the user, using ***min/max*** functions. As in the previous section, we also used ratio of measures to compare with the reference. The ratio values obtained from the disparity map are presented in Table 3 – without compensation of rotation (for each period there is several acquisitions):

Table 3. Ratio values obtained with Kinect using the female phantom torso.

Acquisition period	**Without compensation of rotation**				**With compensation of rotation**			
	Automatic		**Manual**		**Automatic**		**Manual**	
	μ	**σ**	**μ**	**σ**	**μ**	**σ**	**μ**	**σ**
1	1.0667	0.0082	1.1900	0.1257	1.1517	0.0624	1.3150	0.3204
2	2.0433	0.0615	3.5850	0.8373	1.1083	0.0499	1.3600	0.1441
3	1.6367	0.0225	3.0550	0.4260	1.1483	0.0999	1.1067	0.0606
MSE	0.1374	-	0.4351	-	0.0174	-	0.0566	-

By comparing the ratio values obtained with Kinect device and the value obtained with the reference model (see Table 2) we can see great discrepancies between values. In the first acquisition, the phantom does not present too much rotation, so, the ratio, both to manual and automatic labelling, are very similar to the measure performed using the reference model. The other results are far from the reference, because presents some rotation and this fact as to be compensated. For that reason, was implemented a rotation compensation based on values points extracted from the stomach, assuming that region presents similar shape on both sides separated by a vertical line that passes in the middle of the breasts. By looking again to Table 3 we can compare the result with and without compensation by observing the MSE error related to the measure made on the reference 3D model. As is easy to observe the approach using automatic measures and with compensation of rotation present very satisfactory results.

The same scheme was applied to the database of 42 patients subject to mastectomy and immediate reconstruction (see Fig. 10).

Fig. 10. Real Kinect acquisition (left – photographs from the patient acquired with a normal camera; right – disparity map from the patient acquired with Kinect.

After capturing the disparity map from the patient, the same process previous stated was conducted to compute the ratio and estimate volume differences between the breasts of the patient. Afterwards this ratio was compared to another ratio, obtained manually by the physician, of both breasts nipple's height (distance of the medial projection of the nipple to the sternum – taken with 2 rulers). The obtained results, in terms of MSE error is presented in Table 4.

Table 4. Kinect measures in real data (The range of ratios ratio found for the 42 patients was [1; 2.5217].

MSE	**Without compensation of rotation**		**With compensation of rotation**	
	Automatic	**Manual**	**Automatic**	**Manual**
	0.0625	1.0302	0.0562	0.4358

By looking to the table we can state that the results are also very satisfactory, namely for the automatic procedure with compensation of rotation, a very valuable result due to the real application. Although results are only preliminary we believe there is a potential for the use of this, low-cost and user friendly, infrared laser projector, to obtain 3D images (disparity map) that will allow the introduction of volumetric information in the aesthetic objective evaluation after breast surgery.

6. Conclusions

It is noted that BCCT.core can be improved by adding more features. Particularly, it is intended to add dimensionality to the measures in order to drop the limitation of only measuring based on what can be seen in a frontal photograph. The capability of manipulating and measuring over 3D readings from the breasts can improve the accuracy and objectivity of the tool.

3D capabilities are recognised as having high clinical potential. However, the current techniques face two major problems: the high cost of required equipment and the need for specialized operators to work with them. Current techniques are based on specially designed cameras and hardware, mainly resorting to many lenses on the same camera or to laser scanners. Due to these special needs, 3D applications are considered pricey and are not commonly implemented, thus, the benefit of 3D modelling is not availed.

This is a work-in-progress project, and for that reason, the results obtained until now can be considered as satisfactory. The principal objective of this work was to study and develop simple 3D model of a female torso, using low-cost solutions, or merely extract simple 3D information.

The first approach implemented was based in a reconstruction algorithm from two uncalibrated views, through epipolar geometry. The obtained results are acceptable, but more and different test are welcome, namely, the test with real patients to increase the difficult and variability of measures. We are

working with featureless scenes, a very well indentified problem, but we expected in a recent future, to work in the automatic detection of features and matching to replace the laser spots used in this work.
The other implemented approach was based in a Kinect sensor device. In this case the results were very satisfactory, first with the female phantom torso, but principally in the application with real patients. It was possible to detect the volumetric differences of the breasts using the disparity map generated from the Kinect. The results were very similar to the reference made manually by the physician, and for that reason we believe that this approach presents a huge potential for the use of this, low-cost and user friendly, infrared laser projector, in the aesthetic evaluation after breast surgery.

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