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Study on Breast Shape Changing in Various Body Positions Using Depth Camera

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Abstract- **In this research, 3D scan based on depth camera is used to measure, and analyze the breast shape changes in various body positions. 3D breast shapes of women are extracted from data obtained from a depth camera. A measurement method is developed based on cross section lines to get the 2D breast pattern. 3D breast shape and 2D breast patterns in five body positions are determined and compared to each other. To calculate the difference, 3D breast form and volume, also area and form of 2D breast pattern are measured. The results show that the breast form and volume in various body positions is not the same. Women have the highest volume and area of breast in the position 'posture of 45 elbow-bend and arms to the back' subsequent the position 'posture of 45 elbow-bend and arms to the front', 'lower arm beside the body ' and 'raise arm overhead and holding on the brow', respectively. Also in the position 'holding arm overhead' the lowest volume of breast for women is observed. The difference of breast volume in the largest and smallest shape is about 23%. The combination of measuring breast volume and form at the same time can provide effective information for bra cup design.**

Keywords: **breast shape, 3D scan, depth camera, body position, kinect**

I. INTRODUCTION

Garment fit on a body model is an important factor for retailers, manufacturers, and consumers in the clothing industry. The brassiere (bra) is one of the closest fitting garments worn by women, designed to support, and mold the female breast tissue. A correctly fitting and supporting bra is essential to good health. The factors affecting the quality of bra fit include size and shape of body and breast [1], the pattern dimension, the material modulus in different directions [2], and the pressure applied on the skin [3].

However, surveys showed that 70% to 80% of women are wearing the wrong-sized bra [4-6]. And most of fitting failures is caused by cup wrong. The reason for these failures might be that the female breast shape is one of the most complex configurations of the body. Various people have different breast forms. Even two breasts of one person are not the same, because the breast is a pliable object.

The garment fitting refers to how a garment confirms to the three dimensional human body shape. Bra fitting depends on the correct assessment of person body. Therefore, three-dimensional body models are essential for well-fitted bra design. 3D models of human body had been investigated by many researchers. These researches deal with the part of human hand [7], leg [8], facial animation [9], human organ reconstruction [10], and whole-body model [11]. Moreover, there was considerable interest in modeling human body in the clothing industry [12,13]. However, breast that is a flexible part in body is considerable by researchers in garment fitting.

Hardaker and Fozzard in 1997 [14], investigated the methods that used the professional bra designer. Their results showed that the bra design process is unique for each bra type and it is dependent on its design attributes and fabric characteristics. Wang and Zhang in 2007 [15], proposed a method for predicting the amount of personalized bra cup dart in the 3D virtual environment for design of fitted brassiere pattern. Their results showed

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that personalized female breast shapes and various forms of breast made by different bras could be interactively simulated. Yick *et al.* in 2008 [16], made the virtual master molds based on the 3D surfaces of the investigated bra. They developed a bra cup design from the master mold, either by drawing the style lines in the virtual environment or using scissors to cut the molded plastic shot along the desired style lines. Kim *et al.* in 2010 [17] developed the process of making a final 2D pattern from 3D scanned surface. 2D pattern was constructed using non-extensible fabric and the accuracy of the pattern was investigated by shell-shell deviation of original 3D nude and clothed image. Area of each pattern block and corresponding 3D surface block was compared. Yick *et al.* in 2011 [18] obtained the 3D geometric shape of foam cups from 6 types of PU foam materials at various molding conditions and the degree of shape conformity was calculated. Also they investigated the effects of molding temperatures and dwell time on cup shape conformity on bra cup molding. White and Scurr in 2012 [19] investigated use of professional bra fitting criteria to establish best-fit. A comparison was made between women's bra size as measured by the traditional bra fitting method with their recommended bra size based on professional bra fitting criteria. Significant differences were observed between traditional and best-fit cup. Chen and Wang in 2015 [20] proposed a breast volume measuring method by mesh projection based on three-dimensional (3D) data derived from a 3D scanner. Also, they developed an evaluation procedure to decide breast boundary. Breast volumes derived from mesh projection method were compared to the statistical results for validation. Gavor and Danquah in 2016 [21] studied brassieres fitting and the factors influencing the choosing of brassieres by women. Their results indicated that the most influential factors in brassiere selection are size, style, color and brand. Wu *et al.* in 2017 [22] simulated the bra cup molding process with the use of material properties. They investigated the material parameters and head cone shapes with geometric parameters.

Coltman *et al.* in 2017 [23] investigated whether different components of encapsulation-style bras contribute to incorrect bra fit among women and whether this was influenced by breast size. The fit of five key bra components of 309 women's own encapsulation bras was assessed using professional bra fit criteria among four breast size categories. Abtew *et al.* in 2018 [24] introduced the 3D design process using the 3D female body mannequin for general corsetry problem. 3D bra pattern was developed using the adaptive volume to validate the specific obtained volume. The flattened 2D patterns from the 3D model were also compared to the corresponding traditional 2D pattern. Pei *et al.* in 2019 [25] investigated the effect of structured bras and soft bras on breast shape. Participants were scanned in three conditions: wearing a provided structured bra, a provided soft bra, and nude. The impact of the bras on breast asymmetry was quantitatively studied. The change in breast shape and position from the nude condition to the condition when shaped by the bras was also explored.

Bra fitting depended on accurate assessment of body. Therefore, constructing a 3D breast shape which precisely described breast size and shape is essential for well-fitted bra designing. The objective of this study is to extract a 3D breast shape by using depth camera. By considering that the breast is very flexible and its shape varies in different positions, 3D breast shapes for each person in various body positions are extracted. Then by using 3D breast, 2D breast pattern is determined based on proposed method. 3D breast shape and 2D breast pattern in different body positions and two breast positions (right and left) are compared to each other to identify the significant differences of breast shape in various body positions. For this comparison, volume of 3D breast, and area of 2D breast pattern are calculated and compared together.

3D scan technology has been widely used in textile industry to capture the 3D geometric shapes of clothes and the human body. As the recent improvement in scanning technology, commercial depth cameras such as Microsoft Kinect are becoming widely considered. It is composed of two cameras, namely, an RGB and an infrared (IR) camera. The RGB camera captures color information, while the IR camera captures depth information.

Compared with conventional 3D scanners, Kinect is compact, low-price, and as easy to use as a video camera, which can be acquired by general users. Some researchers used Kinect for capturing 3D body models. Conducted research shows that precision of data derived from Kinect camera is acceptable and 3D model of body can be extracted from this camera [26-31]. Therefore, in our study, Microsoft Kinect is used to capture the 3D breast shape in different positions.

II. EXPERIMENTAL

A. Methodology

A.1. Study Participants

Ten female subjects participated in this study. They were 20-40 years old with body shapes (mean height=160.8± 5.4 cm, range 150-170 cm; mean body mass=54.7±6.9 kg, range 49-75 kg). 3D shape of their breast is obtained in five different body positions that is a) Holding arm over head, b) Lower arm beside the body, c) Posture of 45° elbow-bend and arms to the back, d) Posture of 45° elbow-bend and arms to the front, and e) Raise arm over head and holding on the brow. These five positions are illustrated in Fig. 1.

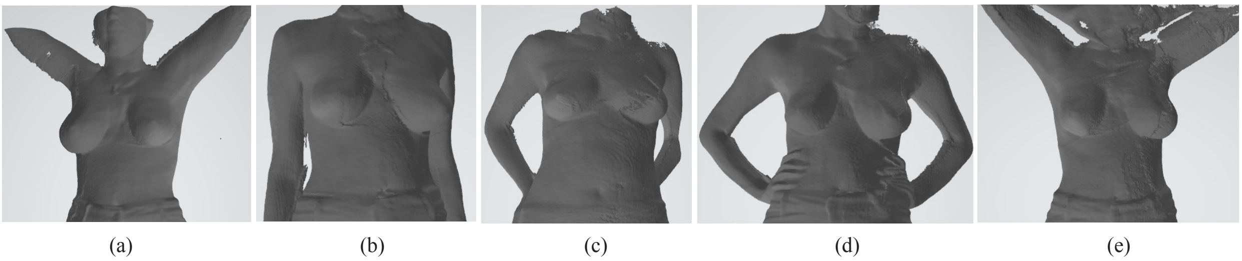


Fig. 1. Five body positions used in the study: (a) holding arm over head, (b) lower arm beside the body, (c) posture of 45° elbow-bend and arms to the back, (d) Posture of 45° elbow-bend and arms to the front, and (e) and raise arm over head and holding on the brow.

B. System Setup

The setup of scanning system is illustrated in Fig. 2. Microsoft Kinect V2 is used to scan the upper part of body. It consists of an RGB camera that takes color images and an IR projector. The IR projector projects an invisible infrared ray to an object and the IR cameras read it to measure the stereoscopic curvature of the object to acquire the depth information. Then, the depth information is combined with the RGB color image to reconstruct the final 3D model of the object.

The scanning of the upper part of body model is done by a single camera. While scanning, the person stands on the turntable. It takes 30 s to scan the whole body while the turntable rotates a round. As seen from the Fig. 2, the Kinect is set about 1 m away from the body.

C. Measurement Processes

In this study, a total of 50 breast shapes are measured from the 3D scanner system. For each woman, five breast shapes are obtained according to the various body positions that are shown in Fig. 1.

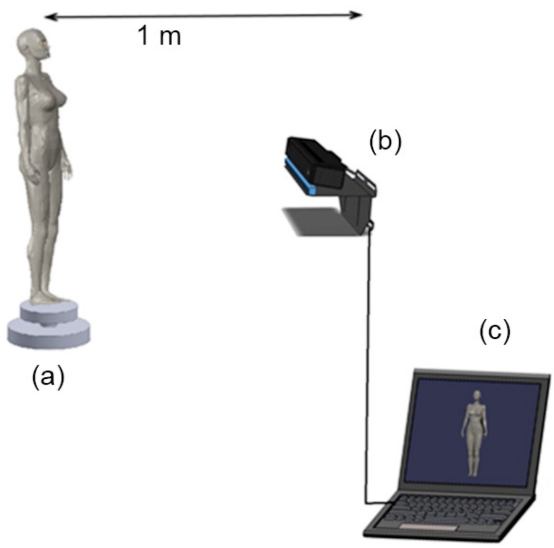


Fig. 2. Schematic of scanning system: (a) turntable, (b) Kinect sensor, and (c) laptop.

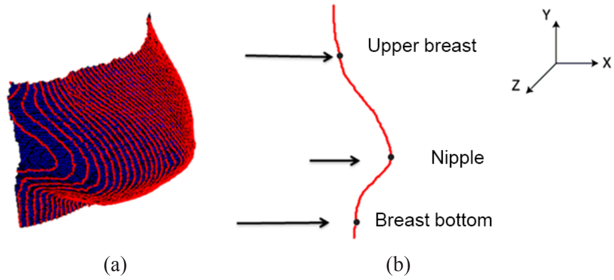


Fig. 3. (a) 3D shape of breast with contour lines and (b) feature points are found using method proposed by Sul and Kang [32].

D. Data Analysis

The purpose of this study is to investigate the breast shape changes in various body positions. In this regard, a method is used that can be described as follows:

The first step is to extract the 3D breast shape from 3D body shape. So, the parts of around the breast (upper part of breast to breast bottom) should be identified correctly. These parts are determined using body feature points detection. In order to detect the feature point locations among different human bodies, curvature method that is proposed by Sul and Kang in 2010 [32] is used as a criterion for detecting the features points. Some features, such as female breast and breast bottom have big curvature changes. To find the maximal curvature point, parallel plans to the plane x-y in various heights are placed. Then, intersection points of planes and mesh triangles are achieved in each height. After that, by using achieved points, contour lines are extracted (Fig. 3). To remove the effect of point density to the curvature value, cubic spline interpolation is done and

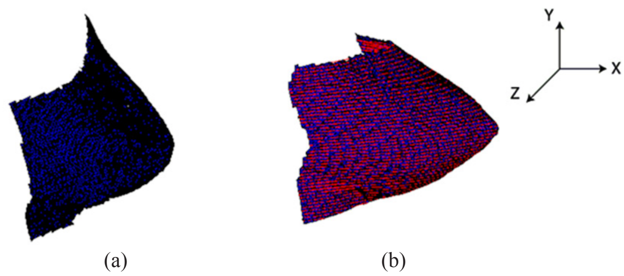


Fig. 4. (a) 3D breast shape and (b) 3D breast shape with contour lines.

curvature is calculated from this spline. By analyzing the variation in curvature, landmarks can be located. And then the feature points (upper part of breast, nipple and bottom part of breast) are assigned to the positive or negative maximal curvature point.

After finding upper and bottom parts of breast, contour lines in 3D breast shape from upper to bottom of breast are achieved. The suitable number of contour lines was 50 (the method proposed by Mozafary and Payvandy [33] is used to determine the suitable number of contour lines). To achieve the cross-section lines, at first, the 3D breast shape is intersected with parallel plans to the plane x-z in various heights. Then, intersection points of planes and mesh triangles are achieved in each height. After that, by using calculated points, contour lines on the mesh surface of the 3D breast shape are extracted. A sample of 3D breast shape with contour lines is illustrated in Fig. 4.

E. Comparison Between the 3D Breast Shapes

3D breast shapes in different body positions are compared together to identify the significant differences among various body positions. In this regard, 3D volume, and shape of breast are compared to each other.

F. Comparing the Form of 3D Breast

In order to compare form of 3D breast, extracted contour lines in 3D breast shapes are compared together. To calculate the difference between two contour lines, contour lines in each height are fitted to the polynomial equation [34]. Mean squared error (MSE) between fitted polynomial equations in breast shape is calculated using Eq. (1):

$$MSE = \frac{1}{n} \times \frac{\sum_{j=1}^{n}\sum_{i=1}^{m}(P_{ij1} - P_{ij2})^2}{m} \quad (1)$$

Where, n is the number of contour lines and m is the polynomial degree, P_{ij1} and P_{ij2} are the polynomial equation coefficients in the two breasts shapes.

G. Calculation of the Volume of 3D Breast

Volume of each breast (right and left) for every sample in five body positions is determined. To calculate the volume of a 3D model, the following method is presented as:

1. Contour lines on the mesh surface of the 3D breast shape are extracted (Fig. 5a). Number of contour lines was 50. Fig. 5b shows a contour line extracted from the 3D breast shape in position 'A' for sample 1.

2. The enclosed area on the contour lines is calculated using Eq. (2). The enclosed area for a contour line is illustrated in Fig. 5c.

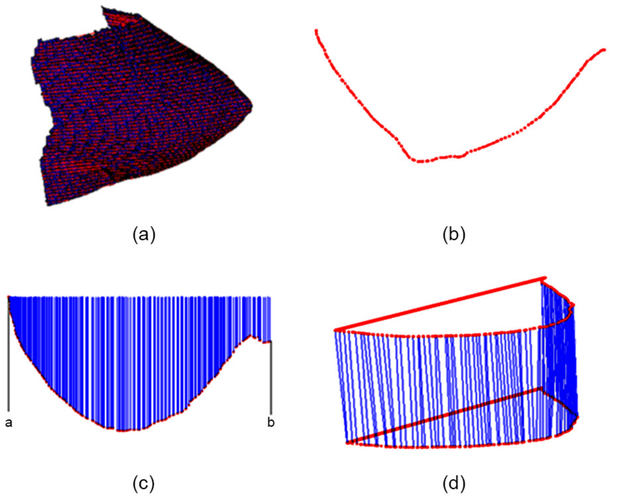


Fig. 5. Steps of measuring the volume of 3D breast: (a) 3D breast shape with cross section lines, (b) A contour line extracted from the 3D breast, (c) Enclosed area for a contour line, and (d) Volume of truncated cone between two cross sections.

Suppose that the interval [a,b] is split up into n subintervals (a is the coordinates of the first point and b is the coordinates of the last point), with n an even number. Then, the enclosed area on the contour lines is given by:

$$S = (b-a)\frac{f(x_0) + 2\sum_{i=1}^{n-1} f(x_i) + f(x_n)}{2n} \quad (2)$$

Where, in Eq. (2), S is the area, x_i=a+ih for i=0,1,..., n-1, n, x_0=a, and x_n=b.

3- Using calculated area in Eq. (2), the volume of truncated cone between two cross sections (Fig. 5d) is calculated according to Eq. (3). Finally, all the volumes are added up by the Eq. (4):

$$V_i = \frac{1}{3}h(S_1 + S_2 + \sqrt{S_1 S_2}) \quad (3)$$

$$V_T = \sum V_i \quad (4)$$

Where, in Eq. (3), V_j is the volume of i-th truncated cone between two cross sections, h is the height between two cross sections, S_1 and S_2 are the enclosed areas on the contour lines that are calculated by Eq. (2), and V_T is the total volume of breast.

H. 2D Breast Pattern Extraction

Because the body model is generated to express the complicated surface structure of human body, it is difficult to make garment pattern directly from body model. Therefore, a method based on cross section lines in breast boundary is used to construct the breast pattern. The

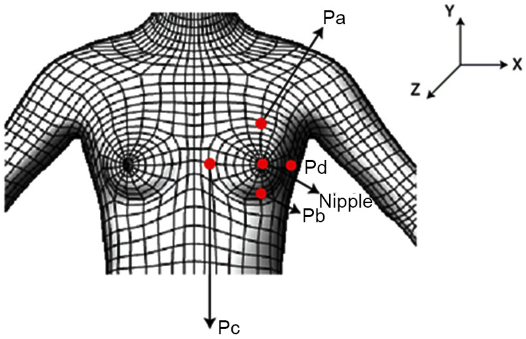


Fig. 6. Schematic diagram of breast boundary points.

method is as follows:

Four points (Pa, Pb, Pc, and Pd) around the breast are used to decide the breast boundary, as shown in Fig. 6. Point Pa is located at the intersection point between the over breast line and the line from the center shoulder point to the nipple. Point Pb is defined as the lowest breast point; Pc and Pd points are located at the inner intersection and outer intersection of the curve of lower breast boundary and the line dividing the body between the over breast line and under breast line by two, respectively [35]. To find the Pa and Pb points, parallel plans to the plane x-y in various heights are placed and contour lines are extracted. Maximal curvature point around the nipple is identified. Also, for finding the point Pc and Pd, parallel plans to the plane y-z in various heights are placed and contour lines are extracted. Maximal curvature point around the nipple is identified

Length of contour line between points Pc and Pd (i.e. fullest part of the breast) measured for both breasts and is called as "length of central line". Then a line in 2D pattern with length equal to the central line length is considered as central line of breast (Fig. 7a). After finding the central line,

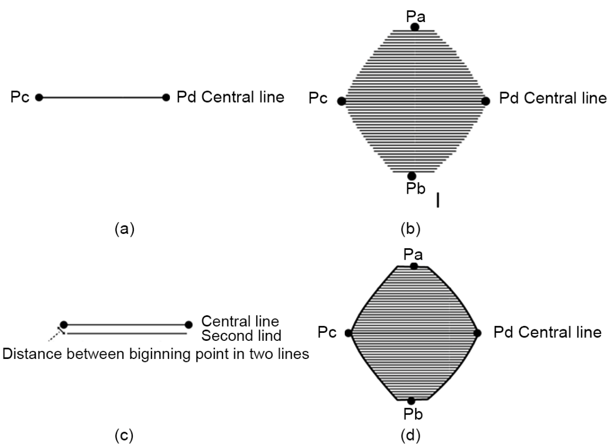


Fig. 7. Steps of extraction the breast cup pattern: (a) plotting central line, (b) plotting other lines in all patterns, (c) distance between the beginning point in second line and the central line, and (d) connecting lines to each other and getting the final shape of cup pattern.

other lines in upper and bottom parts of breast (lines that are located between points Pa to Pb) are calculated with the same method (Fig. 7b). So, 2D pattern of breast cup can be extracted by using obtained lines. In order to achieve a precise pattern, beginning points of lines should be selected correctly. For this purpose, the distance between the beginning point in each line and the beginning point at central line (that is shown in Fig. 7c) is determined. The distance between these points is calculated by their three-dimensional coordinates in 3D shape. Then these lines are connected together to achieve the breast cup pattern (Fig. 7d).

I. Comparison Between 2D Patterns of Breast Cup

2D pattern of breast cup in different body positions is compared together to identify the significant differences among various body positions. In this regard, area of breast cup pattern and form of 2D breast cup are compared to each other.

J. Comparison the Form of 2D Breast Patterns

In order to compare the form of 2D breast patterns, the form differences between two 2D patterns are evaluated. To measure the degree of dissimilarity between two forms, a similarity metric based on radius-angle vector method [36] has been developed as follows:

1. Determining gravity center by using Eqs. (5) and (6):

$$X_O = \frac{1}{k}\sum_{i=0}^{k} X(i) \quad (5)$$

$$Y_O = \frac{1}{k}\sum_{i=0}^{k} Y(i) \quad (6)$$

Where, k is the number of vertices on the polygon and X, Y are the vertices coordinate.

2. Determining the radius-angle vector: The radius-angle vector includes two columns, the first column is distance of polygon vertices to gravity center and the second column is

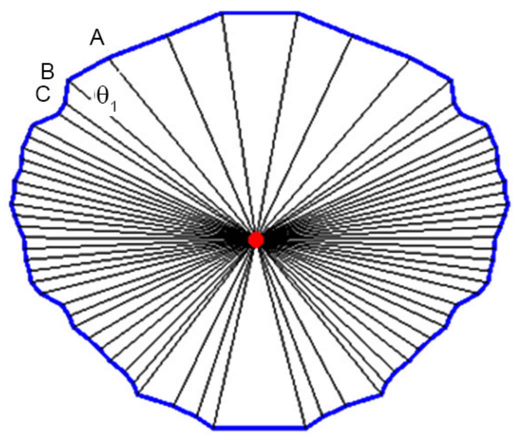


Fig. 8. Parameters of radius-angle vector for sample 1 in position 'A'.

angle between two adjacent line segments or turning angle (see Fig. 8) [34].

The dot product can be used for computing the angle between two adjacent line segments as Eq. (7):

$$\theta_1 = \cos^{-1}([(X_B - X_A)(X_C - X_B) + (Y_B - Y_A)(Y_C - Y_B)] / (|AB||BC|)) \quad (7)$$

According to Fig. 8, A, B, C are the polygon vertices; X_A, X_B, X_C, Y_A, Y_B, and Y_C are the vertices coordinate; and |AB|, |BC| are the magnitudes of line segments.

3. Compressing the radius-angle vectors: The difference value between two forms can be then evaluated by comparing their radius-angle vectors. The radius-angle vectors of two shapes are assumed as f_a, f_b, respectively which are expressed as:

$$f_a = \begin{bmatrix} f_{ar}^{\ 1} & f_{a\theta}^{\ 2} \\ f_{ar}^{\ 2} & f_{a\theta}^{\ 2} \\ f_{ar}^{\ 3} & f_{a\theta}^{\ 3} \\ \vdots & \vdots \\ f_{ar}^{\ k} & f_{a\theta}^{\ k} \end{bmatrix} \quad f_b = \begin{bmatrix} f_{br}^{\ 1} & f_{b\theta}^{\ 2} \\ f_{br}^{\ 2} & f_{b\theta}^{\ 2} \\ f_{br}^{\ 3} & f_{b\theta}^{\ 3} \\ \vdots & \vdots \\ f_{br}^{\ k} & f_{b\theta}^{\ k} \end{bmatrix} \quad (8)$$

Euclidean distance of two vectors is computed using Eq. (9) and is considered as the difference value of two polygon forms:

$$d = \left(\sum_{i=1}^{k} \sum_{j=1}^{2} (f_a(i,j) - f_b(i,j))^2 \right)^{1/2} \quad (9)$$

Where, k is the number of vertices on the polygon.

Two forms are considered similar to each other if and only if Euclidean distance that is calculated using Eq. (9) will be a small value. Therefore, the mean squared error (MSE) can be defined by Eq. (10):

$$MSE = \frac{1}{k} \times \sum_{i=1}^{k} \left[\frac{[\sum_{j=1}^{2} (f_a(i,j) - f_b(i,j))]^2}{(f_a(i,1) + f_b(i,2))^2} \right] \quad (10)$$

K. Calculation of the Area of 2D Breast Pattern

Areas of 2D breast pattern in various body positions are calculated and compared to each other. Eq. (11) is used to compare the area of 2D breast pattern:

$$Area = \sum_{i=1}^{n} (x_i y_{i+1} - x_{i+1} y_i) \quad (11)$$

Where, in Eq. (11), are the coordinate points in 2D pattern that the points are listed in counterclockwise order.

III. RESULTS AND DISCUSSION

A. Comparison the 3D Breasts

Fig. 9 shows 3D breast shape in two breast positions (right and left) for sample 1 in positions 'A', 'B', 'C', 'D', and 'E'.

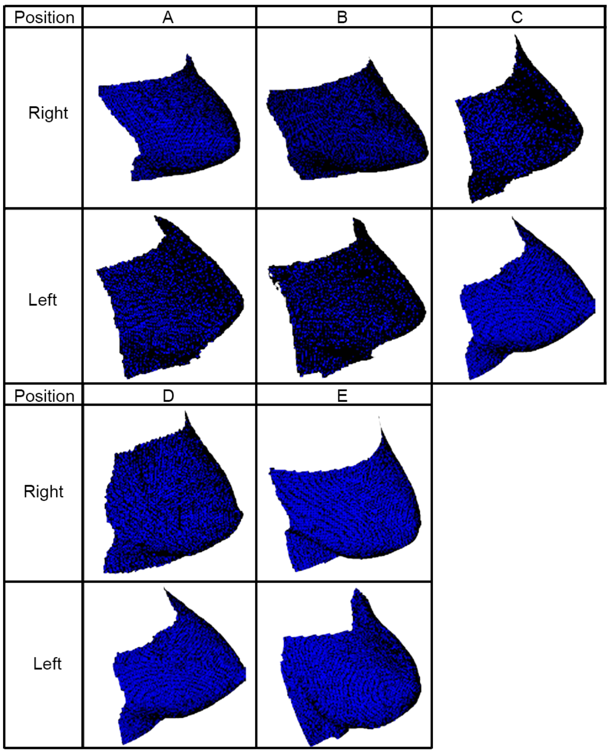


Fig. 9. 3D breast shape in two breast positions (right and left).

It is observed from Fig. 9 that breast cup pattern is different in various body positions.

3D breasts in various body positions are compared together. For this purpose, volume and form of 3D breasts are determined. The differences between two mentioned parameters in five body positions and two breast positions (right and left) are calculated and considered as a criterion to present the amount of difference.

The results of measured volume of 3D breast (that is calculated using Eq. (4)) are presented in Table II. Also, mean squared error (MSE) between right and left breasts in every position is calculated using Eq. (12) and expressed in Table I:

$$MSE = \frac{1}{n} \times \sum_{i=1}^{n} (V_{Li} - V_{Ri})^2 \quad (12)$$

Where, n is the number of contour lines in 3D breast (that is considered as 50), V_{Li} and V_{Ri} are the volume of 3D breast in i-th contour line for left and right breasts, respectively, that are computed using Eq. (4).

In order to evaluate the effects of various body positions and two breast positions (right and left) on volume of 3D breast, the results of volume of 3D breast are statistically analyzed at 5% significant level using analysis of variance (ANOVA). The ANOVA statistical results for volume of 3D breast are presented in Table II.

It is observed from Table II that the volume of 3D breast is significantly affected by the various body positions. However, the effect of breast position on volume of 3D breast is not significant. The interaction effect of body position and breast position on breast volume is also insignificant.

Although effect of two breast positions (right and left) on volume of 3D breast is not significant, there is a considerable difference between left and right breast shape according to Table II. One of the reasons for this difference is that the breast is a flexible object and so even two breasts of one person are not the same. Other reason for this difference could be due to the measurement errors.

The relation between volumes of 3D breast in various body positions is presented in Fig. 10.

As shown in Fig. 10, the experimental results revealed that women have the highest volume of breast in position 'C' subsequent position 'D', 'B', and 'E', respectively. Also in position 'A', the lowest volume of breast for women was observed.

TABLE I
VOLUME OF 3D BREAST FOR 10 SAMPLES IN VARIOUS BODY POSITIONS

Sample No.	Position	Volume of 3D breast (cm^3)			Sample No.	Position	Volume of 3D breast (cm^3)		
		Right	Left	MSE			Right	Left	MSE
	A	448	420	17.71		A	359	376	6.70
	B	468	458	2.26		B	401	410	2.87
1	C	521	495	15.27	6	C	443	413	19.88
	D	493	466	16.47		D	421	415	3.83
	E	437	466	19		E	390	367	12.27
	A	478	498	9.04		A	809	817	1.48
	B	543	532	2.73		B	813	821	2.32
2	C	542	567	14.12	7	C	854	832	11.22
	D	557	524	24.61		D	831	843	3.45
	E	512	502	2.26		E	818	812	4.12
	A	412	420	1.44		A	690	702	4.34
	B	445	459	4.42		B	742	728	5.54
3	C	472	487	5.08	8	C	790	773	6.70
	D	467	452	5.08		D	756	781	14.5
	E	436	415	9.96		E	713	721	2.48
	A	590	601	2.80		A	312	334	11.22
	B	612	628	5.93		B	368	353	5.22
4	C	656	639	7.70	9	C	398	402	2.37
	D	635	643	1.48		D	372	380	3.48
	E	602	617	5.52		E	345	329	5.93
	A	354	378	13.36		A	590	608	7.51
	B	408	429	10.26		B	649	631	8.21
5	C	445	422	12.27	10	C	687	673	4.54
	D	433	413	9.28		D	652	678	15.68
	E	390	368	11.22		E	613	622	3.87

TABLE II
ANOVA STATISTICAL RESULTS FOR VOLUME OF 3D BREAST

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Body position	4	56912.8	6.76	22.85
Breast position	1	27.04	56912.8	0.03
Interaction	4	1244.06	311.01	0.124
Error	90	2241117	24901.3	
Total	99	2299301		

TABLE III
COMPARISON BETWEEN 3D BREAST FORMS IN VARIOUS BODY POSITIONS

MSE (sample 1)							MSE (sample 2)						
Body position		A	B	C	D	E	Body position		A	B	C	D	E
A	Right		8.9	14.3	16.1	4.5	A	Right		10.8	17.4	14.3	5.3
	Left		9.1	15.4	15.5	6.1		Left		11.2	16.5	13.9	4.2
B	Right			15.6	16.5	14.3	B	Right			14.6	15.4	12.2
	Left			18.7	17.3	12.3		Left			17.2	17.3	11.9
C	Right				3.4	11.2	C	Right				4.5	19.2
	Left				2.3	12.6		Left				2.8	16.7
D	Right					13.2	D	Right					18.3
	Left					14.7		Left					15.4
MSE (sample 3)							MSE (sample 4)						
Body position		A	B	C	D	E	Body position		A	B	C	D	E
A	Right		11.2	17.3	18.2	2.3	A	Right		13.2	17.5	17.3	4.1
	Left		10.9	16.2	15.2	5.1		Left		14.7	17.3	14.5	2.4
B	Right			2.3	13.4	15.2	B	Right			13.5	18.4	12.3
	Left			14.5	11.2	17.8		Left			15.4	17.4	13.9
C	Right				3.2	19.2	C	Right				3.2	11.2
	Left				4.2	14.6		Left				5.4	12.9
D	Right					18.2	D	Right					14.3
	Left					19.4		Left					17.1
MSE (sample 5)							MSE (sample 6)						
Body position		a	B	c	d	e	Body position		A	b	c	d	e
A	Right		12.3	18.7	17.8	3.4	A	Right		14.5	17.8	21.4	3.7
	Left		14.5	20.2	19.6	2.1		Left		13.7	18.7	20.2	4.8
B	Right			13.5	12.3	11.7	B	Right			14.2	13.2	17.6
	Left			18.3	10.7	13.8		Left			12.6	14.5	15.4
C	Right				1.3	12.6	C	Right				3.4	15.8
	Left				3.8	14.7		Left				1.6	11.6
D	Right					15.3	D	Right					16.4
	Left					12.6		Left					17.3
MSE (sample 7)							MSE (sample 8)						
Body position		A	B	C	D	E	Body position		A	B	C	D	E
A	Right		13.2	15.6	19.3	3.2	A	Right		12.3	17.7	20.3	2.3
	Left		11.7	18.4	17.8	4.1		Left		14.5	18.6	21.4	4.5
B	Right			13.2	13.5	17.8	B	Right			11.2	17.3	15.6
	Left			12.9	15.4	14.6		Left			14.3	14.5	16.3
C	Right				4.3	12.3	C	Right				3.2	13.4
	Left				2.8	14.1		Left				3.4	15.3
D	Right					16.4	D	Right					17.4
	Left					14.8		Left					14.5
MSE (sample 9)							MSE (sample 10)						
Body position		A	B	C	D	E	Body position		A	B	C	D	E
A	Right		12.3	13.7	18.7	2.3	A	Right		13.5	17.8	21.3	2.6
	Left		14.2	12.4	20.2	3.1		Left		16.7	19.5	17.6	4.8
B	Right			13.5	18.7	12.3	B	Right			16.7	14.6	13.4
	Left			16.7	17.6	14.2		Left			17.5	15.8	15.6
C	Right				3.5	15.6	C	Right				4.3	18.9
	Left				4.6	14.8		Left				3.5	16.7
D	Right					14.3	D	Right					15.6
	Left					13.9		Left					17.3

TABLE IV
BREAST CUP PATTERNS GENERATED BY THE PROPOSED METHOD FOR SAMPLE 1 IN FIVE BODY POSITIONS AND COMPARISON BETWEEN RIGHT AND LEFT BREASTS

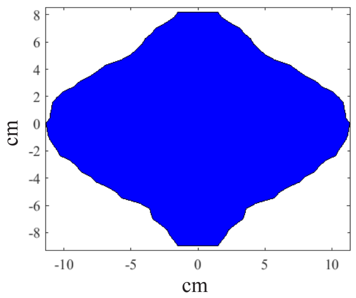
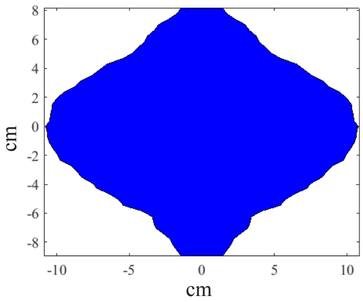
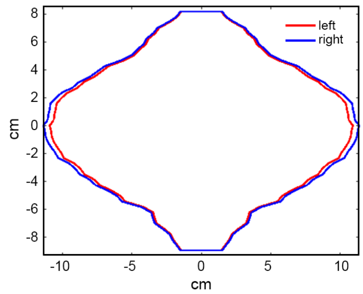
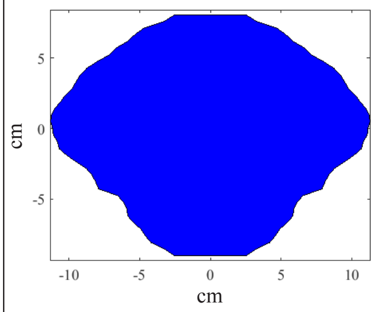
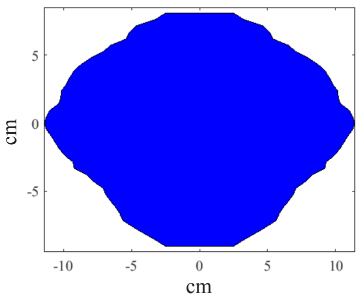
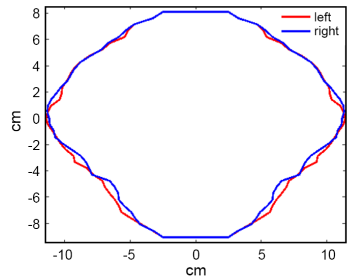
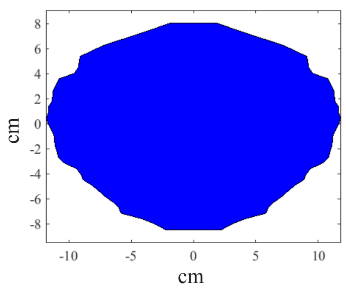
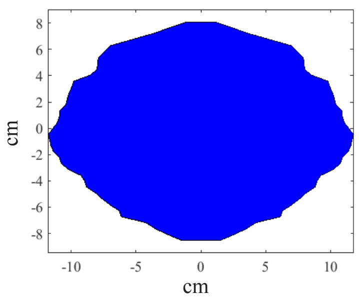
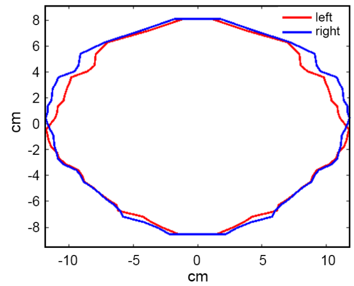
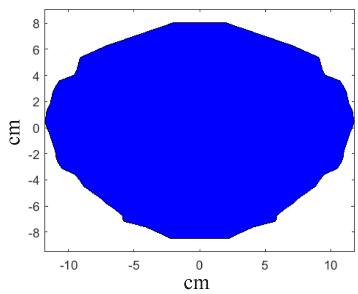
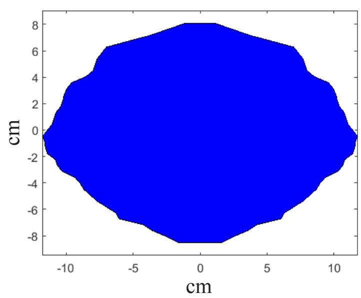
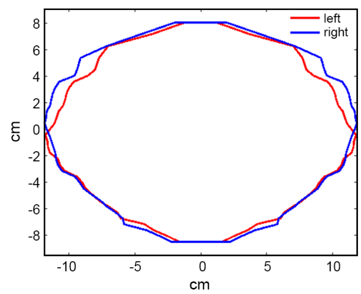
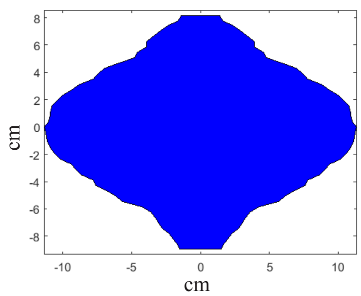
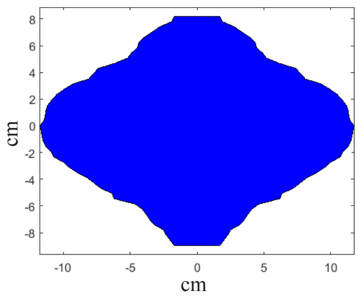
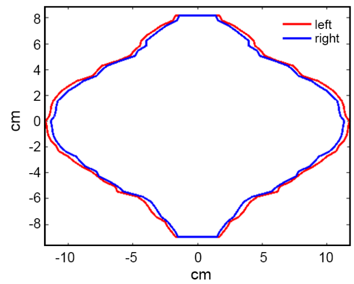
Position	Right breast	Left breast	Comparison between right and left breast
A			
B			
C			
D			
E			

TABLE V
AREA OF 2D BREAST PATTERN FOR 10 SAMPLES IN VARIOUS BODY POSITIONS

Sample No.	Body position	Area of 2D pattern of breast cup (cm^2)			Sample No.	Body position	Area of 2D pattern of breast cup (cm^2)		
		Right	Left	D			Right	Left	D
1	A	235	223	12	6	A	200	188	12
	B	265	268	3		B	226	228	2
	C	289	273	16		C	246	243	3
	D	290	273	17		D	245	231	14
	E	234	247	13		E	197	210	13
2	A	247	233	14	7	A	320	302	18
	B	279	283	4		B	358	363	5
	C	304	299	5		C	392	387	5
	D	302	286	16		D	387	372	15
	E	243	258	15		E	320	334	14
3	A	224	212	12	8	A	290	276	14
	B	250	254	4		B	326	333	7
	C	230	258	28		C	359	351	8
	D	276	259	17		D	347	337	10
	E	221	233	12		E	298	305	7
4	A	257	246	11	9	A	188	177	11
	B	287	298	11		B	212	216	4
	C	312	320	8		C	229	226	3
	D	319	303	16		D	230	217	13
	E	258	274	16		E	186	196	10
5	A	211	199	12	10	A	274	259	15
	B	237	243	6		B	309	315	6
	C	259	253	6		C	339	331	8
	D	262	247	15		D	332	318	14
	E	212	220	8		E	277	288	11

The results of comparison of 3D breast form in various body positions and breast positions are shown in Table III. Mean squared error (MSE) is calculated using Eq. (1).

The data in Table III show that the difference between 3D breast form in body position 'A' and 'E' and also the difference between 3D breast form in body position 'C' and 'D' are less than other positions.

B. Comparison the 2D Breast Patterns

Breast cup patterns generated by the proposed method for sample '1' in various body positions and two breast positions (right and left) are illustrated in Table IV.

2D patterns of breast cup in various body positions are compared together. Therefore, area and form of 2D breast pattern are determined. The differences between two mentioned parameters in five body positions are calculated and considered as a criterion to present the amount of difference between breast shapes.

The results of measured area of 2D pattern (that is calculated using Eq. (11)) are shown in Table V. Also, the differences between right and left breasts in five body positions are calculated using Eq. (13):

$$D = \text{abs}\left|S_L - S_R\right| \tag{13}$$

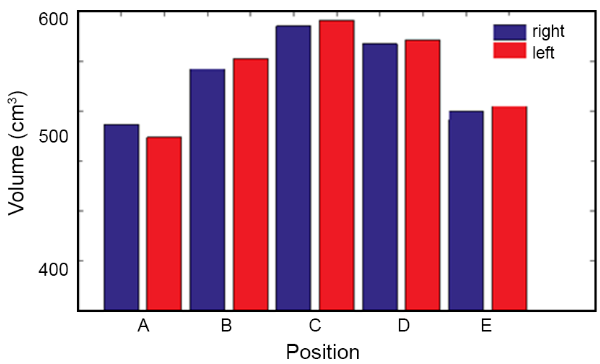


Fig. 10. Relation between volumes of 3D breast in various body positions.

TABLE VII
COMPARISON BETWEEN 2D BREAST PATTERN FORMS IN VARIOUS BODY POSITIONS

MSE (sample 1)						
Body position		A	B	C	D	E
a	Right		7.8	18.7	16.5	3.6
	Left		14.3	21.2	19.5	4.8
b	Right			14.3	8.9	14.3
	Left			11.9	12.5	19.4
c	Right				4.3	15.6
	Left				1.9	17.2
d	Right					13.5
	Left					14.7

MSE (sample 2)						
Body position		A	B	C	D	E
A	Right		13.4	17.4	18.2	3.4
	Left		15.6	15.6	17.4	4.5
B	Right			10.3	17.4	13.4
	Left			12.3	14.8	15.6
C	Right				2.3	14.2
	Left				5.4	16.3
D	Right					15.2
	Left					13.1

MSE (sample 3)						
Body position		A	B	C	D	E
a	Right		14.3	15.4	16.2	4.2
	Left		16.7	17.3	13.5	5.4
b	Right			10.8	11.2	18.4
	Left			15.4	13.9	16.2
c	Right				3.8	18.7
	Left				4.2	17.3
d	Right					20.2
	Left					18.3

MSE (sample 4)						
Body position		A	B	C	D	E
A	Right		17.4	18.3	17.5	3.4
	Left		18.3	20.1	16.4	4.9
B	Right			10.2	14.1	16.4
	Left			16.1	13.2	17.2
C	Right				3.4	14.3
	Left				4.1	15.6
D	Right					13.2
	Left					10.1

MSE (sample 5)						
Body position		A	B	C	D	E
a	Right		13.4	13.5	10.6	4.8
	Left		14.7	18.9	17.2	1.7
b	Right			13.4	15.3	15.6
	Left			12.4	10.6	17.2
c	Right				2.6	16.7
	Left				3.7	14.5
d	Right					10.2
	Left					13.2

MSE (sample 6)						
Body position		A	B	C	D	E
A	Right		16.2	17.2	18.3	2.3
	Left		13.4	14.2	17.9	6.1
B	Right			10.2	13.4	21.2
	Left			13.4	9.8	17.3
C	Right				3.2	14.5
	Left				5.3	13.4
D	Right					14.2
	Left					13.8

MSE (sample 7)						
Body position		A	B	C	D	E
a	Right		12.3	19.3w	17.6	2.7
	Left		11.2	19.4	15.4	4.5
b	Right			10.5	15.6	17.2
	Left			11.3	12.4	16.4
c	Right				4.3	16.5
	Left				5.2	19.4
d	Right					16.7
	Left					14.8

MSE (sample 8)						
Body position		A	B	C	D	E
A	Right		14.5	14.3	13.5	3.5
	Left		13.7	16.4	17.4	4.3
B	Right			10.2	17.3	13.4
	Left			13.2	15.4	14.5
C	Right				4.3	17.6
	Left				5.2	19.3
D	Right					15.6
	Left					17.2

MSE (sample 9)						
Body position		A	B	C	D	E
a	Right		12.4	20.2	21.3	3.2
	Left		15.6	17.3	16.3	6.3
b	Right			13.4	13.6	19.8
	Left			15.6	17.4	17.3
c	Right				2.4	13.5
	Left				4.5	17.2
d	Right					19.3
	Left					16.2

MSE (sample 10)						
Body position		A	B	C	D	E
A	Right		12.3	14.5	16.5	3.4
	Left		14.5	15.3	17.2	5.2
B	Right			13.2	18.4	20.2
	Left			12.6	13.2	16.3
C	Right				3.2	10.2
	Left				4.5	14.3
D	Right					18.7
	Left					19.3

TABLE VI
ANOVA STATISTICAL RESULTS FOR AREA OF 2D BREAST PATTERN

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Body position	4	50951.3	12737.8	5.74
Breast position	1	156.25	156.2	0.07
Interaction	4	2641.7	660.42	0.29
Error	90	199561.5	2217.35	
Total	99	253310.8		

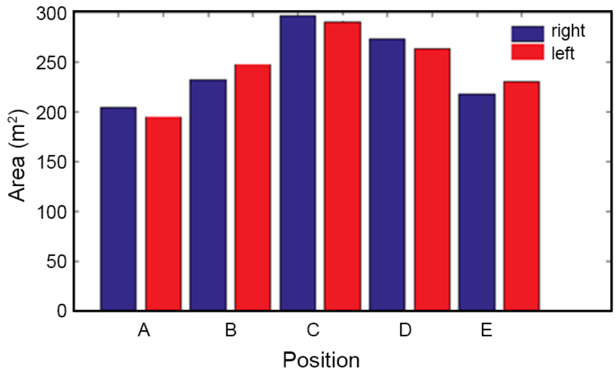


Fig. 11. Relation between area 2D breast patterns in various body positions.

Where, S_L and S_R are the area of 2D breast pattern in left and right positions, respectively, that are achieved using Eq. (11).

In order to evaluate the effects of various body positions and two breast positions on 2D breast pattern, the areas of 2D breast pattern are statistically analyzed at 5% significant level using analysis of variance (ANOVA). ANOVA statistical results for area of 2D breast pattern are presented in Table VI.

It is observed from Table VI that the area of 2D breast pattern is significantly affected by the various body positions. However, the effect of breast position on area of 2D breast pattern is not significant. The interaction effect of body position and breast position on breast volume is also insignificant.

The relation between areas of 2D breast pattern in various body positions is presented in Fig. 11.

As shown in Fig. 11, the experimental results revealed that women have the largest breast in the body position 'C' subsequent the body positions 'D', 'B', and 'E', respectively. Also, the smallest breast for women was observed in the body position 'A'.

The results of comparison of 2D breast pattern forms in various body positions are shown in Table VII. Mean squared error (MSE) is calculated using Eq. (10).

The data in Table VII show that the difference between the form of 3D breast in the body positions 'A' and 'E' and also the difference between the form of 3D breast in the body positions 'C' and 'D' are less than other positions.

The measurement method of breast shape proposed in this study is useful in bra cup pattern making. The combination of measuring breast volume and shape at the same time can provide effective information for bra cup design. Bra patterns can be designed precisely according to the 3D breast shape. These findings can give direction to the design of clothing in new ways and can provide new tools that could help for well-fitted bra design.

IV. CONCLUSION

In this research, 3D shape breast of women in various positions are extracted from 3D point cloud data obtained from a depth camera. In order to determine the difference between breast in various body positions, volume and form of 3D breast in five body positions are obtained and compared to each other. Also, a measurement method is developed to extract the 2D pattern of breast cup from 3D breast shape. 2D breast patterns in every body positions are compared to each other. In this regard, area and form of 2D breast pattern are determined.

Statistical analysis has been performed on both volume of 3D breast and area of 2D breast pattern using ANOVA test method. The results show that volume of 3D breast and area of 2D breast pattern are significantly affected the various body positions. However, the effect of breast position on volume of 3D breast and area of 2D breast pattern is not significant. In addition, the result of this work revealed that women have the highest volume and area of breast in the body position 'posture of 45 elbow-bend and arms to the back' subsequent the position 'posture of 45 elbow-bend and arms to the front', 'lower arm beside the body' and 'raise arm overhead and holding on the brow', respectively. Also in the position 'holding arm overhead', the lowest volume of breast for women was observed.

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