SURFACE SCANNING: AN APPLICATION TO MAMMARY SURGERY

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ABSTRACT

The possibility of mathematically describing the body surface represents a useful tool for several medical sectors, such as prosthetics or plastic surgery, and could improve diagnosis and objective evaluation of deformities and the follow-up of progressive diseases. The approach presented is based on the acquisition of a surface scanned by a laser beam. The 3-D coordinates of the spot generated on the surface by the laser beam are computed by an automatic image analyzer (ELITE system). Using at least two different views of the subject, the 3-D coordinates are obtained by stereophotogrammetry. A software package for graphic representation and extraction of linear superficial and volumetric features from the acquired surface has been developed and some preliminary results with mammary reconstruction are presented. A good mammary reconstruction after mastectomy must achieve two results. First, the reconstruction should follow the patients’ wishes and second, the reconstructed breast should be as similar as possible to the contralateral one (symmetry is the most important aesthetic parameter to be considered). To achieve these goals, a knowledge of breast volume, area, and shape features are essential for the surgeon. In such a context, this system could be a valuable tool in improving breast reconstructive surgery. © 1998 Society of Photo-Optical Instrumentation Engineers.

Keywords surface scanning; optoelectronic system; computer graphics; mammary surgery.

1 INTRODUCTION

The mathematical representation of body surfaces and their measurement is essential for a variety of applications, such as quantification of physical abnormalities, guiding corrective surgery and plastic surgery, manufacturing clothing, and the design of sport and protective equipment and prostheses. In the industrial field, surface acquisition applications are numerous. The mathematical description of prototypes is a key example. In all these fields, the object to be represented cannot be simply expressed as a set of elementary geometric shapes (planes, spherical surfaces, etc.). Only a physical model exists. In order to create a mathematical model of a physical object, one must deal with the problem of the acquisition of the 3-D coordinates of several key points with a suitable spatial resolution by means of a coordinate measurement system.¹

Some techniques, typically those using mechanical devices, are characterized by a low flexibility (it is difficult to analyze objects of very different sizes with the same apparatus) and interfere with the object to be described, modifying the measure.² Ultrasound presents problems with the low spatial resolution of the image.³ Opto-electronic systems offer some important advantages, since they do not require any contact with the object, are characterized by great flexibility, and are marked by high spatial and temporal resolution.

In this paper, an opto-electronic system for the acquisition of 3-D coordinates of surface landmarks is described. It uses a laser beam deflected onto the object to create “virtual” key points, the coordinates of which are computed and stored.

Two different scanning techniques are presented, together with their advantages and drawbacks: manual scanning in which the laser is directed by an operator all over the surface, and an automatic scanning system in which the laser beam is deflected by two mirrors mounted on galvanometers.

The practical application field examined here is plastic surgery and in particular problems related to mastectomy. A good reconstruction should try to satisfy the patient’s wishes and it should lead to symmetry. The problem is, therefore, the choice of a prosthesis that allows reconstruction of a breast as similar as possible to the other one. Up to now this choice has been made by manually measuring some key quantities, such as the inferior, superior, medial, and lateral borders of the breast and the distance between the nipples. The system described here is able to supply the surgeon not only with the quantities just listed but also with volume, area,
and shape measures, which are of fundamental importance for an accurate choice of the prosthesis and which cannot be manually obtained. This system will be compared with others that have been proposed in the past decade as research tools, but which did not find routine practical applications.

2 METHOD

The surface is sampled through the acquisition of the 3-D coordinates of one or more laser spots moved across the surface (manually or by a scanner). Figure 1 shows the acquisition system. It includes a laser beam(s), an optional scanning system, the sensors (CCD TV cameras), the system for the coordinate acquisition, and a computer for graphical processing of the 3-D data. Each part of the system is described in the following subsections.

2.1 LASER AND SCANNING SYSTEM

Two different approaches have been tested for surface scanning. In the first, the laser beam is directed manually over the surface by an operator. The source is an array of semiconductor lasers of 5 mW power and a wavelength of 670 nm (a single beam can be used as well). This type of scanning is useful for surfaces that are characterized by high spatial frequency content, such as the breast or the face. In this way it is possible to increase the sampling rate in regions with a greater curvature. A second method consists of an automatic scanning system in which a 5-mW He:Ne laser is deflected by two mirrors mounted on galvanometers. With this second type of scanning, the sampling of the surface is more regular.

It is important to note that the laser beam cross section should be as round as possible (diameter between 5 and 10 mm) to suit the requirements of the acquisition system. In addition, the laser has to be powerful enough to create a high contrast between the spot and the background, but at the same time it must not be so powerful as to injure either patient or operator. A solution has been found by using the 5-mW laser and having both patient and operator wear protective eyeglasses.

For the application presented here, the manual scanning procedure was chosen for two reasons. First, as mentioned, the breast is characterized by high spatial frequency content. Second, while the automatic scanner allows more accurate surface reconstruction, it is placed in front of the subject in a fixed position, making it impossible to detect the lateral parts of the breast. These are of fundamental importance for an accurate reconstruction of the breast shape (Figure 2). An increase in the number of scanners needed to cover lateral surfaces would increase the cost and the complexity of the whole system and reduce its flexibility.
Regarding respiration movements, data acquisition was not synchronized with breathing, first because every breath is not identical and second because if there are 12 breaths in 1 min on the average, it would take too long to acquire at least 3000 points. The error resulting from using a manual scanning procedure that is randomly distributed all over the surface has been calculated and is not significant. In fact, using the ELITE system, chest wall displacement has been computed during normal breathing (tidal volume). The average displacement is less than 2 mm, which, thanks to its random nature, can be greatly reduced by spatial filtering.

2.2 ELITE SYSTEM

The innovative feature of the ELITE system is the marker detection hardware, which utilizes the shape and size of the markers rather than only their brightness. This characteristic makes the system easy to use compared with others, even in sunlight, and is the reason for ELITE’s very high measurement accuracy. The architecture of the system is hierarchically organized on two levels. The lower or first level includes the interface to the environment (ITE) and the fast processor for shape recognition (FPSR). The higher or second level is implemented on a personal computer (IBM AT-compatible with 386, 486 or Pentium processors).

2.2.1 First Level

The ITE normally includes passive markers of dimensions selected according to the field of view (about 5 mm on a 2-m field of view). These are usually composed of a thin film of retroreflective paper on plastic hemispheres. To acquire a surface with great accuracy, it is necessary to sample a large number of points over the surface. It is therefore impossible to use traditional markers: it would take too long to apply them to the surface and the number of samples would be too limited. For this reason, passive markers are replaced by a laser beam; the reflection/scattering of the laser on the body is recognized by the system as a marker. By pointing the beam, the entire surface can be explored, and, assuming that the surface is stationary, all the collected coordinates are used to mathematically describe the surface. The TV cameras (solid-state CCDs that allow the best definition of the images) with a sampling rate of 100 Hz are also part of the ITE.

The second block of the first level, the FPSR, constitutes the core of the system and performs the recognition of the markers and the computation of their coordinates. The FPSR computes in real time a two-dimensional cross correlation between the incoming digitized signal and a reference mask, and drives the ITE with synchronization signals. The mask is a 6×6-pixel matrix and is designed to achieve a high correlation with the marker shape and a low one with the background.

Fig. 2 The surface acquired by (a) the manual scanning procedure and (b) by the automatic one.
After correlation, the first level sends to the computer the 2-D coordinates of the over-threshold pixels as recorded during the acquisition of the subject.

2.2.2 Second Level

The second level performs the high-level processing: 2-D calibration (camera calibration), 3-D intersection, and further processing, such as filtering, computing derivatives, and modeling. Between the first and the second level (albeit software implemented in the computer), a further step is carried out. By using a coordinate enhancement algorithm, taking into account the cross-correlation function, the 2-D resolution is increased to 1/65,000 of the field of view. This is achieved by computing the center of gravity \((x_c, y_c)\) of the over-threshold pixels (of coordinates \(x_{ij}\) and \(y_{ij}\)) belonging to the same marker weighted by the cross-correlation value \(R_{ij}\) as follows:

\[
x_c = \frac{\sum_{i,j} x_{ij} R_{ij}}{\sum_{i,j} R_{ij}} \quad \text{and} \quad y_c = \frac{\sum_{i,j} y_{ij} R_{ij}}{\sum_{i,j} R_{ij}}.
\]

This processing relies on the fact that the closer the pixel is to the true marker center, the higher the value of the cross-correlation function (Figure 3).

**System Calibration.** The system calibration consists of two steps required to achieve 3-D reconstruction (space intersection): camera calibration and space resection (location of cameras in space). Accuracy in this step is very important because it influences the subsequent processing of the acquired data.

The collinearity equations represent a mathematical model of the cameras that relates the 2-D target coordinates of marker projection, the 3-D coordinates of the marker in the space, and the stereophotogrammetric parameters (the six spatial camera coordinates and their three internal parameters).\(^5\)

\[
x - x_0 = -c \frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}
\]

\[
y - y_0 = -c \frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}.
\]

where

\(X_0, Y_0, Z_0=\) TV camera location (3-D coordinates of the perspective center);

\(m_{ij}\) = nine director cosines, which are functions of the camera rotation angles with respect to an absolute reference system: \(\Omega, \Phi, K\) (pitch, yaw, roll);

\(x_0, y_0=\) TV camera principal point coordinates (intersection of optical axis and image plane);

\(c=\) focal length;

\(X, Y, Z=\) 3-D coordinates of the surveyed point; and

\(x, y=\) 2-D target coordinates of its projection.

\(X_0, Y_0, Z_0, \Omega, \Phi,\) and \(K\) are external geometrical parameters and \(x_0, y_0\) are inner parameters.

In a real situation, we must deal with the quantization stochastic error introduced by the measuring system and optical distortions (systematic error). In order to determine the geometrical parameters in Eqs. (2), our approach to space resection is based on the classical iterative least-squares estimation extended to the inner parameters, which allows the maximum freedom in positioning and setting the TV cameras. By surveying a set of points of known coordinates (control points of coordinates \(X, Y, Z\)), it is possible to write the pair of Eqs. (2a) and (2b) for each of them. All these \(2N\) equations (with \(N\) equal to the number of control points) can be arranged in a nonlinear system, which can be solved after a linearization around a suitable starting point. Each pair of equations will have the following form:

\[
f_1(X_0, Y_0, Z_0, \omega, \varphi, \kappa, x_0, y_0, c) = 0 \quad (3a)
\]

\[
f_2(X_0, Y_0, Z_0, \omega, \varphi, \kappa, x_0, y_0, c) = 0. \quad (3b)
\]
The starting point \( P_i = (X_0, Y_0, Z_0, \omega, \varphi, \kappa, x_0, y_0, c^\bar{c}) \) is obtained by rough estimation from the experimental setup. The linearized equations have the form:

\[
f_1(P_i) + \frac{\partial f_1}{\partial X_0}|_{P_i} \Delta X_0 + \frac{\partial f_1}{\partial Y_0}|_{P_i} \Delta Y_0 + \frac{\partial f_1}{\partial Z_0}|_{P_i} \Delta Z_0 + \frac{\partial f_1}{\partial \omega}|_{P_i} \Delta \omega + \frac{\partial f_1}{\partial \varphi}|_{P_i} \Delta \varphi + \frac{\partial f_1}{\partial \kappa}|_{P_i} \Delta \kappa + \frac{\partial f_1}{\partial x_0}|_{P_i} \Delta x_0 + \frac{\partial f_1}{\partial y_0}|_{P_i} \Delta y_0 + \frac{\partial f_1}{\partial c}|_{P_i} \Delta c = 0
\]

(4a)

\[
f_2(P_i) + \frac{\partial f_2}{\partial X_0}|_{P_i} \Delta X_0 + \frac{\partial f_2}{\partial Y_0}|_{P_i} \Delta Y_0 + \frac{\partial f_2}{\partial Z_0}|_{P_i} \Delta Z_0 + \frac{\partial f_2}{\partial \omega}|_{P_i} \Delta \omega + \frac{\partial f_2}{\partial \varphi}|_{P_i} \Delta \varphi + \frac{\partial f_2}{\partial \kappa}|_{P_i} \Delta \kappa + \frac{\partial f_2}{\partial x_0}|_{P_i} \Delta x_0 + \frac{\partial f_2}{\partial y_0}|_{P_i} \Delta y_0 + \frac{\partial f_2}{\partial c}|_{P_i} \Delta c = 0
\]

(4b)

where all the partial derivatives are computed in \( P_i \) (i.e., \( X_0 = \bar{X}_0, Y_0 = \bar{Y}_0, \ldots, c = \bar{c} \)). These form a \( 2N \) linear equation system in nine unknowns. The equations can be solved by a least-squares technique, leading to a solution vector \( \Delta P_i = (\Delta X_0, \Delta Y_0, \Delta Z_0, \Delta \omega, \Delta \varphi, \Delta \kappa, \Delta x_0, \Delta y_0, \Delta c) \). The new starting point is computed as \( P_{i+1} = P_i + \Delta P_i \). The procedure is repeated until \( \Delta P_i \) is lower than a preset threshold. In order to obtain the number of control points required (at least five not lying on a plane), without having to spend a lot of time in computing their 3-D coordinates, the control points have been located on a plane grid, which is shifted according to reference locations placed on the floor. Very precise measurements are required only once, when the markers are put on the grid and the references on the floor are located, so every time that the system setup has to be changed, little time is required to calibrate it.

The parameters for the correction of the optical distortion errors (the image of a square put in front of the camera appears as a curvilinear quadrilateral), are determined with the acquisition of a grid of markers located on a plane that is parallel to the sensor and at such a distance as to fill it. The coefficients of suitable quadratic functions are computed from the deformation of the meshes of the grid. These functions applied to the points of each mesh compensate for the deformation.

The corrected (undistorted) coordinates \( x_u, y_u \) are obtained by the following equations:

\[
x_u = a_{xi}x + b_{yi}y + c_{xi}x^2 + d_{yi}xy + e_{xi}y^2 + f_{xi}
\]

(5a)

Parameters \( a_{xi}, b_{yi}, c_{xi}, d_{yi}, e_{xi}, f_{xi}, a_{yi}, b_{yi}, c_{yi}, d_{yi}, e_{yi}, f_{yi} \), and \( f_{yi} \) are computed, for each mesh \( i \), by a transformation that transforms the distorted vertices \( (V_{ji}, j = 1,2,3,4) \) in the reference undistorted ones \( (V_{uj}, j = 1,2,3,4) \), transforming the straight lines joining two vertices into straight lines and inner and external points with respect to these lines, again in internal and external points (Figure 4). This type of calibration can be referred to as virtual rather than physical; in fact, the distance between the grid and the camera, the grid dimension and the focal length, are not known. The coordinates are expressed in pixels and not in target physical units.

Once the stereophotogrammetric parameters have been estimated, the space intersection can be carried out. The two straight lines conveyed through the cameras\(^1\) perspective centers \( (c_i) \) and 2-D image projections\(^\circ\) \( (x_i, y_i) \) are considered \( (r \) and \( s \) in Figure 5); the coordinates of the middle point of the minimum distance segment between the lines

\[
y_u = a_{yi}x + b_{yi}y + c_{yi}x^2 + d_{yi}xy + e_{yi}y^2 + f_{yi}.
\]

(5b)
are assumed to be the coordinates of the reconstructed point \((X,Y,Z)\) (Figure 5). The director cosines of \(r\) and \(s\) are computed by the coordinates of the projected point \(x_i, y_i,\) and the focal length \(c_i\) as follows:

\[
I_1' = \frac{x_i - x_{0i}}{\sqrt{(x_i - x_{0i})^2 + (y_i - y_{0i})^2 + c_i^2}} \tag{6a}
\]

\[
I_2' = \frac{y_i - y_{0i}}{\sqrt{(x_i - x_{0i})^2 + (y_i - y_{0i})^2 + c_i^2}} \tag{6b}
\]

\[
I_3' = \frac{c_i}{\sqrt{(x_i - x_{0i})^2 + (y_i - y_{0i})^2 + c_i^2}} \tag{6c}
\]

\[
|I_1'I_2'I_3'|^2 = M_i |I_1'I_2'I_3'|^2, \tag{6d}
\]

where \(M_i\) is the rotation matrix obtained from the angles \(\omega_i, \varphi_i, \kappa_i.\) Since \(r\) and \(s,\) respectively, pass through \(C_1\) of coordinates \(X_{01}, Y_{01}, Z_{01}\) and \(C_2\) of coordinates \(X_{02}, Y_{02}, Z_{02}\), it is straightforward to write their equations and to find the segment of minimum distance joining them.

The local accuracy of the system has been evaluated and the maximum error found with respect to the true value was 1/24,000 of the diagonal \(^{10}\) of the calibrated volume.

The last part of the system, the data processing, will be described after the experimental setup.

### 2.3 EXPERIMENTAL SETUP

As sketched in Figure 1, in the experiments four TV cameras were placed in front of a sitting subject. One camera pair was arranged vertically on the right side, the other on the left side, in order to allow good visibility of the chest surface by at least two cameras. The surface was scanned by using the manual approach described earlier. The time required to explore the surface is an important parameter in the definition of the experimental setup and it is particularly critical because of chest movement due to breathing. Within 30 s, using three lasers and a 100-Hz sampling rate, 9000 points were acquired.

### 2.4. DATA PROCESSING

The software for graphic processing is implemented on a Silicon Graphics workstation. It provides for spatial ordering of the samples, surface modeling, filtering, and representation.

#### 2.4.1 Ordering

If the automatic scanner were used, the spatial ordering procedure would have been made easier by the organization of the samples acquired as a grid of rows and columns. Using manual scanning, the ordering procedure is more difficult. Two indices \((m,n)\) were assigned to each sample of coordinates \(x, y, z\), depending on spatial location of the sample.

Two types of ordering procedures have been developed: the first, Cartesian ordering, is useful for surfaces that can be coarsely approximated to a plane; the second, cylindrical ordering, is used for surfaces that can be coarsely assimilated to a cylinder (the spherical order is straightforward).

In Cartesian ordering, two perpendicular sheaves of parallel planes that intersect the surface have to be defined. To determine the direction of these sheaves, the regression plane has to be computed. This is the plane for which the square sum of the distance from the data points is minimum. Both sheaves are perpendicular to the regression plane. In that way, each point is held in one cell limited by two orthogonal pairs of parallel planes. If more than one point is held in the same cell, the algorithm computes the arithmetic mean of the points’ coordinates. The planes forming the two bundles are numbered in increasing order; therefore the two indices \(m\) and \(n\) are uniquely determined [Figure 6].
The distance between planes, which characterizes the ordering step, may be chosen by the operator or may be automatically set.

In the cylindrical ordering for each point of coordinates \( x, y, \) and \( z, \) the cylindrical coordinates (elevation \( \sigma, \) declination \( \Theta \) and modulus \( \rho \)) have been computed.

\[
\Theta = \tan^{-1}(x/z) \quad \rho = \sqrt{x^2 + y^2 + z^2} \quad \sigma = y.
\] (7)

The surface is sectioned by two sheaves of planes: the first is a proper one and its support is the \( y \) axis; the second one is an improper one and it is parallel to the \( xz \) plane. The \( \Theta \) and the \( y \) coordinates have been quantized [Figure 6(b)]. The quantization step may be chosen by the operator or automatically set. In this case, the points will be bounded by a cylindrical segment (a pie-slice-shaped sector). Again, if more than one point is held in the same cell, the algorithm computes the arithmetic mean of the points’ coordinates.

### 2.4.2 Filtering

A two-dimensional low-pass filtering has been implemented to minimize the effects of quantization and breathing-induced errors. The expression of the filter is

\[
g(n,m,i) = \frac{1}{\sum_{k=-2}^{2} \sum_{h=-2}^{2} a(h,k)} \sum_{k=-2}^{2} \sum_{h=-2}^{2} a(h,k) f(n-h,m-k,i),
\] (8)

where

\[
g(n,m,i) = \text{the } i^\text{th} \text{ coordinate of the filtered point } (i=1...3, \text{ for } x, y, \text{ and } z) \text{ and } m \text{ and } n \text{ are the grid indices cited above;}
\]

\[
a(h,k) = \text{the kernel; ad}
\]

\[
f(n-h,m-k,i) = \text{is the value of the } i^\text{th} \text{ coordinate of the point } n-h, m-k.
\]

The kernel is sampled in a cone centered on \( f(n,m,i) \) and with a base of radius equal to the mean distance between \( f(n,m,i) \) and its sixteen neighborhoods \( f(n \pm 2, m \pm 2, i) \).

### 2.4.3 Surface Modeling

After the ordering and the filtering, the surface was modeled as a triangular-faced polyhedron. The vertices of the triangles were set on the acquired samples. A pseudonormal vector was obtained from an average of the normals of the triangles having as a vertex the point being considered. The pseudonormal vectors approximate the normal ones as more accurately as the sampling is dense. Having estimated the pseudonormal vectors in each triangle vertex, it is possible to use rendering techniques, such as Gouraud, to obtain a realistic shading of the surface. The graphics hardware on Silicon Graphics rapidly shades the triangles, and software libraries allow the definition of lighting models (positions and colors of lights, surface properties, etc.).

### 2.4.4 Feature Extraction

Further data processing was implemented to obtain information on linear, superficial, and volumetric measures. These measures make it possible to choose a prosthesis that better fits the patient’s characteristics. Until now, this choice was based on manual measurements alone.

The first type of measure of clinical interest is the linear one: it is possible to compute distances between points belonging to the surface and lengths on the surface topography. The jugular–nipple distance, which indicates differences in nipple height, the distance between the nipples, and the width of the breast base (corresponding to the mammary fold) are some of the parameters that must be considered during the reconstruction operation. As for the length on the surface topography, the operator must choose the starting points \( (P_n \text{ and } P_m) \) and the algorithm interpolates the intermediate points by an iterative procedure. The next point \( (P_{n+1}) \), chosen among the eight neighborhoods of \( P_n \), is the one that minimizes the vector product of the unit vectors of the straight line joining \( P_n \) and \( P_m \) and of the straight line joining \( P_n \) and \( P_{n+1} \) (Figure 7). The iteration is performed by updating \( P_n \) with \( P_{n+1} \).

Some diameters are useful to the surgeon: the first one is measured 5 cm under the second rib from the sternum and the lateral profile of the breast; the second one, named equatorial, passes through the nipple; and the third one is measured 3 cm under the nipple. Another option defines a region of interest on the surface, in this case the region of the breast. It is possible to compute the area...
of this region as the sum of the areas of the triangles corresponding to the patches of the surface.

The volume under the delimited region has been computed as the sum of tetrahedral volumes. First it is necessary to determine the points belonging to the costal plane. These are defined in two different ways. The first estimates the center of gravity of the points belonging to the contour of the region. Each tetrahedron that forms the volume is delimited by three points belonging to the delimited region and the vertex is the center of gravity.

The second method approximates the costal plane with the regression plane of the contour points: four points belonging to the surface and their projection on the regression plane form a seven-faced polyhedron that can be divided into six tetrahedra. It is also possible to determine the distance between the points belonging to the surface and the costal plane (in the figure the measures refer to the segments labeled from top to bottom).

3 RESULTS AND DISCUSSION

Figure 10 shows the effect of filtering on the breast shape. In Figure 10(a), the effects of quantization noise and of breathing artifacts are evident; in Figure 10(b) they have been greatly reduced while preserving the shape characteristics.

The more innovative capability of this method is volume computation, which currently is entrusted to the surgeons' expertise. The accuracy of the volume estimate has been tested on 7 female subjects. As described earlier, the volume was computed by using two different methods. The best estimate was obtained by computing the volume with respect to the regression plane, which produced an average error of 4.3%. Using the faceted costal plane, an average error of 5.5% was found. The reference volume was calculated by measuring the volume of the water displaced in a graduated vessel (accuracy of 10 ml) into which the breast was immersed.

Linear measures have been estimated on subjects by using traditional (manual) measuring techniques. For the segment measure, the error is 2% on average; measurement of surface topography has an average error of 5%. These errors do not reflect badly on our measurement system because traditional methods are also prone to errors, the measurements were taken at different times and include variation due to expansion of the rib cage.

This method has some advantages with respect to others proposed for evaluating volumes in mammary reconstruction. A device described by Cutting, McCarthy, and Kanron11 (Echo scanner manufactured by Cyberware Laboratories) is not as flexible and it is cumbersome. A low-energy laser light beam is passed through a cylindrical lens so
that a vertical line is projected on the surface. A video camera records the image of this line from a fixed angle to the light source. The mechanical relationship between camera and projector is critical for accurate data but no data on accuracy were given at all.

Loughry et al. described a measurement technique that used close-range stereophotogrammetry to characterize the shape of the breast. Wide-angle stereometric cameras were used for precise metric-quality imagery and combined with an optical projector. Again, no data were provided about accuracy or calibration burden.

Bathia et al. computed the 3-D surface changes that accompany facial surgical procedures. An optical 3-D scanner with 360-deg surface coverage of the subject’s head and a subsecond data acquisition time was used. The scanner used six pairs of white light pattern projectors and digital TV cameras. The accuracy was poor: for an injected volume of 2 cc, three different measurements were obtained: 1.7, 2.9, and 2.7 cc.

None of these approaches have entered clinical practice, perhaps because of their low accuracy, difficulty of use, and high cost. The approach presented in this paper has some potential with respect to the first two characteristics. However, the cost is still high and could be justified only by an intensive use of the system.

4 CONCLUSIONS

A new method has been presented for measuring distances, areas, and volumes of the breast in plastic surgery. The accuracy of the system is very high and tests performed have confirmed it, although the reference taken was not reliable enough for a true comparison. This method could represent a starting point for the design of new expanders and new prostheses. Up until now these industries have received inputs only from surgeons. As reconstruction techniques become more and more accurate and as patients become more and more demanding in term of symmetry, diversification of prosthetic will be necessary. This system could be a tool for a statistical analysis of breast shape and could provide a set of objective data for the design of a new type of prosthesis.

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