

DIGITAL REPRESENTATION OF BREAST GEOMETRY USING 3D SCANNING: APPLICATION TO INDIVIDUALIZED BRA DESIGN

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ABSTRACT

Accurate representation of breast geometry is essential for the development of well-fitting bras. Conventional bra sizing systems are typically based on bust and underbust circumference measurements, which are often insufficient to capture breast shape variability and asymmetry. Therefore, 3D body scanning represents an effective alternative method for acquiring detailed geometric data of the female torso. This study focuses on the identification of anatomical reference points and key parameters describing breast shape and volume. The obtained data enable the creation of simplified digital breast models that can subsequently be used in the bra design process. The results demonstrate the potential of 3D body scanning for more accurate representation and modeling of breast geometry and support the development of individualized bra designs.

KEYWORDS

3D Body Scanning, Breast Geometry, Digital Breast Modeling, Individualized Bra Design, Breast Asymmetry

1 INTRODUCTION

The accurate representation of human body geometry plays a crucial role in the development of well-fitting garments. If the goal is to design a breast model for personalized bra development that follows the natural geometry of the body as accurately as possible, it is essential to obtain high-quality geometric measurements. 3D body scanning can be used to acquire precise body geometry. In the design of standard ready-to-wear bras, the main parameters are the underbust circumference and the bust circumference. Nevertheless, these measurements alone are not sufficient to fully describe and

accurately represent breast geometry [Baidak 2023]. 3D scanning is a technique used to capture a physical object in three dimensions. A 3D scanner is a non-contact, non-destructive digital device that uses a laser to accurately capture the shape of a physical object in a computer-aided design (CAD) environment. The scanner generates a point cloud or a set of data points in a coordinate system that precisely describes the shape and size of the object [Haleem 2022]. This digital representation serves as a fundamental input for virtual prototyping and subsequent numerical simulations, a process already successfully validated in the development of other medical devices, such as 3D printed cranial orthoses [Marsalek 2019].

Scanners are generally classified into two categories: contact and contactless scanners. Contactless scanners function based on the principles of light reflection or transmission and are widely applied in 3D body scanning applications [Verykokuou 2023]. For human body scanning, the most used methods are passive stereo, structured light, and time-of-flight imaging [Bartol 2021]. Passive stereo uses multiple images captured from different viewpoints to reconstruct the 3D surface of an object based on the principle of triangulation [Bartol 2021]. Triangulation is a method used to determine the position of a point on a scanned object using the geometry of a triangle formed by the projector, the camera, and the observed point on the object [Geng 2011]. Structured light projects known light patterns onto the object and the scanned surface is reconstructed based on the deformation of these projected patterns. Time-of-flight operates by projecting modulated light onto an object, while the three-dimensional shape is obtained by measuring the time it takes for the light to travel to the object and back to the sensor [Bartol 2021].

Authors investigating the possibilities of human body scanning have performed it for example using the VectraXT system, in which the body is captured simultaneously by six cameras and the acquired images are subsequently processed into a 3D model. For the scanning process, 13 reference points were first defined on the subject's body [Dijkman 2024]. Body scanning can also be performed using a mobile phone with the EM3D application, where the phone is placed on a flat surface at waist height and the scanned subject gradually rotates by 360° with arms extended. The EM3D application uses 14 reference points [Baidak 2023]. The key points describing the geometry of the breast are illustrated in Fig. 1. These points represent the approximate positions of the nipple (N), the lateral mammary fold (LMF), the inframammary fold (IMF), and the medial mammary fold (MMF).

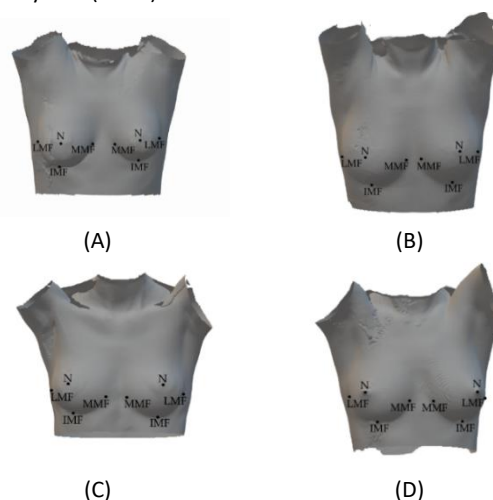


FIGURE 1 SCANNING POINTS IDENTIFIED ON THE TORSO OF EACH SUBJECT: (A) SUBJECT 1, (B) SUBJECT 2, (C) SUBJECT 3, (D) SUBJECT 4.

The measured parameters are significantly influenced by the subject; therefore, it is essential that the subject maintains a predefined and stable body posture throughout the scanning process. Due to individual anatomical differences and natural movements such as chest motion during breathing or slight changes in posture, these factors must be minimized and standardized to ensure accurate capture of body geometry. This aspect is also crucial for the reproducibility of the scanning procedure and for enabling reliable comparison between repeated scans of the same subject [Ernst 2014].

Although 3D scanning provides extensive possibilities for acquiring detailed geometric data, several limitations must be considered. Despite its ability to capture high-resolution surface information quickly and non-invasively, the quality and reliability of the resulting data depend on several technical and human-related factors.

Challenges and limitations of 3D scanning include accuracy limitations (for example lighting conditions or scanning distance), high cost for advanced 3D scanners and surface or material challenges (some 3D scanners face challenges when dealing with specific materials properties, such as high reflectiveness, transparency or dark surfaces) [Onyia 2025].

Despite these limitations, accurate representation of human body geometry is fundamental for applications such as the design of well-fitting bra. Studies suggest that around 80 % of women wear an incorrect bra size, mainly due to limitations in existing sizing systems, shape variability, and fitting methods. Custom-made bras may help overcome these issues by improving fit and reducing discomfort [Baidak 2023]. While often overlooked as a minor concern, inadequate bra fit can result in insufficient breast support, which has been linked to negative health outcomes such as poor posture, headaches, and back pain [Coltman 2017]. To design a bra that ensures proper breast support, it is necessary to understand the biomechanical behavior of the breast. Breast motion relative to the trunk can be described as a three-dimensional sinusoidal pattern [McGhee 2020]. During the design process, it is necessary to consider breast behavior, as it is affected by the mechanical properties of the tissue. The breast exhibits generally nonhomogeneous and anisotropic mechanical behavior. To address these complexities in bra design, it is beneficial to utilize lightweight flexible structures. Such patterns can effectively reduce the contact surface fraction while maintaining necessary support and breathability [Rybansky 2023, Marsalek 2021]. Higher breast tissue stiffness may indicate an elevated risk of breast cancer [Prokop 2022]. In this context, 3D body scans of female subjects wearing different bras and without a bra have been used to experimentally investigate the interaction between the breast and a bra. The analysis focused on pressure distribution along the shoulder strap, where the highest pressure occurs, with strap material significantly influencing the pressure magnitude [Sun 2021]. Finite element simulations of a sports bra confirmed that the highest pressure occurs on the shoulders, with values ranging from 0.67 to 1.87 kPa [Zhu 2020]. The pressure exerted by the bra underband in well-fitting bras ranged from 2.0 to 2.7 kPa, representing a comfortable range [Liu 2017]. These findings highlight the importance of considering mechanical properties, pressure distribution, and breast biomechanics in the design of comfortable and supportive bras.

Existing approaches primarily focus on data acquisition rather than on defining geometric parameters that can be directly applied in bra design and customization processes. Furthermore, breast asymmetry and individual shape variability are still insufficiently incorporated into conventional bra design

methodologies. Therefore, the aim of this study is to apply 3D body scanning to the analysis of breast geometry, identify key geometric reference points and parameters, and evaluate breast asymmetry. The study further assesses the potential of simplified digital breast models for supporting the design of well-fitting and individualized bras.

2 MATERIAL AND METHODS

This section outlines the materials and methods used in this study. It details the selection of subjects, the 3D body scanning system, and the scanning procedure, including the posture adopted during data acquisition. Furthermore, the subsequent processing of the acquired scans and the approach used for approximating breast geometry are described. This study should be considered a pilot study aimed primarily at testing the proposed methodology for digital breast geometry extraction from 3D scans.

2.1 Characteristics of Subjects

In 2025, four Caucasian women were asked to participate in the study. In one day, all subjects were scanned. Three subjects (Subject 1 to Subject 3) were hormonally active, and measurements were carried out between 2nd and 10th day after menstruation. Subject 4 was breastfeeding at the time. All subjects provided consent to the scanning procedure and to the subsequent use of the acquired scans. Subjects were selected to represent average body height, body weight and standard bra size according to conventional ready-to-wear classification to obtain a representative sample for the analysis. The mean patients' age range was 22.4±2.1 years (min. 19 years, Subject 1; max. 27 years, Subject 4) with the mean body weight of 59.8±2.1 kg (min. 58 kg, Subject 3; max. 62 kg, Subject 1). According to the conventional ready-to-wear bra sizing system, the subjects' bra sizes were 85B (Subject 1), 80B (Subject 2), 75B (Subject 3), and 75C (Subject 4). Informed consent for the use of clinical data was obtained from all subjects. The data were subsequently fully anonymized.

2.2 Used 3D Scanner and Its Technical specifications

All 3D chest scans were acquired using a Revopoint MIRACO 3D scanner (Revopoint 3D Technologies Inc., Shenzhen, China). It is a 3D scanner with an accuracy of up to 0.05 mm and a working distance ranging from 100 mm to 1000 mm. However, when interpreting these results, it is essential to account for the uncertainty of measurement, which varies significantly across different 3D scanning methods and the physical properties of the scanned objects [Kozior 2024]. It is equipped with infrared structured light and a 48 MP RGB camera, allowing geometric and color information to be captured. This scanner can be used for scanning both small and large objects and operate in single-shot and continuous scanning modes.

2.3 Preparation and 3D Scanning

For the scanning of the female chest, four subjects were selected to enable the analysis and verification of potential breast asymmetry based on the acquired 3D scans. Prior to the scanning process itself, a suitable location with adequate lighting conditions and sufficient space around the subject was selected to allow the subject to be circled at an appropriate distance, ensuring that the scanner-to-object distance remained within the recommended working distance, as illustrated in Fig. 2. To enable comparison, it is necessary to adopt at least a similar posture for all subjects. However, it is not possible to ensure a fully standardized position for all subjects [Ernst 2014]. Based on prior scanning experience, a posture with the arms raised and the shoulders in a natural position was selected to ensure

high-quality scanning of the chest area while minimizing breast deformation compared to the natural position (Fig. 2).

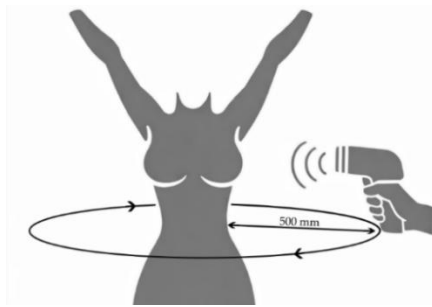


FIGURE 2 SCHEMATIC REPRESENTATION OF THE SCANNING PROCESS.

The subjects were instructed to remain as still as possible while maintaining natural breathing during the scanning process to minimize motion-related distortions of the scan. Subjects 1, 2, and 3 had their nipples and areolae covered with adhesive stickers intended for this purpose to maintain personal comfort, while Subject 4 did not require this. The scanning process for each subject took less than one minute.

Far Mode was used for scanning, as it provides sufficiently high-quality output while making the overall process faster. After the scans are acquired, the One-Tap Edit function is applied, which automatically performs point cloud fusion and generates a mesh. Although manual processing is also available, the One-Tap Edit function is sufficient for this application. As a final step, the scans are transferred to a computer for subsequent processing. The acquired scans are shown in Fig. 3.

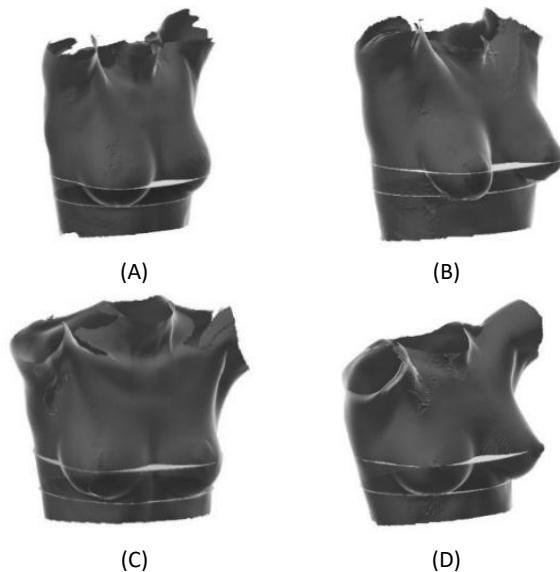


FIGURE 3 APPROXIMATE REPRESENTATION OF THE BUST AND UNDERBUST CIRCUMFERENCES OF EACH SUBJECT: (A) SUBJECT 1, (B) SUBJECT 2, (C) SUBJECT 3, (D) SUBJECT 4.

All acquired scans were subsequently processed using Autodesk Inventor Professional 2024 (Autodesk, Inc., San Francisco, California, USA). The mesh obtained from the scanning process is used to define reference planes for the approximation of the breasts according to the geometry of each subject. The breast geometry is first simplified to determine an approximate center point.

A reference plane passing through this point is then used to divide the breast into two halves. Additional planes are defined around this central plane to segment the breast shape according to its geometry. Where necessary, extra planes were introduced to define the boundary between the breast and

the chest. In each plane, the breast contour is outlined, and the individual profiles are connected to create a continuous 3D shape. Finally, any parts identified as belonging to the chest are removed, resulting in an approximate breast model. The generated 3D models contained 300 000 points for Subject 1, 300 000 points for Subject 2, 500 000 points for Subject 3, and 800 000 points for Subject 4, respectively.

3 RESULTS

The creation of approximate breast models is carried out primarily to demonstrate that the breasts of a single subject differ not only in geometry but also in size. The volume of each individual breast model is calculated, acquired volumes are presented in Table 1. From the obtained values it can be observed that the right breast is generally larger than the left. This is not the case for Subject 4, who was breastfeeding at the time the scan was acquired. Additionally, the percentage differences between the breast volumes were calculated, referenced to the volume of the larger breast. The calculated breast volume asymmetry ranged from 26.9 % to 40.8 %, with the largest asymmetry observed for Subject 1.

TABLE 1 APPROXIMATE BREAST MODEL VOLUMES.

Subject	Right breast volume [cm ³]	Left breast volume [cm ³]	Breast volume asymmetry [%]
1	336	199	40.8
2	424	310	26.9
3	265	183	30.9
4	270	380	29

The breast geometry is defined using scanning points, as shown in Fig. 1. These scanning landmarks can also provide a range of information about the breast geometry of individual subjects. The distances between the LMF and MMF points of the left and right breasts are reported for each subject in Table 2. The distances between these points were measured on the projected plane. Differences in these distances further indicate the presence of breast asymmetry. Additionally, the difference between the distances measured for the right and left breasts was calculated. The calculated differences ranged from 0.6 mm (for Subject 3) to 15.8 mm (for Subject 1). To better express the magnitude of asymmetry, the relative difference was also calculated as the symmetric percentage difference, defined as the absolute difference between the two measurements divided by their mean value and expressed as a percentage. The resulting relative differences ranged from 0.5 % to 14.3 %, indicating varying degrees of breast asymmetry among the subjects.

TABLE 2 APPROXIMATE DISTANCE OF LMF AND MMF POINTS.

Subject	Right breast distance [mm]	Left breast distance [mm]	Distance difference [mm]	Distance difference [%]
1	118.8	103.0	15.8	14.3
2	131.5	120.6	10.9	8.7
3	125.2	124.6	0.6	0.5
4	128.4	113.3	15.1	12.3

Table 3 summarizes the bust and underbust circumferences derived from the 3D scans and those measured before scanning using a 150 cm tailor’s measuring tape with 1 mm resolution (Prym Consumer Europe GmbH, Stolberg, Germany). The difference between measurements obtained by the two methods ranged from 0.1 to 3.6 cm, corresponding to a relative difference of approximately 0.1 to 4.3 %. The relative difference was calculated as the absolute difference between the 3D scan and manual measurement divided by the manual measurement and expressed as a percentage. For Subjects 2 and 4, the discrepancies between the 3D scan and the manual measurements were minimal (< 1 % in most cases), indicating good agreement between the two methods. In contrast, for Subjects 1 and 3, the differences between the recorded values reached up to 4.3 % for underbust and 4.0 % for bust circumference. Nevertheless, the relative error remained below 5 %, which is generally considered acceptable for anthropometric measurements.

Although an attempt was made to refine the identified measurements within the model in Autodesk Inventor Professional 2024, the adjustments were minimal and the results could not be aligned with the values obtained using tailor’s measuring tape. This discrepancy may be caused by differences in body posture or by the subject’s breathing phase during the measurement process (both during scanning and manual measurement). Based on available studies on chest expansion during inspiration, the average change in chest circumference is reported to be approximately 5.5 to 7.5 cm [Derasse 2021].

TABLE 3 APPROXIMATE BUST AND UNDERBUST CIRCUMFERENCES.

Subject		1	2	3	4
3D scans	Underbust [cm]	80.8	76.1	75.1	73.8
	Bust [cm]	92.6	87.6	88.2	86.4
Measuring	Underbust [cm]	79	76	72	73
	Bust [cm]	89	87	85	86
Difference	Underbust [cm]	1.8	0.1	3.1	0.8
	Underbust [%]	2.3	0.1	4.3	1.1
	Bust [cm]	3.6	0.6	3.2	0.4
	Bust [%]	4.0	0.7	3.7	0.5

The obtained results confirm the presence of breast asymmetry in all subjects. The calculated breast volume asymmetry ranged from 26.9 % to 40.8 %. This indicates a significant difference in breast size among the evaluated subjects. The differences between the distances of the LMF and MMF points ranged from 0.5 % to 14.3 %. These differences further confirm geometric asymmetry of the breasts. The comparison between circumferences derived from the 3D scans and circumferences obtained from measuring with tape showed generally good agreement for some subjects, but larger discrepancies were observed for others. These differences might be influenced by different factors such as body posture, breathing phase or human error during manual measurement with a tailor’s measuring tape.

4 DISCUSSION

The detected breast asymmetries indicate that the assumption of symmetry, on which ready-made bras are based, does not

fully reflect reality. Given that the differences in distances between the LMF and MMF points do not directly correspond to differences in breast volume, it is advisable to consider additional geometric parameters for a more comprehensive description of breast shape.

The advantage of using 3D scanning lies in its ability to capture detailed geometric data on breast shape, which cannot be obtained using conventional circumference measurements. The digital model allows for the analysis of basic dimensions, spatial geometry, asymmetry, and mass distribution, all of which are key for the design of personalized bras. The data obtained could thus inform the design of custom-made bras.

It is also important to acknowledge the limitations of this study. The accuracy of the scans can be affected by several factors, such as body posture during scanning (arm raised), breathing, or environmental conditions. Additional inaccuracies may be introduced during the subsequent processing of the scans.

Although these influencing factors were identified, their impact on the repeatability of the measurements and the overall measurement uncertainty was not quantitatively assessed. In particular, variations caused by posture, breathing, and operator-dependent factors may lead to deviations between repeated scans of the same subject. Therefore, future work should include a systematic and quantitative evaluation of repeatability and measurement uncertainty.

For these reasons, future research could focus on the development of standardized scanning procedures, the identification of key geometric parameters, and the design of a personalized bra design workflow. Such knowledge could contribute to increasing comfort and improving the overall fit of bras to individual anatomical characteristics.

Given the very small sample size (only four subjects), the findings should be considered preliminary and interpreted with caution; therefore, future studies should include a larger number of subjects with a broader age range to improve the generalizability of the results.

5 CONCLUSION

This study demonstrated the effectiveness of 3D scanning for analyzing breast geometry and asymmetry, which was demonstrated both in terms of breast volume (on average 31.9 %) and geometric parameters (distances between the LMF and MMF points). However, the sample size is limited, which restricts the generalizability of the findings. The results highlight significant differences that are typically not considered in the mass production of bras, which generally assumes breast symmetry. These findings support the need for individualized bra design approaches based on digital body geometry.

The percentage-based analysis further confirmed that breast asymmetry ranged from approximately 26.9 % to 40.8 %, while the differences between 3D scanning and manual measurements remained below 5 % in most cases, indicating acceptable agreement between the methods.

A comparison of 3D scans with manual measurements revealed deviations in some cases, likely caused by variations in body posture, breathing phase during measurement, or human error. Although breast models derived from 3D scans may contain certain approximation errors, the method proved to be highly valuable for obtaining detailed data that cannot be acquired using conventional measurement techniques.

Therefore, 3D scanning provides an objective and reliable tool for designing bras that are better adapted to individual anatomical characteristics.

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