Depth-Map Images for the Aesthetic Evaluation of Breast Cancer Treatment

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***Abstract*—Breast Cancer Conservative Treatment (BCCT) is now the preferred technique to treat breast cancer. The limited reproducibility of standard aesthetic evaluation methods led to the development of objective methods, such as the Breast Cancer Conservative Treatment.cosmetic results (BCCT.core) software tool. Although the results are satisfactory, there are still limitations concerning complete automation and the inability to measure volumetric information.**

The objective of this work is to develop disparity map images of a female torso using low-cost solutions, namely: a reconstruction algorithm from two uncalibrated views, using an epipolar geometry approach and making use of a Kinect sensor device. Afterwards, using the generated depth-map, the simultaneous detection of breast contour and breast peak points is addressed. Experimental results show the suitability of our depth-map based approach. The proposed algorithm has proven accurate and robust for a wide number of patients. Additionally, in comparison with previous research, the procedure for detecting prominent points was automated.

I. Introduction

Breast conservative treatments present a better aesthetic result than mastectomy, although the cosmetic outcome has no evaluation standard [1]. Until recently, the evaluation was subjectively performed by the physicians; however, it soon became clear that exemption is no guarantee, reproducibility is difficult to achieve and the level of agreement between observers is low. BCCT.core [2] is a recent computer-aided medical system, which aims to overcome the disadvantages of previous methodologies. Using frontal photographs of patients, several features with an impact on the overall cosmetic results are semi-automatically extracted and combined to predict the overall cosmetic result. Although it is innovative and reproducible, this tool has important setbacks that are related to the complete automation of the software – which is fundamental for high reproducibility – and the ability to extract volumetric information to improve the overall cosmetic evaluation. The goal of this work is to develop a depth-map model of the female torso using low-cost solutions. The simultaneous extraction of breast contour and breast peak points is also addressed.

II. Depth-map Images

Several research groups have recently made attempts with tri-dimensional (3D) technology [3], [4]. These methodologies are very expensive, they are not suitable to automatically evaluate aesthetic results and they are not a feasible option for daily clinical practice.

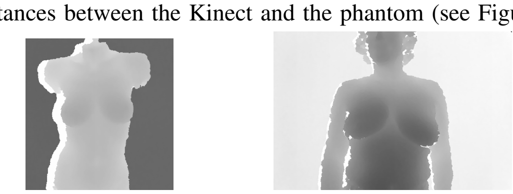
A. Uncalibrated Environment Using Epipolar Geometry

The process of stereo matching consists of finding correspondences for the maximum number of pixels in each image, assuming a low baseline. If the knowledge between the different views is unknown, every reconstruction is relative to a trivial projective transformation. Based on Hartley and Zisserman [5], it is possible to build a mathematical model in order to relate two views. By pre-aligning the views, the correspondence problem is simplified so that corresponding epipolar lines are horizontally aligned. Using simple triangle similarity, it is possible to verify that: $Z = (f \cdot T)/d$, with $T << Z$, where f is the focal distance, T is the displacement between the two cameras, d is the disparity information and Z is the surface data.

Using a laser scanner several light spots were projected onto the female phantom to make it easier to detect and match pixels [6]. The proposed algorithm was implemented as a sequence of a few high-level operations: 1) identification and matching; 2) rectification; 3) depth computation and 4) torso surface fitting. In order to validate this methodology, a reference model of the female phantom [6] was created using the acquisition system from the Politecnico di Milano group [4]. The height of both nipples was measured usinga simplified equation $Z = 1/d$, since f and T are unknown. Due to this simplification we worked with the ratio between nipples information. From the reference 3D model we obtained a ratio of 1.16, whereas, from the generated surface model an average ratio of 1.12 and a standard deviation of 0.10 were obtained. The obtained results are not far from the reference, but there were high variations in the results [6].

B. Kinect Based Method

The Kinect device is a low-cost platform, which makes it possible to obtain a disparity map image. We started by applying it to the female phantom torso [6]. Data was collected on three different occasions to assess the accuracy of the measurements with different relative rotation of the phantom, translation of the Kinect, and different distances between the Kinect and the phantom (see Figure 1(a)).



(a) (b)

Fig. 1. a) Phantom disparity map; b) Patient disparity map

As in the previous methodology, we measured the nipple height and compared the results with the reference model. We obtained an average ratio of 1.14 with a standard deviation of 0.07.

The same scheme was applied to a database of 42 patients that underwent mastectomy and immediate reconstruction surgery (see Figure 1(b)). For all the of patients in the database, the difference of the height between each nipple was estimated using a ratio value. Afterwards, this ratio was compared to another ratio of the height of both nipples (distance between the medial projection of the nipple and the sternum measured with 2 rulers) obtained manually by the physician. A Mean Square Error of 0.06 was obtained between the ratios obtained with the two processes.

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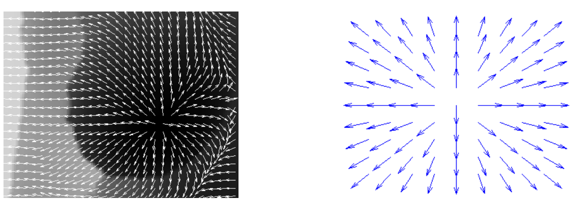
III. Simultaneous Detection of Breast Contour and Breast Peak Points

Researchers are now paying more attention to the context to aid visual recognition processes. We model the mutual context of *breast contour* and *breast peak* (the area in the breast that is closer to the camera, not necessarily the nipple) so that each can facilitate the recognition of the other [7]. The two tasks can benefit greatly from serving as context for each other, since they are non-trivial if performed independently. The algorithm was implemented with the following operations: 1) background segmentation; 2) breast peak candidates detection; 3) contour detection; 4) peak and breast contour decision.

Although the background should preferably be uniform for the acquisition process, sometimes it is cluttered. The presence of different objects at different depths, possibly at depths similar to the patient's, dismisses the application of simple thresholding methods, such as Otsu's [7]. To solve this problem we admit that the patient is in a somewhat central position in the image and it is likely the object' closer to the camera. A density image was defined by transforming the depth information on the XY plane to the XZ plane, where the value at position (x, z) represents the histogram of the column x, by counting along the Y direction [7].

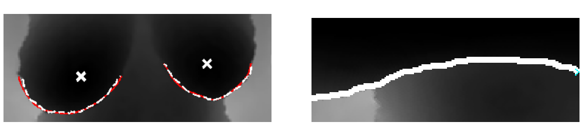
To model the breast peak point, a filter is used which evaluates the degree of divergence of the gradient vectors within its region of support from a pixel of interest (see Fig. 2). The similarity between the template (see Fig. 2(b)) and the image was assessed using the cross-correlation factor: $((f * g)[n] \overset{def}{=} \sum f^*[m]g[n+m])$, where f^* denotes the complex conjugate of f.



(a) (b)

Fig. 2. (a) Gradient vector field (5-px spacing); (b) Template vector field

The breast contour is modelled as a short path in a graph with nodes that correspond to the pixels in the image and the edges connecting neighbouring pixels. The weight function on the edges is defined so that short paths correspond to paths that maximise the gradient strength in the image along the path (see Fig. 3).



(a) (b)

Fig. 3. (a) Breast contour - ground truth (solid red line), detected (dashed white line); (b) Polar image and detected contour (white line).

The quality or probability of the join model $(Q(Cp) = \mu(\Delta C) \cdot \rho_p)$ for the co-occurrence of breast peak and breast contour will be proportional to the individual qualities of the two parts, where $\mu(\Delta C)$ is the mean gradient alongside the contour and ρ_p is the cross-correlation of the centre candidate.

The database now consists of 144 cases acquired during several sessions throughout an entire year. Manual ground truth annotation was performed for both breast peak position and breast contour definition. The breast peak point detection accuracy was measured using the Euclidean metric distance. We obtained a 'zero' miss-detection with an average error of 6.25 $\mathtt{px}$ and a standard deviation of 3.52.

The breast contour detection error using the join model for the co-occurrence of breast peak and breast contour was evaluated based on the Hausdorff and the average distances (Table I). The Hausdorff distance is defined as $h(A, B) = \max_{a \in A} \min_{b \in B} \|a - b\|$, where B represents the set of pixels of the ground truth, A is the segmented breast contour and $\|.\|$ is the Euclidean distance. The motivation for using this metric is that it represents the worst case scenario.

TABLE I

Breast contour detection error (in pixels).

	Right breast		Left breast	
	Mean	Hausdorff	Mean	Hausdorff
Average	1.89	5.55	1.79	5.24
Stdev	1.50	4.15	1.26	3.71

IV. Conclusion

The first objective of this work was to study and develop a simple 3D model of a female torso using low-cost solutions. The first approach was based on uncalibrated views using epipolar geometry. The results obtained were unsatisfactory but expected since we are working in a feature-less domain. On the contrary, the Kinect based method achieved very promising results principally when applied to real patients. It was possible to detect the volumetric differences of the breasts using the disparity map generated from the Kinect.

In the second part we presented the simultaneous detection of prominent points on the breast using depth-map data acquired with a Microsoft Kinect sensor. Breast peak points were found based on gradient vector field information associated with the convergence filter theory. Breast contour was found as the solution to the shortest-path problem is the graph theory framework, after conveniently modelling the image as a weighted graph. It was shown that depth-map images facilitate the automation of BCCT.core, keeping this software low-cost and easy to perform. The results obtained also indicate an excellent performance and robustness for a wide variety of patients. Since the Kinect resolution is 1.3mm/px, the average error corresponds to 2.39mm.

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