FORMATION OF COMPLEX 3D SURFACES SCANS FOR GARMENT CAD

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ABSTRACT

Algorithms for building scans of complex surfaces of the human body based on three-dimensional measurements were founded. A mathematical model of the surface was developed, followed by the definition of triangulation parameters. The accuracy of building sweeps followed by pattern making depends on the direction and number of geometric elements. The obtained data should be used to improve garment CAD for pattern making for individual consumers.

KEYWORDS

3D Surface; Scans; Garment CAD; Pattern making; Kinect device.

INTRODUCTION

The human body is a complex geometric shape, which is an individual feature for each individual person. In addition, the asymmetry of the right and left parts of both a typical and atypical figure can be of varying degrees. Anthropometric standards reveal certain unified features that can be separated into separate groups. Such features are reduced to geometric measurements. One of the main requirements for clothing that is designed and manufactured for a specific person is a quality fit, which in many cases determines the proximity of the surface of the clothing to the surface of the human body. For this reason, the corresponding part of the clothing in the design process should have the appearance of a three-dimensional figure spread over a plane. Pattern sweeps are commonly known as garment elements in various garment design systems. The implementation of known methods in modern garment CAD did not expand fundamentally their capabilities in obtaining particularly accurate pattern drawings taking into account the plasticity of the figure.

The theory of three-dimensional design opens up new perspectives for improving the methods of graphic reproduction of the surface of the human body, and the functioning of modern systems of automated clothing design cannot be effective without solving the problems of information support. Initial anthropometric information about the surface of the figure of garment consumers in the form of their digital models for 3-CAD/CAM expands the possibilities of using computer systems in the design preparation of production. The methods of 3D clothing modelling provide a new level of design activity by using graphic software packages for modelling 3D space and 3D printing of design objects.

Digital 3D technologies, primarily three-dimensional scanning technologies, open up new opportunities for more accurate garment pattern making. Despite the considerable amount of research in this direction, there remains a complex of problems that determines the features of anthropometry of individual areas of the human body surface, as well as practical directions for improving the anthropometric database and designing clothes taking into account the real three-dimensional geometry of the body.

A number of recent studies and publications are devoted to the implementation of three-dimensional technologies in the process of designing clothes.

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Received February 13, 2023; accepted May 31, 2023

The value of three-dimensional technologies for the garment pattern making is considered in [1]. This work is an overview and needs further detailing.

The study [2] assessed the potential of three-dimensional dynamic fashion clothing together with three-dimensional virtual modelling systems. This research led to a discussion of the possible future of digital fashion design. The three-dimensional presentation of clothes is considered a real problem. Not enough attention is paid to the process of actually designing clothes to ensure the best optimal fitting conditions.

The paper [3] investigated the problem of combining 3D and 2D design methods based on the use of key modules of 3D digital modification of the morphological structure of the body and 2D generation of scans of jacket details. Recommendations are developed for a limited range.

The problems of improving the selection of clothes without manual measurement are given in the study [4]. The developed methods involve sizing garments based on a shape model using large-scale 3D scanned measurements as input. Determination of design features for an individual consumer is not provided.

Alternative methods of determining real forms of clothing without the use of expensive 3D scanners are proposed in the article [5]. Such systems require significant preparation in the form of multi-colored painting. In some cases [6], the use of 3D scanners can be replaced by cheap kinect devices.

The article [7] presents the results of anthropometric studies of the human body using 3D scanning. The relationships between the main dimensional features were revealed. Traditional signs although 3D technologies were used in the study, allow to determine any signs (positions in space of the main levels of the figure, perimeters of contours, on the right and left parts of the body separately) and introduce new ones.

Studies [8, 9] are devoted to the development of real pattern making methods based on the development of a 3D garment model. The developed algorithms allow pattern making after two-dimensional parameterization. The work does not provide methods for building structures of individual parts of the human body that are complex in shape.

The problems of creating real structures based on three-dimensional measurements are also considered in [10, 11]. The study added methods of virtual dressing and fitting.

A three-dimensional prototype of clothing was developed in the study [12] to ensure a better fit and balance of clothing in the process of dynamic anthropometry. Allowances for loose fit were researched. The task of practical creation of structures taking into account the complex shape of individual parts of the human body has not been proven.

It was proved in work [13], that the morphological parameters of the zones of the female torso affect the methods and parameters of the formation of typical articulations of corset products. Methods of three-dimensional visualization were applied.

3D scanning methods make it possible to advance significantly research in the direction of anthropometric standardization. Supplementing the database with new measurements for use within existing or newly created clothing design methods is not excluded. This direction requires careful approaches for different parts of the body. The most famous studies were conducted on the shape of female breasts [14]. Deeper segmentation of parts of the human body, as well as the importance of studying their shape, is proven in [15]. Features of the formation of a typological series of dimensional features for the construction of waist products are given in the work [16]. The importance of continuing anthropometric studies using three-dimensional technologies is also noted in [17].

As a result of the analysis of the state of the issue, it is possible to draw conclusions about the relevance of further anthropometric studies of parts of the human body that have a complex spatial shape for further standardization, as well as the creation of designs for the individual consumer that best match the body structure. For research, the shoulder zone and the breast gland zone, the geometry of which is insufficiently covered in existing standards and scientific publications, were selected.

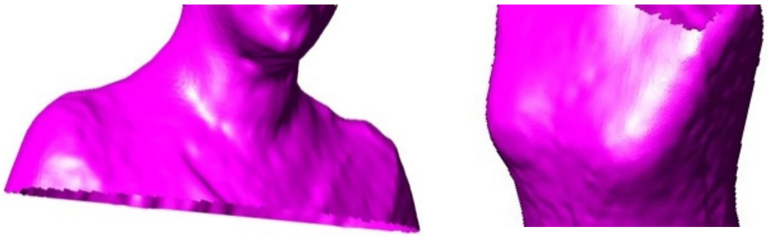
The aim of this study is to substantiate additional anthropometric data followed by pattern making of complex geometric shapes of the human body based on 3D scanning.

MATERIALS AND METHODS

The support surface for shoulder clothing is limited by the lines of articulation of the neck and arm with the torso and the protruding points of the chest and shoulder blades.

Real three-dimensional anthropometric studies determine the expediency of using modern means of three-dimensional scanning, which, accordingly, determines the fulfilment of certain requirements for software and material support of this process.

Modern gadgets in the form of Kinect systems have a budget cost and are quite capable of being used as means of three-dimensional determination of dimensions. The use of KScan3D software compatible with Meshlab in the process of scanning the human body gives the ability to form a network of points in the form of a DXF file, which determines the coordinates of all points in the triangulation network that forms the surface. Such a network allows to obtain the surface of any part of the human body



(a) (b)

Figure 1. The surface of a part of the human body, obtained with the help of a kinect device: (a) the area of articulation of the neck and arms with the trunk; (b) the area of protruding points of the chest.

(Fig. 1), as well as to determine any dimensions in an arbitrary projection.

Coordinates of surface points obtained as a result of 3D scanning allow creating approximation models in the form of polynomials. Such models are capable of solving the task of creating a structure by scanning the resulting analytical surface onto a plane.

RESULTS

To achieve the goal, the shoulder and breast areas of 57 women aged 18 to 29 from different regions of Ukraine were examined. The resulting surfaces have a rather diverse shape, which is shown in Fig, 2 on the example of the shoulder area.

Modern three-dimensional software tools allow to compare the general spatial form, as well as to analyse the appearance in different projections and sections. The frontal projection can be the most informative. The frontal view of the shoulder area for different respondents is shown in Fig. 3.

In the process of statistical analysis, a hypothesis was made about the normal distribution of the obtained results. For this sample of 57 people, confidence probability parameters within 95% were determined, and a confidence interval of 4.51% was determined for the five proposed parameters.

For further analysis of the obtained data, the projection curves of the shoulder zones were tied to a rectangular coordinate system. The graphs obtained in the specified coordinates together with noticeable discrepancies have common features.

The general appearance of the graph is a smooth, rising curve. That is, such dependence can be described by a continuous increasing function. Measurements can determine the total length of the section equal to the width of the shoulder, as well as the height of the shoulder near the neck above the zero value.

All graphs at a certain distance have an inflection point. Up to this point, the convexity of the graph is directed upwards and determines the gradual decrease in the intensity of the growth of the function, which is mathematically determined by the negative values of the derivative function. The intensity of growth increases after this point, the derivative of the function has a positive sign. At the inflection point, the derivative changes sign. In the conditions of traditional anthropometric measurements, it is difficult to determine the exact location of this point.

In the conditions of three-dimensional modelling and saving information in DXF format, access to the coordinates of all points of the surface is provided, in particular, the points defining the outline of the shoulder. After placing the points in ascending order, a simpler algorithm determines the height difference between the next point and the previous one. The first section of the function is characterized by a gradual decrease of this difference. The inflection point determines the beginning of the increase in the difference between the coordinates of the next and previous points:

$$y_{k+1} - y_k > y_k - y_{k-1} . \qquad (1)$$

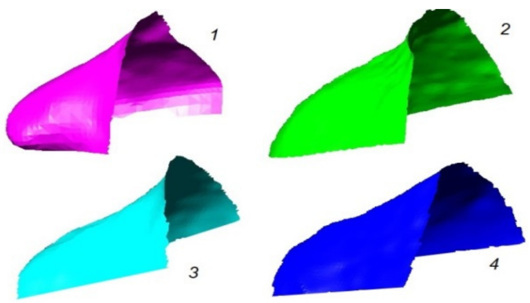


Figure 2. Spatial shapes of shoulder zones obtained by 3D scanning methods.

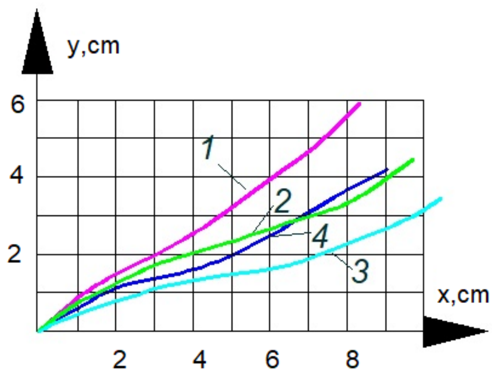


Figure 3. Front projections of shoulder zones.

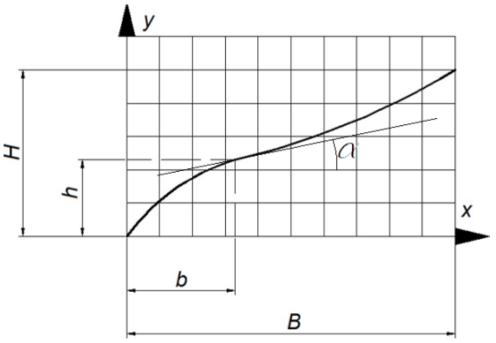


Figure 4. Graphic dependence of the shoulder line.

In such conditions, it is quite simple to determine for each adjacent pair of points the derivative, which is equal to the tangent of the angle of inclination of the tangent to the graph.

$$tg\alpha = \frac{y_{k+1} - y_{k-1}}{x_{k+1} - x_{k-1}} . \quad (2)$$

Then, for the characteristics of the frontal projection of the shoulder zone, it is advisable to highlight the following indicators, which are determined on the basis of three-dimensional scanning algorithms and subsequent computer processing of the results (Fig. 4).

Height of the shoulder above the base point is $H = \sum_{i=1}^{n} y_i$. Shoulder width is $B = \sum_{i=1}^{n} x_i$ (n is the total number of points). The height of the inflection point is $h = \sum_{i=1}^{k} y_i$. Distance to the point of intersection is $b = \sum_{i=1}^{k} x_i$. Angle of inclination of the tangent at the inflection point is *α*.

The function describing this curve can be represented in the form of two branches of square parabolas:

$$y = \begin{cases} a01 + a11 \cdot x - a21 \cdot x^2, x \le b \\ a02 + a12 \cdot x + a22 \cdot x^2, x \ge b \end{cases} . \quad (3)$$

The condition *y*=0 at *x*=0 gives the value *a*01=0.

At the point *x*=*b* for both functions *y*=*h*, and the derivatives of both functions are the same and equal to the tangent of the angle of inclination of the tangent to the shoulder line and the given point *t*=tan(*α*).

At the point *x*=*B*, the value of the function *y*=*H*.

The derivative of a function can be defined as:

$$\frac{dy}{dx} = \begin{cases} a11 - 2 \cdot a21 \cdot x, x \le b \\ a12 + 2 \cdot a22 \cdot x, x \ge b \end{cases} . \quad (4)$$

The above-mentioned conditions create a system of equations:

$$\begin{cases} a11 \cdot b - a21 \cdot b^2 = h \\ a02 + a12 \cdot b + a22 \cdot b^2 = h \\ a02 + a12 \cdot B + a22 \cdot B^2 = H \\ a11 - 2 \cdot a21 \cdot b = t \\ a12 + 2 \cdot a22 \cdot b = t \end{cases} . \quad (5)$$

The solution of the system can be presented in the form of:

$$a21 = \frac{h}{b^2} - \frac{t}{b}, \; a22 = \frac{H-h}{(B-b)^2} - \frac{t}{B-b},$$

$$a11 = \frac{2h}{b} - t, \; a12 = \frac{t \cdot (B+b)}{B-b} - \frac{2 \cdot (H-h) \cdot b}{(B-b)^2}, \quad (6)$$

$$a02 = h - \frac{t \cdot B \cdot b}{B-b} + \frac{(H-h) \cdot b^2}{(B-b)^2} .$$

Examination of horizontal cross-sections of the back surface of the shoulder demonstrates the proximity of them and the general vertical projection to an ellipse with semi-axes B and A (Fig. 5).

Under these conditions, the cross-section function can be written in the form:

$$z = A \cdot \sqrt{1 - \left(\frac{x}{B}\right)^2} . \quad (7)$$

The described functions make it possible to synthesize the general equation of the surface.

The obtained data make it possible to determine the lengths of arbitrary areas on the surface and to construct a surface sweep with any accuracy (Fig. 6).

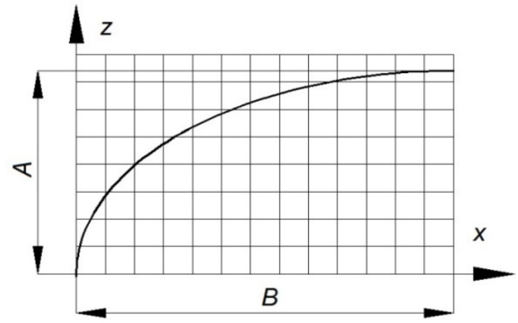


Figure 5. Vertical projection of the back surface of the shoulder.

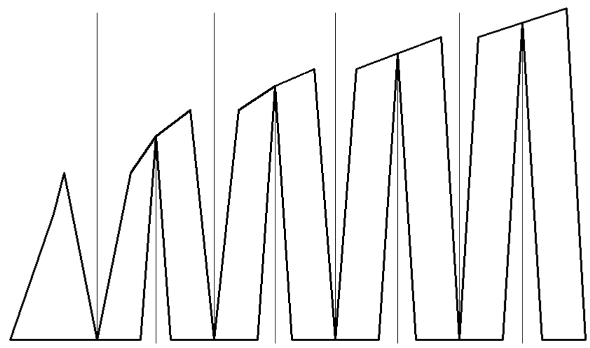


Figure 6. Sweeping of the back surface of the shoulder.

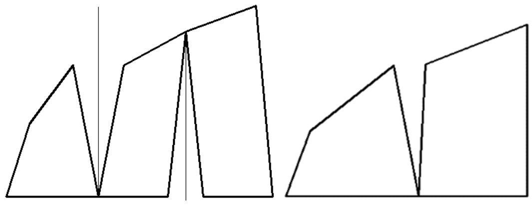
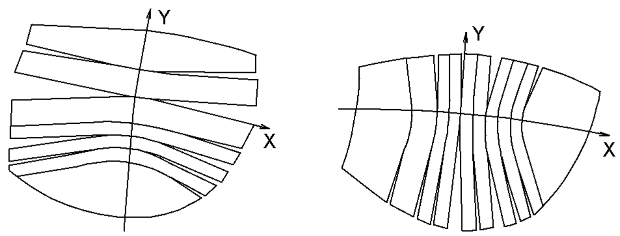
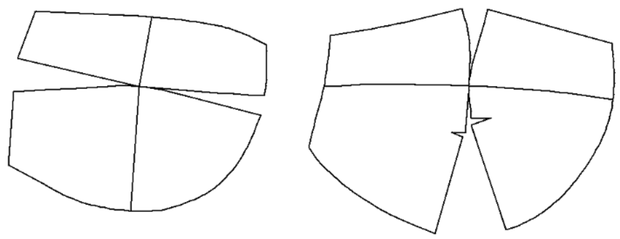


Figure 7. Sweeping of the back surface of the shoulder.



(a) (b)

Figure 8. Breast expansion: (a) initial expansion axis Y; (b) the output axis of deployment X.



(a) (b)

Figure 9. Design of the cup: (a) with horizontal division; (b) with vertical membership.

The actual design of the shoulder area of clothing can be created as a reduced sweep with two or one darts (Fig. 7).

According to a similar algorithm, the construction of the sweep of the mammary glands was performed, taking both the vertical and the horizontal as the starting axis of the sweep (Fig. 8).

The real design of the cup can be created with both horizontal and vertical articulation (Fig. 9).

Designs built on the basis of three-dimensional scanning provide a high quality fit for the individual consumer of both typical and atypical figures.

DISCUSSION

In contrast to previous studies, this article provides a thorough analysis of the most complex surfaces of the human body, which are surfaces of double curvature. In reality, such surfaces can be examined exclusively with the help of 3D measuring devices. At the same time, in the process of real pattern making, it is desirable to use a limited amount of information, reduced to certain dimensional features. 3D scanning allows to determine known dimensional features, as well as discover new ones. The dependencies obtained in the previous section allow us to formulate the basic requirements for dimensional features that define surfaces with double curvature, which include shoulder and chest areas. Thus, five dimensional characteristics are required to provide a description of the shoulder area. Two well-known parameters determine the width and height of the shoulder. The 3D scanning procedure allows to determine additional parameters. Direct measurement of the scanned surface determines the coordinates of the inflection point of the shoulder line, as well as the angle of inclination.

Comparison with previous studies gives the following advantages of the proposed method:

Possibility of using cheap Kinect devices instead of expensive ones for 3D scanning purposes is proved, whereas in previous studies [1,2,9] expensive 3D scanning methods are used.

Additional dimensional characteristics, which can be determined using 3D scanning, allow to achieve a greater level of proportionality of clothing in places of complex geometry. In previous studies, conventional dimensional characteristics were used [3,4]. Other studies used mathematical approaches [8,12], which are difficult to reduce to known methods. In previous studies, conventional dimensional characteristics were used [3,4]. Other studies used mathematical approaches [8,12], which are difficult to lead to or compare with known methods.

Assembling patterns with different number of cuts allows to adjust accuracy and proportionality;

Conducted research can clarify existing dimensional standards, taking into account that previous studies mainly discussed the general issues of improving anthropometric standards [17], the studies did not foresee additional dimensional characteristics that can be provided by 3D scanning methods [7].

The scanned surface in the form of a DXF file defines an array of point coordinates that can be calculated in distances using triangulation methods. The resulting parameters allow creating pattern with any accuracy, which is determined by the number of individual elements. At the same time, real pattern making determines the limitations of the structural elements. The overall size of the clothes for the specified body parts is determined by the number of individual elements of the sweep. Co-dimensionality parameters depending on the type of construction require additional research.

CONCLUSIONS

As a result of the analysis of three-dimensional scanning of the human body, the possibility of approximating the frontal projection with two branches of the parabola has been proven. New anthropometric points and dimensional features are defined, which are determined on the basis of three-dimensional scanning with the use of computer modelling. Such features include the height and width of the shoulder from the base point, the height and coordinate of the inflection point, the angle of inclination of the frontal projection curve at the inflection point. The analytical model of the surface of the human body in the area of the shoulders and chest allows you to build a surface scan with arbitrary accuracy, as well as the construction of the shoulder area of clothing with a given number of folds, which ensures a high quality of fit.

REFERENCES

1. Scott E.L.: The role of 3D measurement technology and anthropometric data for improved garment fit and sustainable manufacturing, Digital Manufacturing Technology for Sustainable Anthropometric Apparel, The Textile Institute Book Series, 2022, pp. 23-48. https://doi.org/10.1016/B978-0-12-823969-8.00002-2
2. Choi K-H.: 3D dynamic fashion design development using digital technology and its potential in online platforms, Fashion and Textiles, 2022, vol. 9, iss.I. https://doi.org/10.1186/s40691-021-00286-1
3. Slavinska A., Mytsa V., Syrotenko O., Dombrovska O.: Method of optimization of geometric transformations of design surfaces of a man's jacket, IOP Conference Series: Materials Science and Engineering, 2021, 1031. https://doi:10.1088/1757-899X/1031/1/012021
4. Jochen V., Lore V., Thomas P., et al.: Predicting User's Measurements without Manual Measuring: A Case on Sports Garment Applications, Applied Sciences, 2022, vol. 12(19), 10158. https://doi.org/10.3390/app121910158
5. Xia S., Li J., Istook C.L., et al.: A 2D image body measurement system developed with neural networks and a color-coded measurement garment, International Journal of Clothing Science and Technology, 2022, vol. 34, pp. 967-978 (12). https://doi.org/10.1108/IJCST-08-2021-0114
6. Riabchykov M., Alexandrov A., Trishch R., et al.: Prospects for the Development of Smart Clothing with the Use of Textile Materials with Magnetic Properties, Tekstilec, 2022, vol. 65(1), pp. 36-43. https://doi:org/10.14502/tekstilec.65.2021050
7. Rahman O., Navarro H.D.: Men's Physical Stature: Tackling Heightism and Challenges in Fashion Consumption, Behavioral Sciences, 2022, vol. 12(8), 270. https://doi.org/10.3390/bs12080270
8. Pietroni N., Dumery C., Falque R., et al.: Computational pattern making from 3D garment models, ACM Transactions on Graphics, 2022, vol. 41, iss.4, pp. 1-14. https://doi.org/10.1145/3528223.3530145
9. Zhang K.: Application of 3D Technology in Garment Design Template, Part of the Lecture Notes on Data Engineering and Communications Technologies book series, vol. 97, October 2021. https://doi.org/10.1007/978-3-030-89508-2_37
10. Bao C., Miao Y., Gu B., et al.: 3D interactive garment parametric pattern-making and linkage editing based on constrained contour lines, International Journal of Clothing Science and Technology, 2021, vol. 33, pp. 696-723. https://doi.org/10.1108/IJCST-09-2020-0137
11. Riabchykov M., Vilkov S., Nechipor S., Popova T.: Two-dimensional studies of thermomechanical properties of textile materials for 3D formation, Vlakna a Textil, 2018, vol. 2, pp. 87-92. http://vat.ft.tul.cz/2018/2/VaT_2018_2_14.pdf
12. Avadanei M.L., Olaru S., Dulgheriu I., Dorin Ionesi S., et al.: A New Approach to Dynamic Anthropometry for the Ergonomic Design of a Fashionable Personalised Garment, Sustainability, 2022, vol. 14(13), 7602. https://doi.org/10.3390/su14137602
13. Slavinska A., Syrotenko O., Mytsa V., Dombrovska O.: Development of an adaptive method for regulating corset comfort based on the parameters of design zones identification, Eastern-European Journal of Enterprise Technologies, 2020, vol. 5(1(107)), pp. 71-81. https://doi.org/10.15587/1729-4061.2020.211997
14. Zhang B., Sun Y., Zhong Z., et al.: Breast shape classification and discrimination driven by local features-focusing on Chinese women in their 20s, International Journal of Industrial Ergonomics, 2022, vol. 90, 103304. https://doi.org/10.1016/j.ergon.2022.103304
15. Chi C., Zeng X., Bruniaux P., Tartare G.: A study on segmentation and refinement of key human body parts by integrating manual measurements, Ergonomics, 2022, vol.65, pp. 60-77. https://doi.org/10.1080/00140139.2021.1963489
16. Slavinska A., Syrotenko O., Dombrovska O., Mytsa V.: Simulation model of the morphological field of data for constructing a universal design of trousers, Eastern-European Journal of Enterprise Technologies, 2020, vol. 1(1(103)), pp. 52-61. https://doi.org/10.15587/1729-4061.2020.192590
17. Wang X., Wang Y.: Development status and application of 3D anthropometric technology, Wool Textile Journal, , 2021, vol. 49(10), pp. 106-111. https://doi.org/10.19333/j.mfkj.20210103506