Classification and recognition of young males' waist-abdomen-hip shape based on body photos

DOI: 10.35530/IT.073.05.202160

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ABSTRACT – REZUMAT

Classification and recognition of young males' waist-abdomen-hip shape based on body photos

To improve somatotype and realize rapid customization of clothing, this study proposed a body-shape recognition method based on the front and side body photos. The shape parameters such as angles, heights, lengths, and ratios at the waist-abdomen-hip position were measured or calculated based on the manual and three-dimensional (3D) point cloud data of 180 young men. Through analysis, four morphological parameters were determined to classify the waist-abdomen-hip shape and establish the classification rules of the four body types (fat, normal, forward fat and obese). Finally, according to the front and side photos of the human body, the orthogonal silhouettes were extracted to obtain the four parameters that can be used to distinguish the waist-abdomen-hip body shape of young men, and the photo-based recognition method of the waist-abdomen-hip body shape could be realized automatically. The verification results showed that the recognition accuracy ratio reaches 93.3%, indicating that the waist-abdomen-hip shape identification system using this body-shape recognition method based on body photos is effective and can provide a basis for personalized clothing customization to satisfy the individual needs of the consumers.

Keywords: *waist-abdomen-hip shape, somatotype method, discriminant rules, size extraction, body photos*

Clasificarea și recunoașterea formei taliei-abdomenului-șoldului la bărbații tineri pe baza fotografierii corpului

Pentru a identifica somatotipul și a realiza personalizarea rapidă a îmbrăcămintei, acest studiu a propus o metodă de recunoaștere a formei corpului bazată pe fotografiile frontale și laterale ale corpului uman. Parametrii formei, cum ar fi unghiurile, înălțimile, lungimile și raporturile la poziția taliei-abdomenului-șoldului au fost măsurați sau calculați pe baza datelor manuale și a celor tridimensionale (3D) ale norilor de puncte pentru 180 de bărbați tineri. Prin analiză, au fost determinați patru parametri morfologici pentru clasificarea formei taliei-abdomenului-șoldului și stabilirea regulilor de clasificare a celor patru tipuri de corp (gras, normal, gras în partea frontală și obez). În cele din urmă, conform fotografiilor frontale și laterale ale corpului uman, siluetele ortogonale au fost extrase pentru a obține cei patru parametri, care pot fi utilizați pentru a distinge forma corpului pentru talia-abdomenul-șoldul bărbaților tineri, iar metoda de recunoaștere pe bază de fotografie a formei corpului ar putea fi realizată automat. Rezultatele verificării au arătat că raportul de acuratețe a recunoașterii ajunge la 93,3%, ceea ce indică faptul că sistemul de identificare a formei taliei-abdomenului-șoldului care utilizează această metodă de recunoaștere a formei corpului pe baza fotografiilor corpului este eficient și poate oferi o bază pentru personalizarea îmbrăcămintei pentru a satisface nevoile individuale ale consumatorilor.

Cuvinte-cheie: *forma taliei-abdomenului-șoldului, metoda somatotipului, reguli discriminante, extragerea mărimii, fotografii ale corpului*

INTRODUCTION

With the improvement of living standards, consumers need higher requirements for the individualization of clothing. The accurate classification of human body shape is an important factor to improve clothing fit since the body shape varies greatly due to the influence of various factors such as gender, age, generation and lifestyle [1]. Therefore, the somatotype method has become a heated topic in the field of clothing research.

To meet the needs of different body types for clothing fit, many scholars and global organizations focus on the classification researches of the whole human body shape based on the body parameters of the samples with different age groups or from different regions, mainly including the front and side body silhouettes, the curve characteristics of the body transverse and longitudinal section, the angles of the body surface, BMI value, etc. [2, 3].

For the ready-to-wear industry, women's body shape was first classified according to their age (such as Women, Misses and Junior) and body measurements (such as bust girth) [4]. According to the standard ISO/TR 10652-1991, the body shape was classified based on girth differences such as chest-waist girth difference [5]. However, the size differences cannot properly identify the specific morphology, since the shape of the waist curve may be different even if the waist girth is the same.

Therefore, scholars began to use quantitative indicators that can represent the characteristics of the human body for classification [6]. Petrova [7] took the hip-to-waist circumference ratio as a classification index and divided 24 women aged between 35 and 55 years old into straight, medium and curvy body types. Moreover, some scholars focused on using angle measurements to classify body shapes. Yoon et al. [8] measured six space angles of the body side surface to classify 317 Korean men into four types, including straight type, swayback type, bend-forward type and back-forward type. In the above research, the upper and lower body were considered as a whole part to classify body types according to height, girths, angles etc., however, the shape differences of the local positions such as neck, bust and hip were ignored.

The shape of the local positions has been analysed later. Hu et al. [9] focused on the different characteristics of the shoulder cross-section curves closely related to the shape to subdivide the shoulder shapes into four types. Pei et al. [10] proposed a new way of systematically extracting breast measurements and an asymmetry index to quantify the degree of asymmetry between left and right breasts to analyse breast shape. However, there are few researches on male body classification, especially on the waist-abdomen-hip position, therefore, it is difficult to meet the demands on men's trousers fit. Finding an appropriate classification method of waist-abdomen-hip shape, which is a research emphasis in the clothing industry, cannot only help consumers identify their body types easily but also help garment manufacturers produce well-fitting pants.

The above researches on body type classification generally used 3D scanning to obtain human body characteristic parameters and then conducted some mathematical statistical analysis to conclude [11]. Though the efficiency of 3D body scanning, from which an infinite number of measurements, body shape analyses, angles, and relational data can be extracted, is well known, high price and poor mobility issues have slowed their widespread applications in routine apparel production, particularly in small-business settings [12, 13]. Therefore, some scholars have explored more simpler and economical approaches for body measurement that have the potential to be used for small business applications and even for home use.

To obtain human body data quickly and realize body-shape recognition more conveniently, this research proposed a waist–abdomen–hip shape recognition method based on the front and side body photos, which has the potential to be used for clothing customization. The 3D body scanner was used to obtain the point cloud data of 180 young men, and the characteristic parameters, such as the angles, thicknesses, heights, and widths at each featuring part were measured to classify the waist–abdomen–hip shape and establish the body type classification rules. According to the human body contour extracted from the human body photos, the corresponding parameters were obtained to identify the body-type category automatically. The research results will provide the basis for virtual fitting, intelligent pattern design and 3D modelling, etc. [14–16].

METHODS

Body measuring experiments

The subjects were 180 male college students aged 20–25 years old, with heights between 162.0 and 180.0 cm, and weights between 51.00 and 80.00 kg. The temperature of the environment was (25±2)°C and the relative humidity was (65±5)%, which meets the environmental standard for naked measurement [17]. [TC] ^{2} 3D body scanner from the USA was used to obtain the human body data, and the subjects needed to stand in a designated position with a normal breathing state, wear white light-colour and tight-fit clothes and a hat to completely cover their hair without accessories.

Body measurements

By considering the influence of young men's waist-abdomen-hip shape on the pant structure design, 13 shape parameters such as the angles, heights, widths, and thicknesses of the waist-abdomen-hip position were selected for the shape analysis, and the definitions and measuring method of these specific shape parameters are shown in table 1 and figure 1. Since there were missing point-could data at the foot and head position by 3D scanning, the height data were manually measured, and the 3D method was used for the rest. The waist position is the thinnest position of the upper body from the front view, and the abdomen and hip positions are both convex from the side view. The edge points which intersect with the contour of the human body at these three sections (S_W, S_A and S_H) are the waist point (P_W), abdomen point (P_A) and hip point (P_H). A_W is used to reflect the curvature of the waist and the other two angles including A_A and A_H are necessary to characterize the prominence of the abdomen and hip. R_n (n = W, A, H) means the ratio between the width and depth at the waist, abdomen and hip position, which can represent the flat or round degree of the curve shape.

Before measuring, the 3D human body point cloud data were denoised to avoid the appearance of noise and holes, which will cause the body contour curve to be uneven [18], and then the parameters of all the subjects were measured by the software IMAGEWARE.

Silhouette extraction from body photos

The photos of the subjects were obtained by the 2D body measured method, which simply uses digital photos taken from off-the-shelf cameras to obtain body photos [19], as shown in figure 2 and needed to be pre-processed, such as adjusting the contrast and sharpness to make the body easier to recognize. The pixels of the photos were divided into several areas

Table 1

DEFINITIONS OF THE PARAMETERS RELATED TO THE WAIST-ABDOMEN-HIP SHAPE

Methods	Number	Name	Definition
Manual method	1	H	The distance from the top of the head to the ground
	2	H_W	The distance from the S_W to the ground
	3	H_A	The distance from the S_A to the ground
	4	H_H	The distance from the S_H to the ground
3D method	5	W_W	The horizontal distance at the waist from the front view
	6	W_A	The horizontal distance at the abdomen from the front view
	7	W_H	The horizontal distance at the hip from the front view
	8	T_W	Maximum horizontal depth of the waist at the level of P_W
	9	T_A	Maximum horizontal depth of the abdomen at the level of P_A
	10	T_H	Maximum horizontal depth of the buttock at the level of P_H
	11	A_H	The angle of the hip convex with the apex of P_H
	12	A_A	The angle of the abdomen convex with P_A as the apex
	13	A_W	The angle of the waist with P_W as the apex

Methods	Number	Name	Definition	Number	Name	Definition	Number	Name	Definition
Calculated method	14	R_W	W_W/T_W	17	R_{WWA}	W_W/W_A	20	R_{TWH}	T_W/T_H
	15	R_A	W_A/T_A	18	R_{WWH}	W_W/W_H	21	R_{HWA}	H_W/H_A
	16	R_H	W_H/T_H	19	R_{TWA}	T_W/T_A	22	R_{HWH}	H_W/H_H

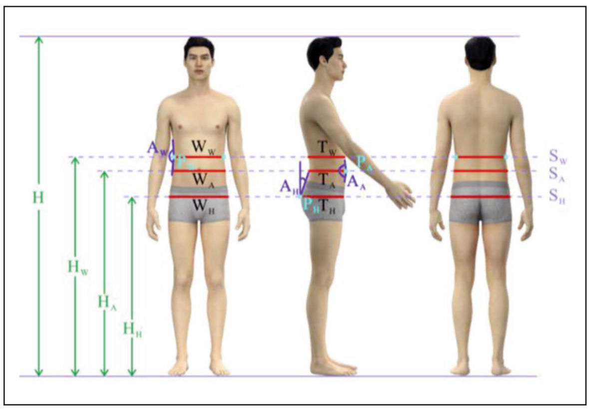


Fig. 1. Measurement methods

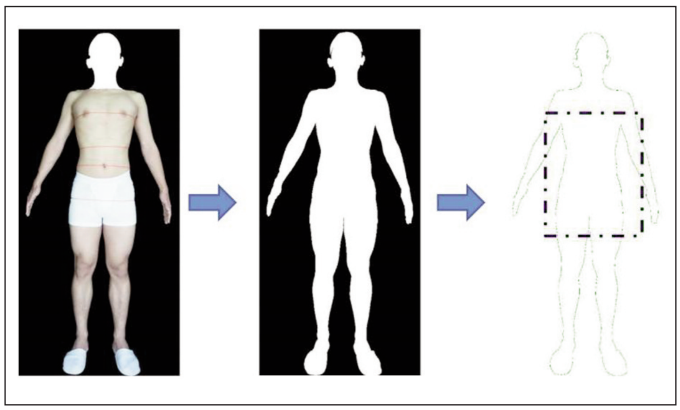


Fig. 2. Original photo, photo binarization and body silhouette

according to the grey level, and then the Optimum Thresholding (OTSU) [20] method was used to find a suitable threshold to convert the original RGB photo into a binary photo, as shown in figure 2. To make the target contour smooth and eliminate holes, the opening operation was used with the imopen function to eliminate the cluttered and small areas in the binary image caused by the original image noise, and the filling holes method was used with the imfill function to turn all non-boundary areas in the binary image into the background colour. Finally, the body silhouette was extracted, and the dotted box area was located to recognize the feature points at the waist-abdomen-hip part, as shown in figure 2.

RESULTS AND DISCUSSION

To ensure the accuracy and reliability of the measurements, all the data were firstly pre-processed, and 173 valid samples were determined. The measured data were tested for normal distribution and descriptive statistics, and all 22 parameters were distributed normally. Therefore, a subsequent analysis of the sample data could be performed.

Cluster analysis

The major problem of using the K-means algorithm in data mining is the choice of variables [21]. If all 22 variables were extracted, the high dimensional space would be formed with poor clustering results. Therefore, it is important to determine the appropriate variables.

To avoid the repeatability of the variables, the calculated variables (such as the ratio between the widths and thicknesses) and the angles were analysed, and the coefficient of variation [22] was used to determine the appropriate variables. The larger the coefficient of variation (standard deviation/mean), the bigger the difference between the data, and the greater influence on the waist-abdomen-hip shape.

Table 2

STATISTICAL ANALYSIS OF RELATED VARIABLES						
Variables	A_H (°)	A_A (°)	A_W (°)	R_W	R_A	R_H
SD	3.640	6.221	4.982	1.879	0.090	0.075
Mean	12.370	168.60	164.787	1.364	1.430	1.418
CV(%)	**29.423**	3.690	3.023	**7.222**	**6.298**	5.294
Variables	R_{WWA}	R_{WWH}	R_{TWA}	R_{TWH}	R_{HWA}	R_{HWH}
SD	0.044	0.048	0.053	0.065	0.024	0.030
Mean	0.924	0.798	0.970	0.832	1.079	1.238
CV(%)	4.793	6.067	5.419	**7.862**	2.224	2.402

Note: SD means standard deviation. CV means coefficient of variation.

Descriptive statistics such as the standard deviation (SD), Mean and coefficient of variation (CV) of each parameter are listed in table 2. According to table 2, the coefficient variation of A_H, R_{TWH}, R_W, R_A, R_{WWH} is significantly higher than other characteristic variables, indicating that the five characteristic variables have a greater degree of dispersion and impact on the waist-abdomen-hip shape. By comparing the correlation of five variables, the correlation coefficient between R_{TWH} and R_{WWH} is 0.748, which shows that there is a high correlation between the two variables. Therefore, four variables including A_H, R_{TWH}, R_W and R_A were selected as the variable subsets for the K-means cluster.

Since the reasonable cluster number will also affect the cluster effect, Elbow Method [23] and Silhouette Coefficient Method [24] were both used to determine the cluster number.

The core indicator of the Elbow Method is the sum of squares due to error (SSE), and its calculation formula is the following:

$$SSE = \sum_{i=1}^{k} \sum_{p \in C_i} |p - m_i|^2 \quad (1)$$

In formula 1, C_i represents the i-th cluster, p is the sample point in C_i, m_i – the centroid of C_i, and SSE – the clustering error of all samples, representing the quality of the clustering effect.

In addition, the Silhouette Coefficient is also a way to evaluate the quality of the clustering results. The silhouette coefficient of the sample point X_i is defined as follows:

$$S = (b - a) / \max(a,b) \quad (2)$$

In formula 2, a means cohesion which represents the average distance between X_i and other samples in the same cluster, and b is the average distance from all samples in the nearest cluster, named the degree of separation. The value of the Silhouette Coefficient is between [–1,1]. The larger the value, the better the cohesion and separation.

Combing the results of figures 3 and 4, when the cluster number is two, the classification effect is the best, and when the number is four, the classification result is better. Considering that the complexity of human body shape, two kinds of body shapes cannot reflect the difference in body shape, and it is difficult to meet the requirements of subsequent personalized clothing customization for fit. Therefore, the cluster number was set as four to carry on the K-means cluster analysis by using four variables, including A_H, R_{TWH}, R_W and R_A.

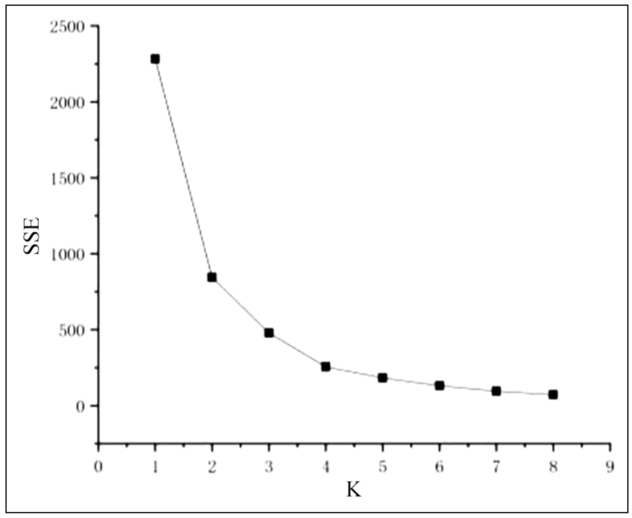


Fig. 3. Elbow method

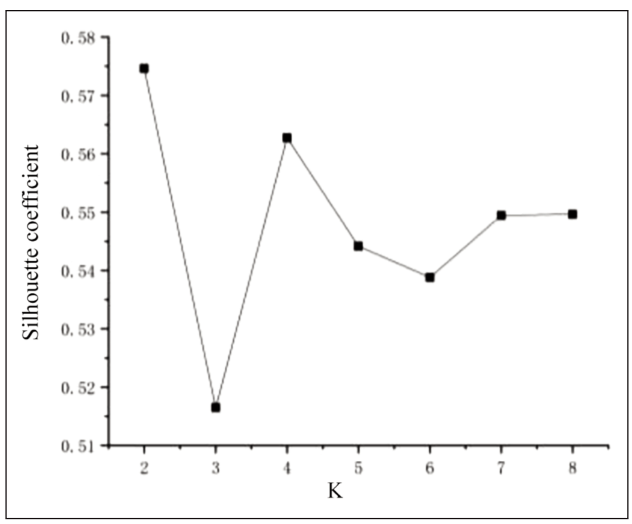


Fig. 4. Silhouette coefficient method

Shape classification

The waist-abdomen-hip shape of 173 young men was divided into four categories, and the results are shown in table 3. The number of the first and fourth types is relatively even, and the third body type accounted for a relatively small proportion of less than 10%.

There are certain differences between body types, especially the value of A_H, and the values differ significantly between the first and the third types.

To analyse the four different body types of waist–abdomen–hip shape more intuitively, the front, side and sectional shapes of the four types were compared, and it is found that the shape difference is more obvious from the side and sectional view, as shown in figures 5 and 6.

Figure 5 shows the side view extracted between the waist and crotch lines, the hip and abdomen curves are landmarked to represent the hip and abdomen convex respectively, which are drawn by two red curves. The vertical distance between the abdomen and hip lines can reflect the differences among the four body types, and the D_{WH} value of each body type, which means the horizontal distance between the left side points at the waist and hip position from the side view, is also significantly different. From the side view, the body shape of the first type is slightly fatter, though the abdomen and hip convex are not obvious. The second type is well-proportioned and the abdomen is flat. The third type has a raised hip, with a sunken back waist, and the whole waist-abdomen-hip leans forward. The fourth type has a plump hip and higher abdomen with a significant protrusion, the whole waist-abdomen-hip shape is round from the overall view.

Figure 6 shows the sectional view of the waist, abdomen and hip which can also reflect the difference between each type. The point cloud data of the cross-sectional curves were extracted to be moved and rotated as shown in figure 6, *a* and then the

Table 3

FINAL CLUSTERING CENTER						
Clustering type	**Number of samples**	**Proportion (%)**	A_H (°)	R_{TWH}	R_W	R_A
1	36	20.81	7.75	0.832	1.365	1.419
2	74	42.77	11.38	0.850	1.341	1.420
3	15	8.67	19.88	0.793	1.410	1.482
4	48	27.75	15.02	0.816	1.383	1.473

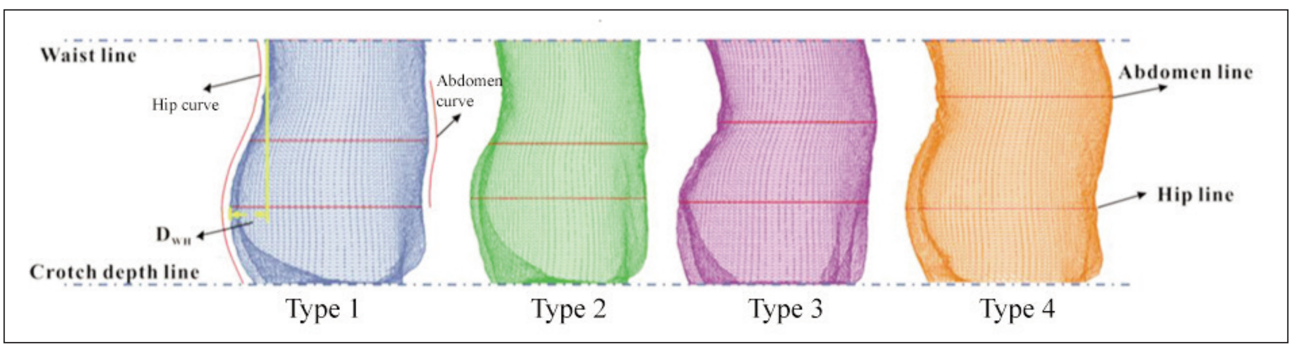


Fig. 5. Side view of the waist-abdomen-hip shape

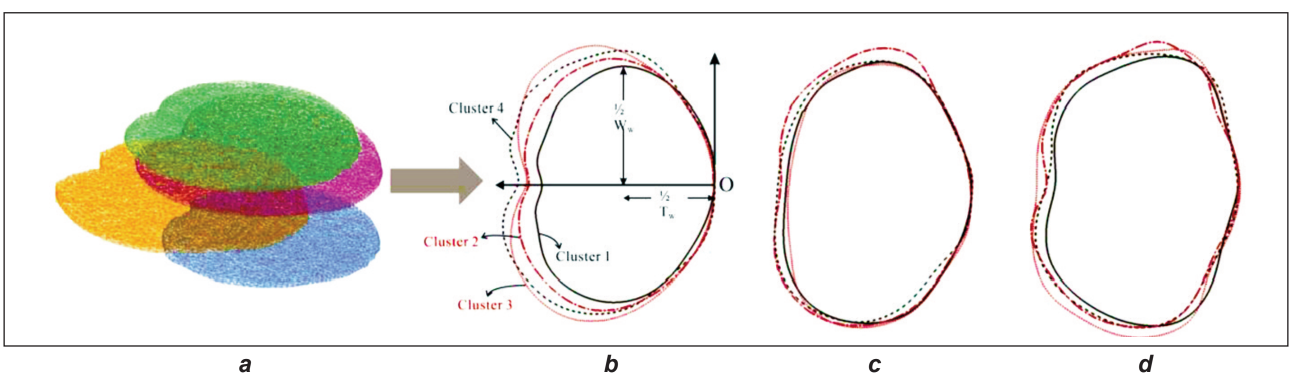


Fig. 6. Sectional view of the waist-abdomen-hip shape:
a – messy point cloud; *b* – waist section; *c* – abdomen section; *d* – hip section

curves of the four body types were overlapped at the convex points of the waist, abdomen and hip, as shown in figure 6, *b, c* and *d*.

By comparison, there are significant differences among the cross-sectional curves of the waist, which is related to the R_W of each body type. Take the R_W value of cluster one as an example, the value can be calculated by (1/2) W_W / (1/2) T_W, as shown in figure 6, *b*. From the perspective of the cross-sectional curve, the depth of the waist curve of the third and fourth types is larger than others, and the curve shape of the second type is relatively round.

Therefore, with the combination of the differences at the side and sectional views of the four types, the first type is named fat body, the second type is the normal body, the third type is the forward fat body, and the fourth type is the obese body respectively.

The discriminant rules were finally established to identify the four body types based on four parameters including A_H, R_{TWH}, R_W and R_A, and the results are shown in table 4.

Table 4

DISCRIMINANT RULES OF THE FOUR WAIST-ABDOMEN-HIP TYPES

Clustering type	Classification rules
1	F1>F2,F1>F3,F1>F4
2	F2>F1,F2>F3,F2>F4
3	F3>F1,F3>F2,F3>F4
4	F4>F1,F4>F2,F4>F3
Discriminant formula	
$F1 = 5.47*A_H + 859.55*R_{TWH} + 417.35*R_W + 212.34*R_A - 815.47$	
$F2 = 7.96*A_H + 868.60*R_{TWH} + 416.19*R_W + 213.12*R_A - 846.40$	
$F3 = 13.66*A_H + 865.32*R_{TWH} + 419.29*R_W + 208.28*R_A - 930.16$	
$F4 = 10.41*A_H + 864.32*R_{TWH} + 420.00*R_W + 206.97*R_A - 871.59$	

The discriminant rules were also verified with 173 samples, and 172 samples were correctly classified to show the accuracy ratio reaches 99.4%, indicating that the classification rules are effective.

Body type recognition based on body photos

According to the contour curve characteristics of the body's front and side body shape, the typical height range for the limits was analysed to look for a landmark, and then the shape characteristics were used to determine the actual position [25]. To obtain the four parameters in the discriminant rules, the main feature points including waist point (P_W), abdomen point (P_A), and hip point (P_H) ought to be identified, as shown in figure 7, *a*.

Take the abdomen landmark as an example. Through the statistical analysis of the basic body proportion, the abdomen height is between 40% and 47% of the body height. As shown in figure 7, *b* the line *LA* is the upper limit, and the line *LB* is the lower limit. The line *L* represents the random line between the line *LA* and the line *LB*.

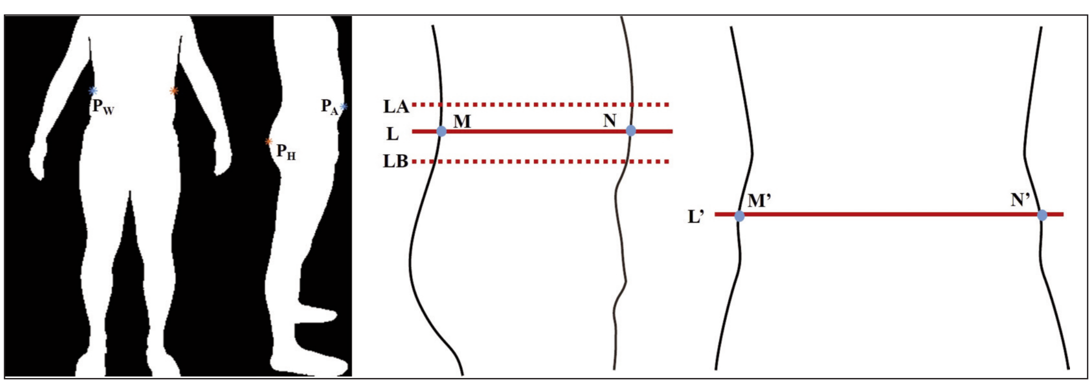
From the side view of the human body, the most prominent point on the right side at line *L* was searched from *LA* to *LB* with a line spacing of one pixel and was marked as point *N*. Then the left point *M* at line *L* was also obtained, and the distance between point *M* and *N* on line *L* was the abdomen thickness (T_A).

From the front view, *L′* could be determined by using the height of line *L*, as shown in figure 7, *c*. The left and right points at the line *L′* with the intersection of the body contour were marked as the points *M′* and *N′*, and the distance between them was the abdomen width (W_A). The determination method of the other points was similar, and the corresponding parameters such as angles and ratios were calculated.

Error analysis

To verify the accuracy of this body-type identification method based on body photos, the body photos of 30 samples were obtained to extract the four variables, and according to the established discriminant rules, the body type was automatically classified.

Compared with the classification results of the 3D measurements, the results are shown in figure 8. Among the 30 samples, 28 are correctly classified to show the accuracy ratio reaches 93.3%, with a 3.3 percent increase by comparing with the results in Cai's [26] paper.



a *b* *c*

Fig. 7. Graphical representation of: *a* – feature points; *b* – abdomen thickness; *c* – abdomen width

Table 5

ERROR ANALYSIS BETWEEN THE PHOTO AND THE 3D MEASUREMENTS							
Variable name	**Type**	**Mean**	**Standard deviation**	**Error range**	**Mean absolute error**	**Sig of t-test**	**Correlation coefficient**
A_H	2D extracted	10.937	2.931	–1.16~1.34	0.541	0.143	0.982
	3D measured	10.533	3.372				
R_{TWH}	2D extracted	0.817	0.052	–0.10~0.03	0.016	0.129	0.901
	3D measured	0.827	0.044				
R_W	2D extracted	1.375	0.085	–0.09~0.10	0.027	0.344	0.904
	3D measured	1.364	0.076				
R_A	2D extracted	1.411	0.089	–0.12~0.09	0.037	0.637	0.837
	3D measured	1.416	0.075				

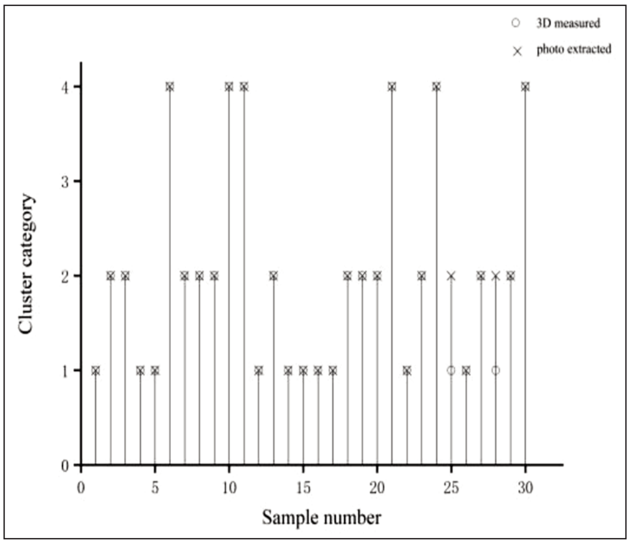


Fig. 8. Recognition result of 30 samples

The photo and 3D measurements were also compared and analysed to verify the accuracy, and the error results are shown in table 5. The difference in the mean and standard deviation between the photo extracted value and the 3D measured value is not significant, and the correlation coefficient of each variable is high, indicating that there is a high consistency between the two methods. However, the correlation coefficient of R_A is 0.837, since the position of the abdomen was difficult to be determined, influencing the accuracy of the width and thickness at the abdomen position.

The photo-based extracted values and the 3D measured values were further paired with the t-test, and the results are shown in table 5.

The Sig. value of the t-test is greater than 0.05, indicating that there is no significant difference between the 3D measured and the photo-based extracted values, and the error ranges of the ratio values almost are all within ±0.1. Therefore, it can be considered that the automatic recognition method of the waist–abdomen–hip shape based on the body photos is feasible.

CONCLUSIONS

In this study, the automatic recognition method of the waist-abdomen-hip shape based on body photos was proposed. 180 male college students aged 20–25 were selected to obtain human body data through 3D measurement, photo measurement and manual measurement. Based on the analysis of the shape parameters extracted from 3D point cloud data, the waist-abdomen-hip shape was divided into four types, including the fat type, normal type, forward fat type and obese type, and the corresponding classification rules for the four types were established based on the four parameters (such as A_H, R_{TWH}, R_W and R_A). The automatic extraction of the parameters based on body photos was realized through feature point recognition, and the waist-abdomen-hip shape recognition system was developed with the classification rules. The verification results show that the accuracy of automatic recognition was 93.3%, and the significance (Sig) of the t-test was greater than 0.05, indicating that there is a good consistency between the photo extracted and 3D measurements to show that the method is feasible and effective. This research results can provide the basis for the pattern design of young men's trousers, and the method proposed in this research can be extended to other parts of the body and enrich the body type classification of young men even children and young females.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (Grant No. 61702461), Application and Basic Research Project of China National Textile And Apparel Council (Grant No. J202007), the Fundamental Research Funds of Zhejiang Sci-Tech University (Grant No. 2020Q051), the Clothing Culture Innovation Team of Zhejiang Sci-Tech University (Grant No. 11310031282006), Science and Technology Guiding Project of China National Textile and Apparel Council (Grant No. 2018079), 2021 National innovation and entrepreneurship training program for college students(Grant No. 202110338042).

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