ESTIMATION OF SHOULDER WIDTH AND NECK GIRTH BASED ON 3-D POINT CLOUD DATA

by

Xin LU[a], Panpan GUO[b], and Guolian LIU[b*]

[a] School of Textile Garment and Design, Changshu Institute of Technology, Suzhou, China
[b] College of Textile and Clothing Engineering, Soochow University, Suzhou, China

Original scientific paper
https://doi.org/10.2298/TSCI200311047L

The 3-D point cloud map in the anthropometry has attracted intensive attention due to the availability of fast and accurate laser scan devices. Inevitably, there is a data deviation between 3-D measurement and manual tests. To address this problem, shoulder width and neck girth are accurately determined from 3-D point cloud, the two-scale fractal is used for 3-D point cloud simplification, and young female samples are used in our experiment to show the accuracy.

Key words: *3-D point cloud, Shoulder widthm, neck circumference, fitting method, two-scale method*

Introduction

As an important measurement method, the 3-D anthropometry is widely used to provide a basic body morphology for the garment design. During the measuring procedure, the point cloud is deemed as the most emblematic representation due to its comprehensive and intuitive information. The accurate and reliable data from the point cloud not only contribute to the morphological analysis and geometric measurement of body model, but also make up the drawback of conventional contact anthropometry [1-5].

With these obvious advantages of convenience, accuracy and speedy, a series of researches on the reliability of 3-D anthropometry were carried out. In [1], the consistency analysis on 17 groups of body parts were compared among Image Twin test, Cyberware test, and SYMCAD test. The significant data deviation at the same body part was found since that these three methods had different definitions and anchor points on the same measurement terms. Comparative dimension analysis of 14 body parts showed that most of body girth from 3-D measurement were larger than those manual data [2], which resulted from the low accuracy of the instrument algorithm and the different original somatotype models used by instrument algorithm. Ren *et al*. [3] aslo analyzed 29 morphological indicator data from 174 groups of people (74 men and 100 women) to see if the manual method and 3-D measurement were consistent. Results showed that 14 morphological indicators were relatively consistent, with an error of less than 3%. The difference rates of iliac width, chest width and chest thickness were more than 10%. The error rates of other 12 morphological indexes were be tween 3% and 10%. In our previous report, 50 groups of young female body dimensions were measured with manual measure, 2-D non-contact test method and 3-D body scanner, respectively [4, 5]. Compared with 3-D test, the data error between 2-D measure results and manual measurement data is smaller,

* Corresponding author, e-mail: liuguolian@suda.edu.cn

which attributes to the changing body postures during the measure process, the precise location of manual measure tape and basic data setting for non-contact measuring methods.

Based on these analyses, the data deviation poses a significant obstacle in the application of 3-D body scanners, especially for important body parts that are difficult to be determined. For example, the neck girth and shoulder width are both critical garment components and design points, which directly affect the overall garment style. However, the obvious difference is often detected in the manual test process. It is essential to combine 3-D anthropometry with manual test to reduce data error through data correlation analysis and regression fitting analysis.

In this paper, the feature points of shoulder width and neck girth are extracted from 3-D point clouds of young female. With the data processing, simulation algorithms of these two parts are established to provide accuarte dimensions.

Experimental design

The 250 groups of young female aged from 19-26, with a height from 150-178 cm, and a weight from 40-70 kg were selected as the measurement objects. The experiment conditions were setted $T = 25 + 2$ °C, $RH = 65 + 5\%$, Soochow University.

The manual measure method was carried out according to the National Standard of the People's Republic of China GB/T 1660-1996. The main measuring tools are soft ruler, goniometer, altimeter, rangefinder and sliding gauge.

The 3-D body scanner (Symcad, German) were used to automatically measure body dimensions without contact and the effect of human movement. The required measurement posture was shown in fig. 1(a). Participants were asked to wear light-colored tights and swimming cap to cover their hair. Also accessories must be removed to assure the photo and scanning effect.

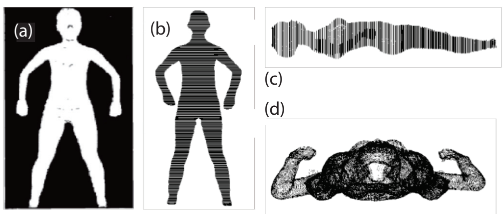

Figure 1.(a) The required measurement posture, (b) front view, (c) side view, and (d) top view

Scattered cloud data extracted from 3-D scanner were converted into TXT format for treatment. The virtual 3-D co-ordinate system was generated in fig. 1(b)-1(d). These 3-D point cloud map can be dragged freely from any direction make the observation and measurement process clear and comprehensive.

Determination of shoulder width and neck girth eigenvalues

Before measuring the shoulder width, the position of two shoulder endpoints should be determined first. According to our previous report [4], the junction connecting right torso and the lowest arm edge was founded as underarm point O in fig. 2(a). The location of shoulder endpoint A was obtained by intersecting the vertical line through point O and the shoulder edge. While the location of left shoulder end point B was determined by intersecting the horizontal line crossing point A and the shoulder edge.

Straight-line distance connecting two shoulder endpoints and the curve distance along the human body surface are typical eigenvalues of shoulder width. After the determination of two shoulder endpoints, the linear distance and curve distance are directly measured in fig. 2(b). The linear distance is the straight line length between right endpoint A and left endpoint B. The curve distance was fitted with 3-D B-spline tool to match the human shoulder curve.

The back enter angle is another typical eigenvalue of shoulder width, which is used as a criterion classify body shapes. The larger back enter angle, the more prominent back protrusion. The determination process of back enter angle was given Two feature points involved the most prominent point C on the back, fig. 2(c), and the posterior cervical point BNP, fig. 2(d), also need to be determined before eigenvalue extraction. Located at the tip of the spinous process of the seventh cervical vertebra of human body, BNP is the most prominent cervical vertebra point of posterior neck. From fig. 2(e), the back enter angle was formed by intersecting vertical line through point C and the diagonal connecting point C and point BNP.

Neck circumference is the cervical girth at the lower margin point of the thyroid cartilage projection known as the Adam's apple. Compared with male, Adam's apple of female is not prominent. To make the Adam's apple more obvious, participants are required to keep head up and eyes looking straight ahead.

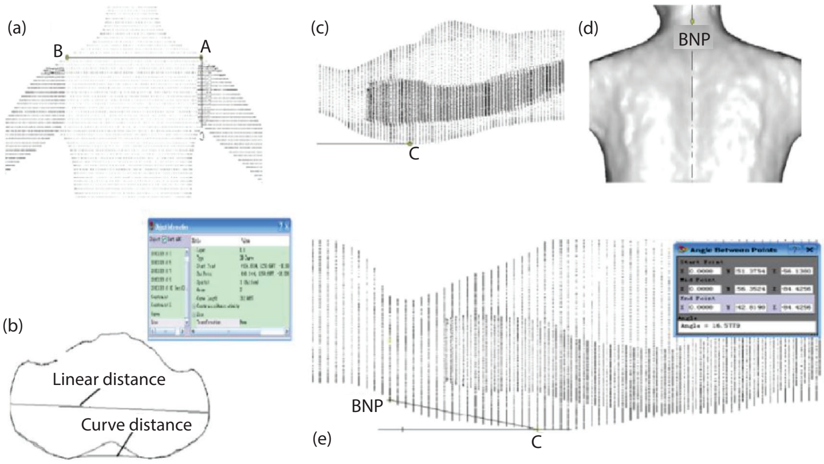

Figure 2. (a) Shoulder endpoints, (b) fitting process of shoulder width eigenvalues; back enter angle, (c) point C, (d) point BNP, (e) and measure process of the back enter angle

Determination process of left endpoint D and right endpoint E was shown in figs. 3(a) and 3(b). Zoom in 3-D point cloud, the prominent point at the middle of the neck is the Adam's apple point. The lower edge point of the Adam's apple was taken as origin point, and the arrow direction along *Z*-axis was moved to make it basically consistent with the line on the neck surface. The neck girth section can be obtained until the straight line in *Y*-direction is basically perpendicular to the neck part. Then, the left and right end points (D and E) were determined.

Three characteristic values involved neck width, neck thickness and neck girth were measured in the neck section. Neck width is the straight line distance between the left and right endpoints (D and E) in the elevation view. While the neck thickness refers to the straight line

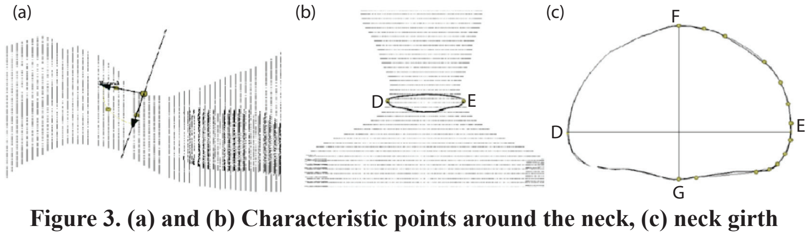

Figure 3. (a) and (b) Characteristic points around the neck, (c) neck girth

distance between the top and bottom endpoints (F and G) in the elevation view. The straight line connecting two points D and E is perpendicular to the straight line crossinging two points F and G. Extraction process of characteristic values of neck girth was shown in fig. 3(c).

Fitting method of shoulder width and neck circumference

The back enter angle is used as classified norm to describe shoulder width. The maximum value 29.7 and minimum value 9.4 were found out from 250 sets of back enter angles. All the data was graded by trisection the difference between 29.7 and 9.4. From tab. 1, the number of people in the first and third grade was smaller, while that of the second gear is the largest. The number of second grears accounted for nearly 70%, representing most shoulder features.

Table 1. Range difference of each grade and the corresponding proportion of people

Subject	First gear	Second gear	Third gear	Total
Range difference	9.4-11.6	16.2-22.9	23-29.7	9.4-29.7
The number of people	30	174	46	250
Proportion [%]	12	69.6	18.4	100

Based on the distribution model of shoulder shapes, correlation analysis were listed in tab. 2. The correlation coefficients between linear distance and curve distance were 0.919, 0.819, and 0.797 for these three grades, respectively. Results of two-tailed test were lower than 0.01 for all these grades, meaning significantly positive relationship between these two parameters. The curve width increased with the increase of straight width. These associations appeared to be strongest in first gear due to the highest correlation coefficient 0.919. The smaller back enter angles, the more obvious their positive correlation.

The linear regression model was used to establish the optimum fitting formula between curve shoulder width and straight shoulder width. From tab. 2, the significance levels for all regression coefficients (all $p = 0.000$) and regression constants (first gear, $p = 0.002$; second gear, $p = 0.007$; third gear, $p = 0.003$) were lower than 0.01, indicating credible fitting results. Linear regression fitting formula between curve distance and linear straight distance were established.

$$\text{First gear}: Y_1 = -138.310 + 1.653 X_1 \tag{1}$$

$$\text{Second gear}: Y_2 = 26.961 + 1.129 X_2 \tag{2}$$

$$\text{Third gear}: Y_3 = 65.612 + 0.997 X_3 \tag{3}$$

where, X_1, X_2, and X_3 were the linear straight distance in these three gears, respectively, while Y_1, Y_2, and Y_3 were the corresponding curve distance, respectively.

Table 2. Correlation and regression analysis between curve distance and linear distance

Gear		Non-standardized coefficient		Standardized coefficient	*T*-value	Two-tailed test *P*
		B	Std. Error	Beta		
First	(Constant)	–138.310	40.962		–3.377	0.002
	Linear distance	1.653	0.134	0.919	12.312	0.000
Second	(Constant)	26.961	18.495		1.458	0.007
	Linear distance	1.129	0.060	0.819	18.672	0.000
Third	(Constant)	65.612	34.462		1.904	0.003
	Linear distance	0.997	0.114	0.797	8.749	0.000

Note: dependent variable: Curve distance

Manual measure method was used to test the reliability and accuracy of fitting formula of shoulder width. The 250 groups of straight shoulder width measured with 3-D measurement were inputted into the aforementioned prediction formula to obtain predicted value of curve shoulder width. The predicted curve shoulder width was compared with those manual test values. The data deviation between these two results was verified through independent sample T-test. From tab. 3, the fitting shoulder width was close to the manual value due to small mean difference 0.0399 cm. Moreover, there was no significant difference in shoulder width between two groups ($p = 0.802 > 0.05$), indicating the excellent applicability and accuracy.

Table 3. Independent sample T-test of shoulder width from fitted and manual measure

Method	Mean value	Mean difference	Standard error	T	Sig. (Two-tailed test) p
Fitted value	38.081	0.0399	0.159	–0.25	0.802
Manual value	38.12				

To reduce the individual difference among different neck section shapes, the ratio of neck width and neck thickness was selected as classification standard to describe neck girth features. The ratio of neck width and neck thickness from 250 groups of human body was calculated. All ratio data was graded by trisection the difference between the maximum value 1.53 and the minimum value 0.92. From tab. 4, the number of people in the second gears was the largest, while the number of the third gear was the smallest. The people number in the first gear and second grear accounted for 93.6%, representing most neck features.

Table 4. Range difference of each grade and the corresponding proportion of people

Subject	First gear	Second gear	Thrid gear	Total
Range difference	0.92-1.11	1.12-1.32	1.33-1.53	0.92-1.53
The number of people	92	142	16	250
Proportion [%]	36.8	56.8	6.4	100

From tab. 5, the correlation coefficients between neck width and neck girth was 0.880, 0.859, and 0.869 for these three grades, respectively; while those between neck thickness and neck girth were 0.895, 0.878, and 0.816, respectively. Two-tailed test values were all lower than 0.01, meaning significant positive correlation between neck width or neck thickness and neck girth. The neck girth increased as the increase of neck width or neck thickness. Associations appeared to be strongest in the first gear due to the highest correlation coefficient. For the neck thickness and neck girth, the smaller the ratio of neck width and neck thickness, the more obvious their positive correlation. For the neck width and neck girth, their positive correlation was firstly stronger then weakened as the increase of the ratio of neck width and neck thickness.

Table 5. Correlation relationship between neck girth and neck thickness or neck width

Gear		Neck width		Neck thickness	
		Correlation coefficient	Two-tailed test	Correlation coefficient	Two-tailed test
First	Neck girth	0.880**	0.000	0.895**	0.000
Second	Neck girth	0.859**	0.000	0.878**	0.000
Third	Neck girth	0.869**	0.000	0.816**	0.000

** correlation coefficient level at 0.01 (two sides)

The linear regression model was used to establish the optimum fitting formula between neck girth and neck width or neck girth. From tab. 6, the fitting results were credible due to the high correlation coefficient 0.956, 0.938, and 0.887 for these three grades.Linear regression fitting formula between neck girth and neck width or neck thickness were established:

$$\text{First gear } Y_1 = -22.171 + 1.578X_1 + 1.763X_2 \tag{4}$$

$$\text{Second gear } Y_2 = -7.984 + 1.547X_1 + 1.651X_2 \tag{5}$$

$$\text{Third gear } Y_3 = 52.119 + 1.636X_1 + 0.811X_2 \tag{6}$$

where X_1 and X_2, were the neck width and neck thickness in these three gears, respectively, while Y_1, Y_2, and Y_3 were the corresponding neck girth, respectively.

Table 6. Regression analysis between the neck girth and neck width or neck thickness

Gear		Non-standarized coefficient		Standardized coefficient	*T*-value	Correlation coefficient
		B	Std. error	Beta		
First	(Constant)	–22.171	11.584		–1.914	0.956
	NW	1.578	0.144	0.489	10.930	
	NT	1.763	0.145	0.542	12.126	
Second	(Constant)	–7.984	10.779		–0.741	0.938
	NW	1.547	0.137	0.474	11.289	
	NT	1.651	0.129	0.538	12.809	
Third	(Constant)	52.119	39.138		1.330	0.887
	NW	1.636	0.603	0.614	2.714	
	NT	0.811	0.593	0.310	1.358	

Manual measurement method was also used to test the reliability and accuracy of fitting formula of neck girth. The 250 dimensional groups of neck width and neck thickness measured with 3-D measurement were inputted into the aforementioned prediction formula to obtain the predicted neck girth. The predicted neck girth were compared with those manual values. The difference between these two results was verified through independent sample *T*-test. From tab. 7, the fitting value of neck girth was close to the mean value from manual measurement due to the small mean difference 0.11 cm. Furthermore, there was no significant difference in shoulder width level between two groups (0.479 > 0.05), showing the the applicability and accuracy.

Table 7. Independent sample *T*-test of neck girth from fitted and manual measurement

Method	Mean value	Mean difference	Standard error	*T*	Sig. (Two-tailed test)
Fitted value	33.389	0.11	0.155	0.708	0.479
Manual value	33.279				

Discussion and conclusion

The neck girth is similar to the length of the well-known coastline, it depends upon the measured scale, a smaller one always results a more accurate result. Shoaib *et al.* [6] suggested the fractal bubble algorithm for simplification of 3-D point cloud data, however, it is critical to fast determine the neck girth according to the given accuracy. The two-scale fractal [7-9] is an effective tool for this purpose, that is we needed another scale to improve the accuracy, the approximate estimation discussed previously is based on a large-scale, if we want to improve the accuracy, a smaller scale is needed to re-analyze the cloud data.

In conclusion, the eigenvalue determine method of shoulder width and neck girth was analyzed according to 3-D point cloud map of young female body. The back enter angle and the ration of neck width and neck thickness were confirmed as standard parameters to classify body shapes. All the data from 3-D measurement method can be interpreted with regression fitting formula, combining with an outstanding consistency with those data from manual measurement method. Moreover, this comprehensive research method is easy to be extanded into dimension extraction of other female body part, even into the dimension extraction of male body.

Acknowledgment

The authors are grateful for the financial support of this research by Key project of Natural Science Foundation of Liaoning Province (No. 20170540403)

References

[1] Karla, P. S., *et a*l., Body Measurement Techniques: Comparing 3-D Body-Scanning and a Thropometric Methods for Apparel Applications, *Journal of Fashion Marketing and Management*, *7* (2001), 3, pp. 306-332
[2] Hyunsook, H., *et al*., Comparative Analysis of 3-D Body Scan Measurements and Manual Measurements of Size Korea Adult Females, *International Journal of Industrial Ergonomics*, *40* (2010), 5, pp. 530-540
[3] Ren, H., *et al*., Application of 3-D Body Scan Technique to the Measurement and Evaluation in Sports Science (In Chinese), *Journal of Beijing Sports University*, *36* (2013), 1, pp. 51-54
[4] Guo, P. P., *et al*., Reliability Analysis of Anthropometric Data Based on Young Female Body (In Chinese), *Journal of Beijing Institute of Clothing Technology*, *35* (2015), 2, pp. 35-40
[5] Wu, W. G., *Application of Clothing Standards* (in Chinese), Beijing Publishing House, Beijing, 2002, p. 106
[6] Shoaib, M., *et al*., Fractal Bubble Algorithm for Simplification of 3-D Point Cloud Data, *Journal of* Int*elligent and Fuzzy Systems*, *37* (2019), 6, pp. 7815-7830
[7] Ain, Q. T., He, J. H., On Two-Scale Dimension and Its Application, *Thermal Science*, *23* (2019), 3B, pp.1707-1712
[8] He, J. H., Ji, F. Y., Two-Scale Mathematics and Fractional Calculus for Thermodynamics, *Thermal Science, 23* (2019), 4, pp. 2131-2133
[9] He, J. H., Ain, Q. T., New Promises and Future Challenges of Fractal calculus: from Two-Scale Thermodynamics to Fractal Variational Principle, *Thermal Science, 24* (2020), 2A, pp. 659-681

Paper submitted: March 11, 2020
Paper revised: June 13, 2020
Paper accepted: June 13, 2020

© 2021 Society of Thermal Engineers of Serbia
Published by the Vinča Institute of Nuclear Sciences, Belgrade, Serbia.
This is an open access article distributed under the CC BY-NC-ND 4.0 terms and conditions