Mong Hien Thi Nguyen[1], Tuong Quan Vo[1], Mai Huong Bui[1], Van Anh Pham[2]
[1] University of Technology-VNU–H CM, Faculty of Mechanical Engineering, Ho Chi Minh City, Vietnam
[2] Pham Van Dong University, Faculty of Engineering - Technology, Quang Ngai, Vietnam

The Algorithm to Automatically Extract Body Sizes and Shapes
Algoritem za samodejno pridobivanje podatkov o velikosti in telesnih oblikah

Corresponding author/*Korespondenčna avtorica:*
Mong Hien Thi Nguyen
E-mail: ntmhien14719@h cmut.edu.vn
ORCID ID: 0000-0002-5384-9775

Abstract

This study presents an algorithm to automatically extract the size and body shape of a 3D scanned model. The methods used in this research include factor analysis, linear regression equation, cluster analysis, and discriminant analysis. These are used to analyze the body's shape and choose the best primary dimensions for establishing the sizing system table. Authors use fuzzy logic to establish the mathematical model. In this model, the input variables are the inseam height and the neck girth measurements, and the output variables are the numbers of the human size coding and body shape. In addition, the rotation matrix and the optimal function are used to write an algorithm to estimate the neck girth and inseam measurements. Furthermore, a simple approach based on vertices and surface normal vector data, together with optimal searching, is adapted to estimate the primary dimensions. This estimation algorithm, combined with the fuzzy logic model, makes the automated process of extracting the size and body shape possible. The findings of the study suggest a new research method for quickly informing people about their body shape. This supports purchasing clothes and designing tailored clothing. The automatic algorithm will be very useful for buying clothes face-to-face or online.
Keywords: 3D scanner, extracting size, body shape, automatic, fuzzy logic

Izvleček

V prispevku je opisan algoritem za samodejno ugotavljanje velikosti in oblike telesa iz 3-D skeniranega modela. Za postavitev tabele dimenzioniranja so bile uporabljene metoda faktorske analize in linearna regresijska enačba ter analiza grozdov, diskriminantna analiza pa je bila uporabljena za analizo oblike telesa in izbiro najprimernejših primarnih dimenzij za načrtovanje ciljne funkcije. Metoda mehke logike je bila uporabljena za postavitev matematičnega modela z vhodnimi podatki, ki so spremenljive vrednosti primarnih dimenzij, in sicer sta to višina v razkoraku in obseg vratu. Te spremenljive vrednosti v velikostni tabeli kažejo na velikost in obliko telesa. Poleg tega se metoda rotacijske matrike združuje z optimalno funkcijo, ki se uporablja za pisanje algoritma pri oceni obsega vratu in dolžine v razkoraku. Preprost pristop, ki temelji na podatkih o vozliščih in površinskih normalnih vektorjih ter optimalnem iskanju, je prilagojen za oceno obsega vratu in višine v razkoraku. Te vrednosti bodo povezane z algoritmom mehke logike, ki se izvaja pri avtomatizaciji procesa. Študija podaja novo raziskovalno metodo za hitro določanje velikosti in oblike telesa posameznika za potrebe nakupovanja oblačil oz. oblikovanja oblačil. Ta samodejni algoritem je uporaben tako za kupce pri nakupu oblačil v trgovini ali na spletu kot tudi za izdelovalce oblačil za optimalno izbiro velikosti pri oblikovanju modela za potencialnega kupca.
Ključne besede: 3-D skener, določanje velikosti, oblika telesa, samodejno, mehka logika

1 Introduction

In the process of manufacturing garment technology, measurements have a significant impact on pattern making, establishing the sizing system tables, and analyzing the body shape. Much research has been done on measuring the human body with 3D scanners, which are widely used in the garment industry, such as creating avatars to illustrate the measurement method [1–4]. The authors extracted the measurements and saved body shapes using a 3D body scanner. In addition, 3D scanning also applies to assessing body movement and testing virtual samples [5]. This study was conducted on a sample consisting of 54 healthy males. Participants ranged in age from 9 - 37 years old, with an average height of 1.63‑1.87 m with a weight range of 35‑95kg. The 3D body scanner is used to test the correlation between the body and the virtual samples [6‑9]. Updating anthropometric data will help garment and leather companies ensure product quality, so several studies have been aimed at extracting anthropometric data with 3D scanners [10‑12]. The results of the 3D scanner are applied to classify the body shapes and are tested with the body dimensions [13‑17]. Avatars of various sizes are created by automated 3D scanning. Avatars wear realistic clothes [18, 19]. This research aims at comparing the accuracy of the body's dimensions extracted by the 3D scanner to the real-life models. The first model wore underwear and clothes for scanning. The second model only wore underwear. The results show that the dimensions of the first model are larger than those of the second model [20]. In another study that used 3D scans to accurately determine the position of the bodies' necks for different types of neck shapes, the authors cut across the neck position on the 3D scanner. The results show that the neck girth has the shape of a spline curve [21]. Measurements extracted from a 3D scanner were applied to the design of a 2D pattern or when simulating avatars [22‑25]. There are many other studies about designing 3D pattern to be converted to 2D patterns [26, 27]. This shows that body dimensions on 3D scanners are used for establishing sizing tables, analyzing body shapes, researching the fit of clothes, simulation of 3D patterns, designing patterns, or designing a virtual costume. No research has been conducted on the subject of automatically extracting the size and body shapes through primary dimensions.

2 Material and Methodology

2.1 Material

Data to perform measurement extraction on the 3D body scanner were collected from a group of young men aged 18–25 years. The numbers of the samples are calculated by equation 1:

$$n = \frac{t^2 S^2}{m^2} \qquad (1)$$

where n is a number of samples, S is standard deviation, $m = 1$, and $t = 2.58$. The total number of people attending this sampling measurement process is 542.

The dimensions to input into the equation for the extracted measurements are the neck girth and inseam height. These are two variables to put into the equation to get the fit size and body shape. The dimension of the neck girth is determined by 3 points: the front neck hollow point (a), the neck point that intersects the shoulder and the neck (b), and the point on the seventh cervical vertebra (c). The inseam height is determined from the bottom to the floor (d) (Figure 1), [28].
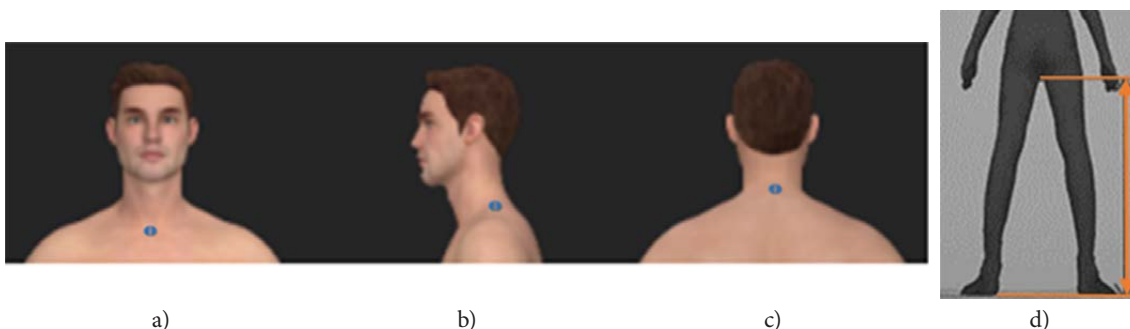

| a) | b) | c) | d) |

Figure 1: The neck girth and inseam height

2.2 Methodology

The Matlab software uses the fuzzy logic method to extract the size and shape.

The interpolation and optimization method in the algorithm automatically extracts two primary dimensions and combines them with the fuzzy logic method to extract size and body shapes.

3 Results and Discussion

3.1 The size selection model

The mathematical model includes the sizing system data and two primary dimensions (Figure 2). These two primary dimensions are the inputs of the fuzzy controller. The first output is the size, and the second output is the size's shape. In every dimension group, the boundary conditions are different, such as 37.26 cm $\leq$ x1 $\leq$ 44.02 cm, and 62.5 cm $\leq$ x2 $\leq$ 87.5 cm. Subsequently, the results of the simulation are compared with the coding size and body shape in the size system given in Table 1. The values of the model's set parameters are the results of establishing the sizing system table. Two output variables are the coding size and sign shape. The range values of the two variables depend on the limitation and show differences between selecting the size by the traditional or the fuzzy method. There are five membership functions for input 1, and five membership functions for input 2.

3.2 The coding sizing system table

The coding sizing system table is added with two information columns: the coding size column and the inseam measurement column. The coding size column is numbered from 1-24. Inseam measurement is coded according to the group. Group A is 65 cm, group B is 70 cm, group C is 75 cm, group D is 80 cm and group E is 85 cm. In this table, every group has a different range of the inside leg measurement (Table 1). This range is the standard deviation of the inseam.

3.3 The Input-Output of the fuzzy logic

There are two variables for the input and two variables for the output of the fuzzy controller. Each input has multiple membership functions, such as the first input, which has five membership functions: very small, small, average, large, and very large (Figure 3a). The second input is the inseam dimension, which has five membership functions: very short, short, average, high, very high (Figure 3b).
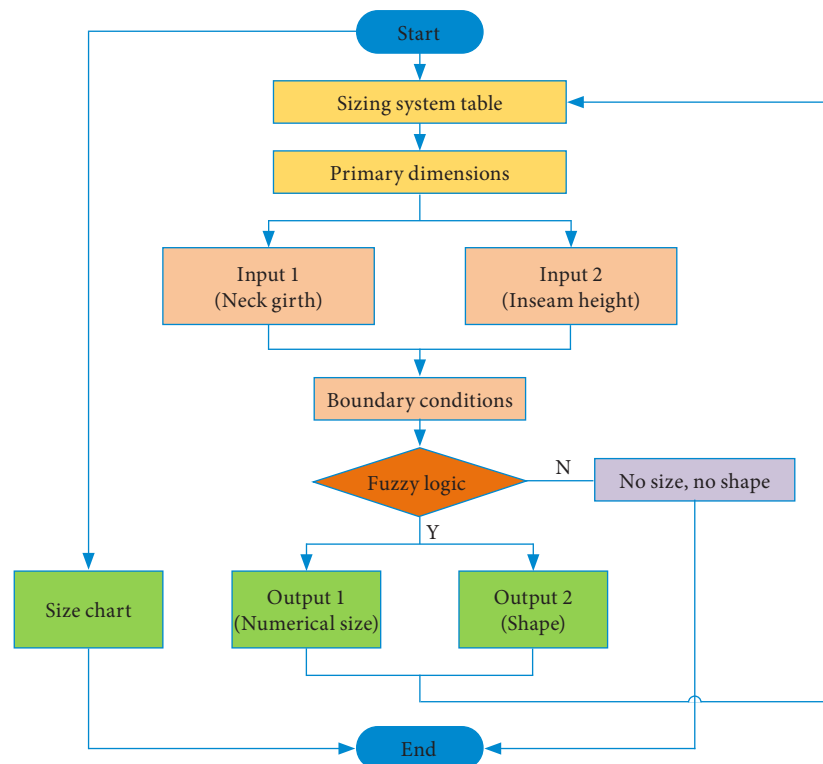
Figure 2: Selecting the size and the size's shape in fuzzy techniques

Table 1: The coding of groups

| Group A: Inseam length [62.5−67.5 cm]				
Sign size	65/A1-1	71/A2-1	77/A3-2	83/A4-2
Coding size	1	2	3	4
Sign shape	1	1	2	2
Neck girth (cm)	37.73	38.66	39.60	40.53
Inseam (cm)	65	65	65	65
Group B: Inseam length [67.5−72.5 cm]				
Sign size	65/B5-1	71/B6-1	77/B7-2	83/B8-2	89/B9-3
Coding size	5	6	7	8	9
Sign shape	1	1	2	2	3
Neck girth (cm)	38.25	39.18	40.12	41.05	41.99
Inseam (cm)	70	70	70	70	70
Group C: Inseam length [72.5−77.5 cm]				
Sign size	65/C10-1	71/C11-1	77/C12-2	83/C13-2	89/C14-4
Coding size	10	11	12	13	14
Sign shape	1	1	2	2	4
Neck girth (cm)	38.77	39.70	40.64	41.57	42.51
Inseam (cm)	75	75	75	75	75
Group D: Inseam length [77.5−82.5 cm]				
Sign size	65/D15-1	71/D16-1	77/D17-2	83/D18-2	89/D19-4
Coding size	15	16	17	18	19
Sign shape	1	1	2	2	4
Neck girth (cm)	39.29	40.22	41.16	42.09	43.03
Inseam (cm)	80	80	80	80	80
Group E: Inseam length [82.5−85 cm]				
Sign size	65/E20-1	71/E21-1	77/E22-2	83/E23-2	89/E24-4
Coding size	20	21	22	23	24
Sign shape	1	1	2	2	4
Neck girth (cm)	39.81	40.74	41.68	42.61	43.55
Inseam (cm)	85	85	85	85	85
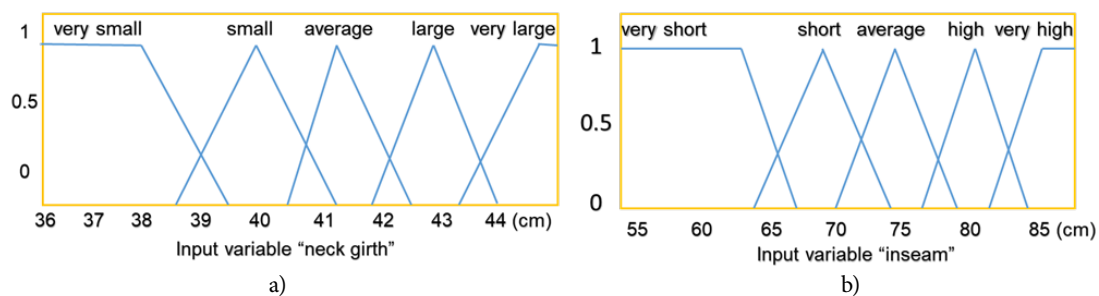
Figure 3: a) The flowchart of membership functions of the first input,
(b) The flowchart of the membership functions of the second input

Additionally, there are 24 output membership functions for the valve output 1 on the system (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24), and the result is numerical 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24. In output 2, there are four shapes (trapezoid short leg, trapezoid tall height, oval, and rectangle). They are coded as 1, 2, 3, 4. These outputs are all constants (Table 2).

The curved plane of the fuzzy logic for the algorithm results (Figure 4) shows that there is a difference between the sizes of the four body shapes. It is perfectly consistent with the size chart setup results.
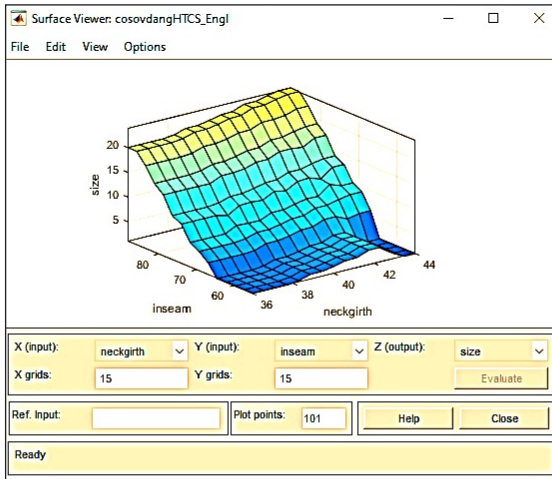
3.4 Flowchart for automatic extraction of size and body shape from 3D scanner data

The Matlab software uses the established size chart and built in algorithm to automatically estimate the neck girth and inseam, presented in flowchart form (Figure 5).

3.5 The process of automating the body scan to extract the size and body shape

The process of extracting the size and body shape is automated by using the algorithm to estimate the neck's girth and the inseam height measurements on the Matlab software. In this algorithm, the neck measurement process on the 3D scan database follows two schemes. In the options, a theta is the angle between the plane D and the floor; the D-plane contains the neck hollow and is perpendicular to the model's symmetry plane.

Figure 4: Curved plane fuzzy logic of the algorithm result

Table 2: *The range of the parameters of membership functions for input variables*

| The first input					
Membership function	Parameter (cm)	Size	Membership function	Parameter (cm)	Size
Very small	[3726 37.73 38.20]	1	Large	[40.06 40.53 41]	4
	[37.78 38.25 38.72]	5		[40.58 41.05 41.52]	8
	[38.30 38.77 39.24]	10		[41.10 41.57 42.04]	13
	[38.82 39.29 39.76]	15		[41.61 42.09 42.56]	18
	[39.34 39.81 40.28]	20		[42.14 42.61 43.08]	23
	[37.26 38.77 40.28]			[40.06 41.57 43.08]	
Small	[38.19 38.66 39.13]	2	Very large	[41.52 41.99 42.46]	9
	[38.71 39.18 39.65]	6		[42.04 42.51 42.98]	14
	[39.23 39.70 40.17]	11		[42.56 43.03 43.50]	19
	[39.75 40.22 40.69]	16		[43.08 43.55 44.02]	24
	[40.27 40.74 41.21]	21		[41.52 42.77 44.02]	
	[38.19 39.7 41.21]		The second input		
Average	[39.13 39.60 40.07]	3	Membership function	Parameter (cm)	
	[39.65 40.12 40.59]	7	Very short	[60, 65 70]	
	[40.17 40.64 41.11]	12	Short	[65 70 75]	
	[40.69 41.16 41.63]	17	Average	[70 75 80]	
	[41.21 41.68 42.15]	22	High	[75 80 85]	
	[39.13 40.64 42.15]		Very high	[80 85 90]	
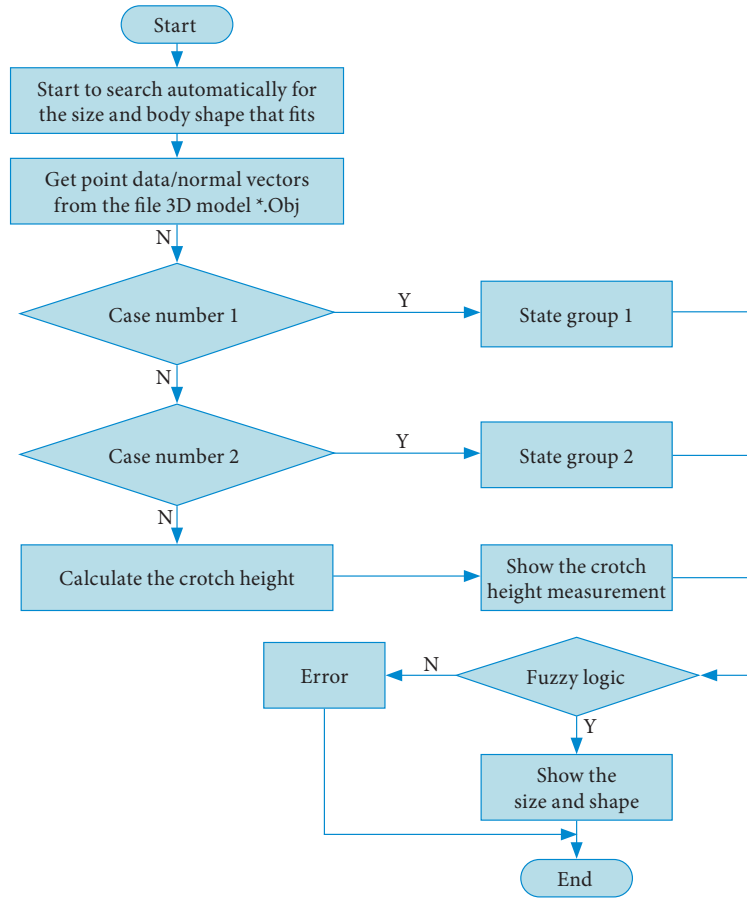
Figure 5: Automated flowchart for extracting size and body shape from 3D scanner data

Case 1: Estimate the neck girth by scanning the neck hollow

Using data from a 3D scanned object in *.obj file format (Figure 6), including three-dimensional position coordinates and corresponding unit normal vectors, a point on the face of object is defined by a vector , where v_x, v_y and v_z are components of the position vector, vn_x, vn_y and vn_z are elements of the normal vector with respect to the coordinate axes x, y, z. The process of estimating the neck girth is performed in 4 stages in the first case (Figure 7).
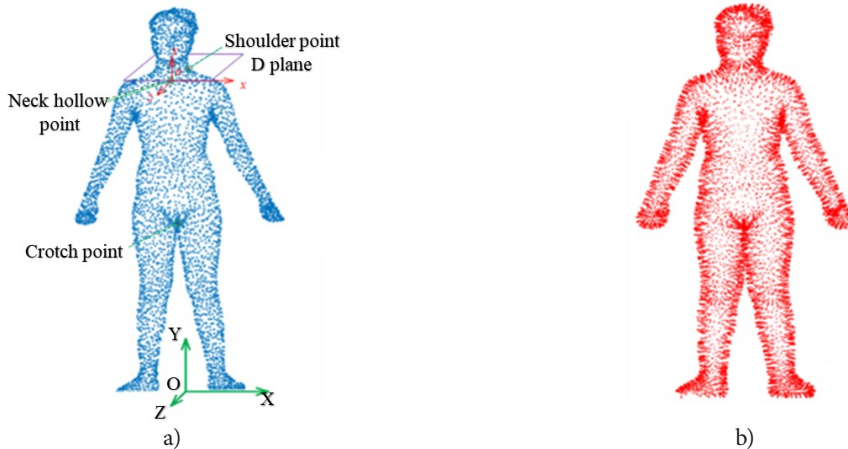

Figure 6: a) The original coordinate system and the co-ordinate system at the cervical point, b) The point coordinates and vector on the scanned model are scanned
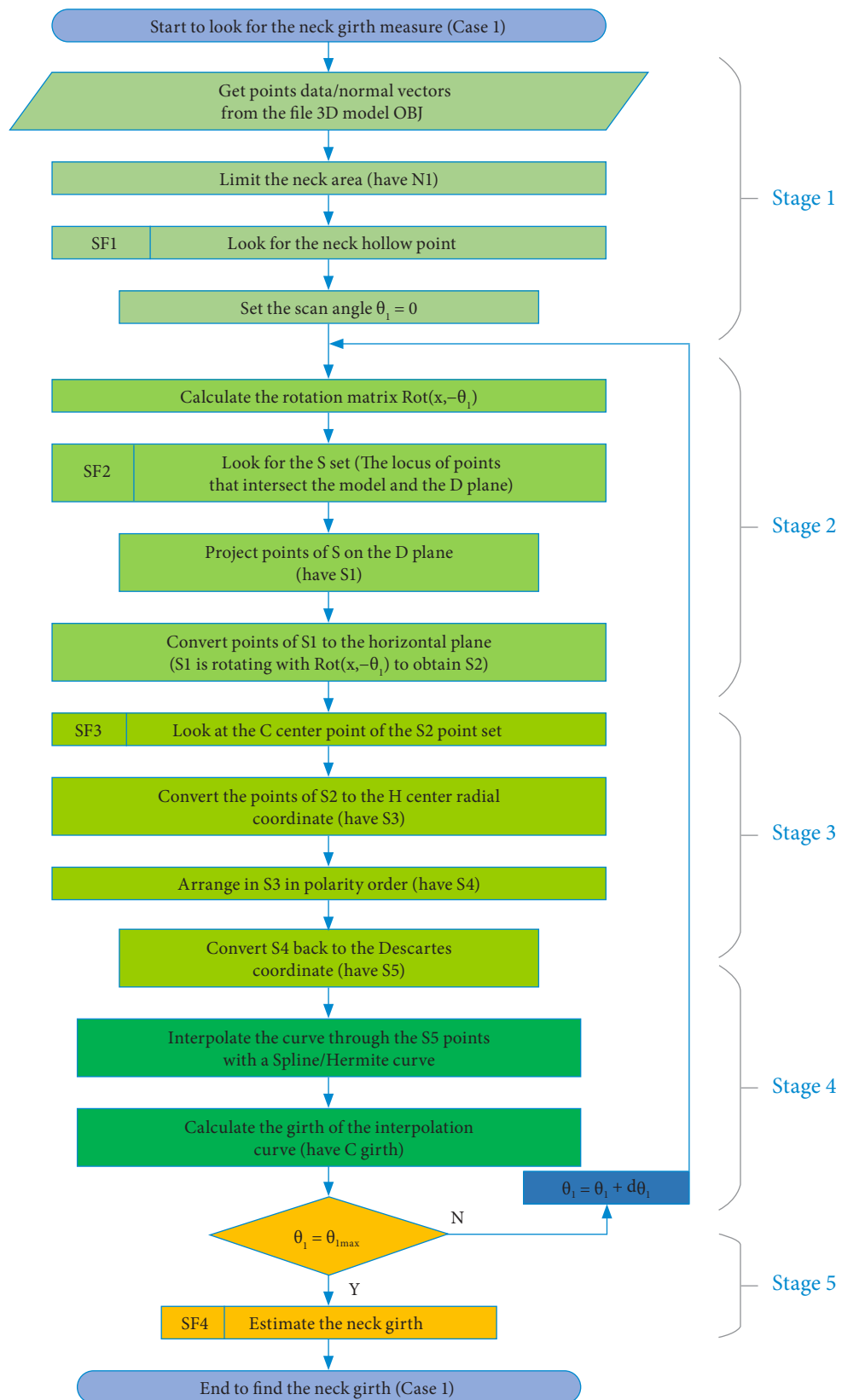
Start to look for the neck girth measure (Case 1)

Get points data/normal vectors
from the file 3D model OBJ

Limit the neck area (have N1)

SF1 | Look for the neck hollow point

Set the scan angle $\theta_1 = 0$

Stage 1

Calculate the rotation matrix $Rot(x, -\theta_1)$

SF2 | Look for the S set (The locus of points
that intersect the model and the D plane)

Project points of S on the D plane
(have S1)

Convert points of S1 to the horizontal plane
(S1 is rotating with $Rot(x, -\theta_1)$ to obtain S2)

Stage 2

SF3 | Look at the C center point of the S2 point set

Convert the points of S2 to the H center radial
coordinate (have S3)

Arrange in S3 in polarity order (have S4)

Convert S4 back to the Descartes
coordinate (have S5)

Stage 3

Interpolate the curve through the S5 points
with a Spline/Hermite curve

Calculate the girth of the interpolation
curve (have C girth)

$\theta_1 = \theta_1 + d\theta_1$

Stage 4

$\theta_1 = \theta_{1max}$ N

Y

SF4 | Estimate the neck girth

Stage 5

End to find the neck girth (Case 1)

Figure 7: The algorithm to estimate the neck measurement according to case 1

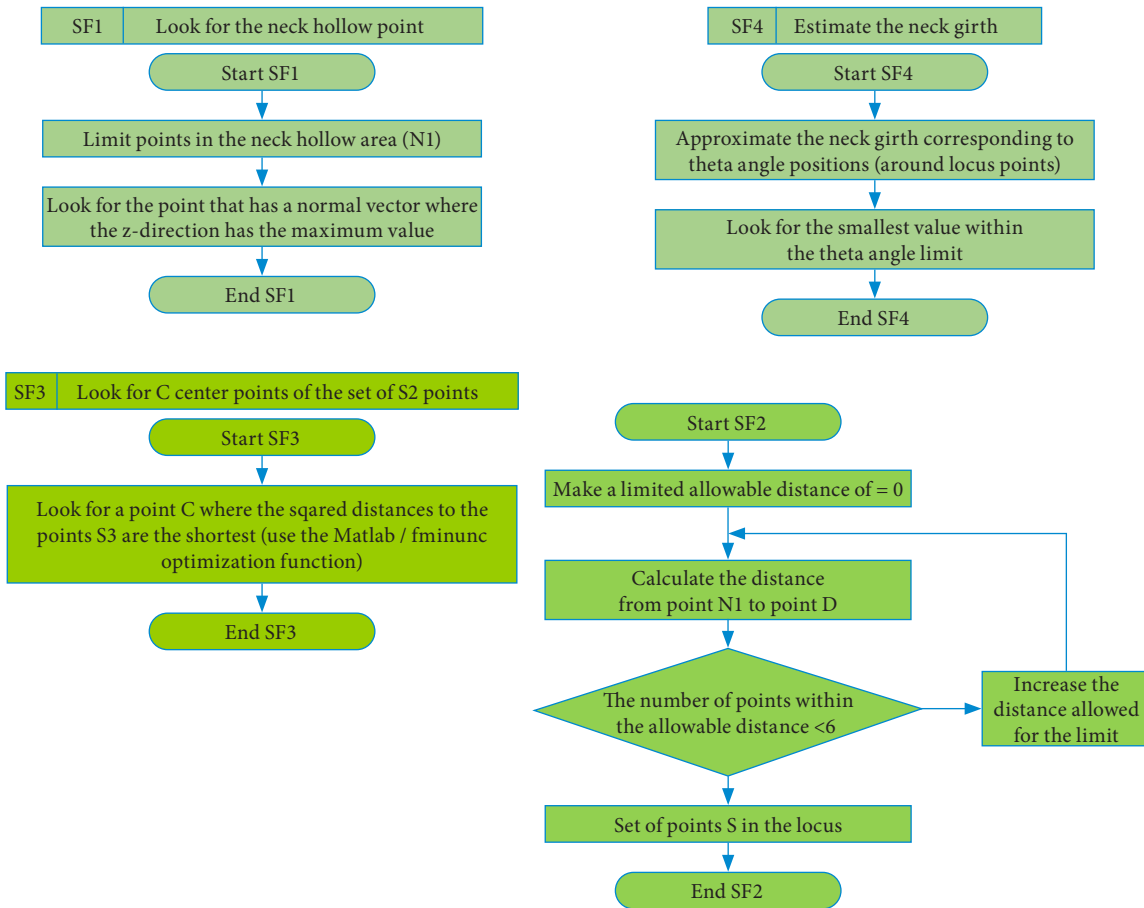Subfunctions for that algorithm in case 1 (Figure 8):

Figure 8: Subfunctions in case 1

The first stage: Prepare the scanned model data and the limited neck region data. Next, find the hollow point of the neck by searching for a point whose normal vector is closest to the normal vector of the xoy-plane. Assign the original scan angle (Figure 9).

The second stage: Calculate the rotation matrix.

Here:

$$Rot\,(x, -\theta_1) = \begin{bmatrix} R_1 & O \\ O & I \end{bmatrix}$$

$$R_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_1) & -\sin(-\theta_1) \\ 0 & \sin(-\theta_1) & \cos(-\theta_1) \end{bmatrix}; O_{3\times3}, I_{3\times3};$$

where O_{3x3} and I_{3x3} are zero and unit matrixes. θ is the angle between the D-plane and the xoz-plane.
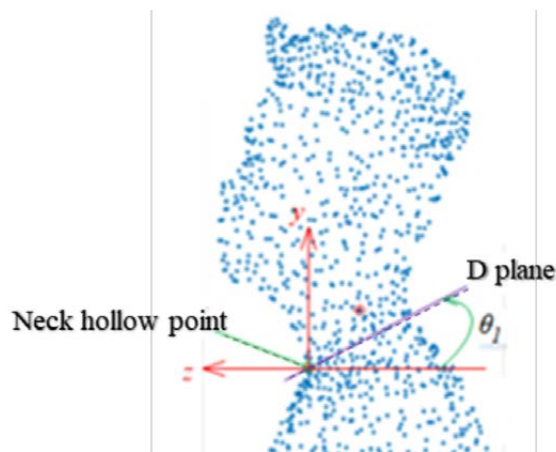

Figure 9: Limiting scanning data to the neck area

Then, search for the set S (a set of neighborhood points that intersect the 3D scan and the D plane). If you project the points of the set S onto the D-plane,

you will get the set S1. Next, convert the points of S1 to the horizontal plane (by rotating S1 by Rot) (x_theta). This defines the set S2. When creating S2, the S2 phase assigns the distance to the limit point of O and then calculates the distance from the point N1 to the D plane, which gives the number of points within the allowable distance. When this condition is satisfied, a set of points S is given in the locus. Conversely, increase the allowable limit and recalculate the distance between N1 and the D-plane until you obtain a set of points S with an allowable distance. This procedure guarantees that the required number of fast points is always found within a flexible limit.

The third stage: Find the center C of the set of points of S2 set

Convert the points in S2 to the polar coordinates of the H center. This becomes S3. In the third stage, we look for a center C, whose sum of squared distances to the points S3 is smallest.

The fourth stage: Interpolate the neck curve

Corresponding to each point of θ_1, we interpolate a Spline/Hemite base on point set S5. Calculate the neck girth by measuring the length of the closed Spline, which has just been determined. Next, check if the scanning angle satisfies the conditions $\theta_1 = \theta_{1ma}$. If satisfied, proceed to stage 4. On the contrary, if $\theta_1 = \theta_1 + d\theta_1$, this section returns to the matrix calculation $Rot(x. \theta_1)$ and follow the stages until the correct results are obtained to finish the process of measuring in this phase.

The fifth stage: Estimate the neck girth

Average the perimeters of the necks corresponding to the changes in θ_1 angular positions, and then find the smallest value within the limit θ_1 corner.

Case 2: Estimation of neck girth by determining the shoulder peak point.

From the scanned 3D data, including point positions and normal vectors, we can calculate the neck girth at the D-plane position containing the shoulder peak point. However, to reduce geometric errors in calculations, we need to limit the n-region data (front side from the neck hollow point to the chin,

back side from the seventh vertebra position to the neck) (Figure 10). In this case, implementation is done in five stages.
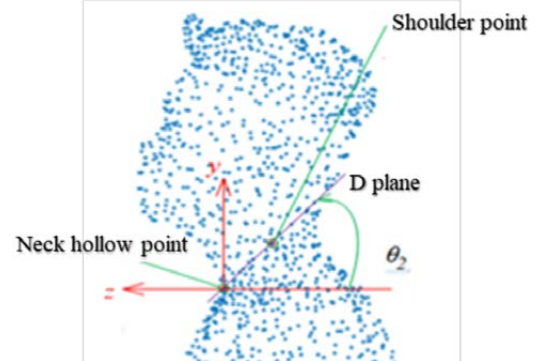

Figure 10: The neck range limit

The first stage: Find the neck hollow point

The steps of this stage include: First, prepare the 3D object data with the point coordinates and the corresponding unit normal vectors; second, limit search data to the neck region; third, find the neck-hollow point using the points whose unit normal vector is closest to that of the oxy-plane. Using a similar approach, we can easily find the peak point of the shoulder. Note that θ_2 is the angle between the D-plane and oxz-plane (see Figure 10). The D-plane contains the peak points of the ox-axis, the hollow neck and the shoulder. Finally, calculate the value of θ_2.

The second stage: Calculate the rotation matrix

$$Rot(x, -\theta_2) = \begin{bmatrix} R_2 & O \\ O & I \end{bmatrix}$$

where, $R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_2) & -\sin(-\theta_2) \\ 0 & \sin(-\theta_2) & \cos(-\theta_2) \end{bmatrix}$

Find a set of point, named S, which are neighbors of the intersection between the limit 3D model and the D2-plane. By projecting the points of set S on the D2-plane, we obtain a new set named S1. Then, by continuously converting the points of S1 to the horizontal plane through rotation transformation , we get the new set, denoted S2.

The third stage: Find the C center point of the S2 points

Convert the points of the S2 set to the H central coordinate will give the S3 set. Then, arrange the

points into the S3 in the polar coordinate system order to obtain an S4.

The fourth stage: Interpolate neck curve

Interpolate the curve through the S5 points by the Spline/Hemite to get the closed neck value.

The fifth stage: Calculate the neck girth

The algorithm flowchart for estimating the neck measurement according to case 2 (Figure 11). Subfunctions for that algorithm are shown in Figure 12.
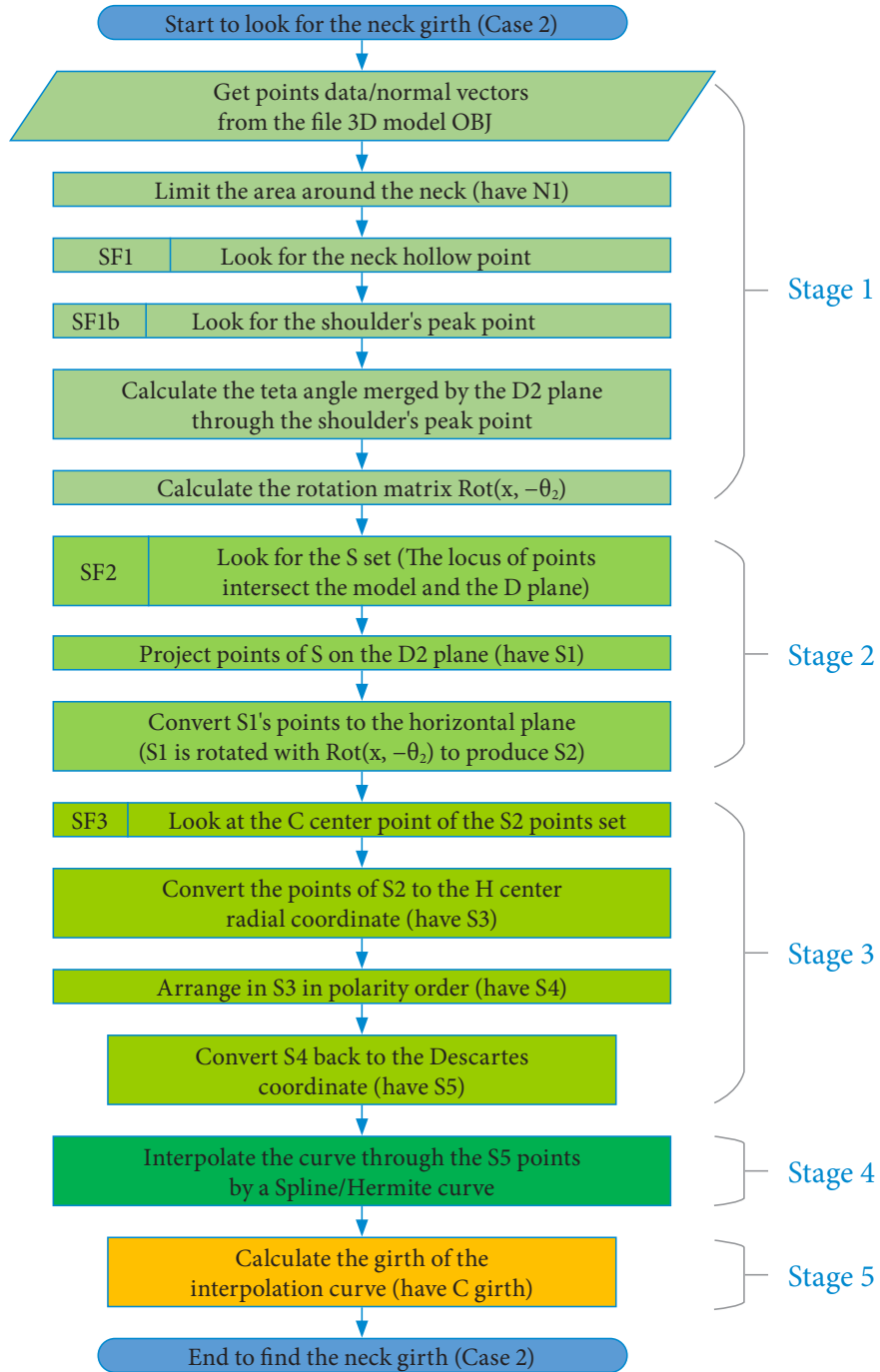

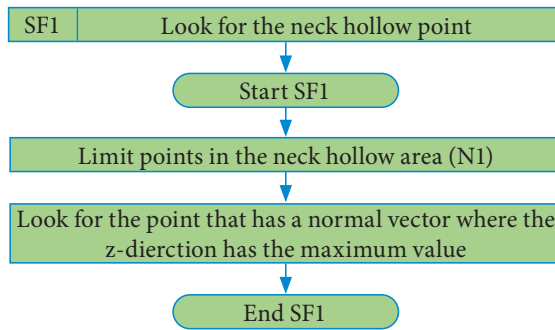Figure 11: The algorithm to estimate the neck measurement according to case 2

Figure 12: Subfunctions in case 2

Calculate the crotch height

The first stage is to limit the points within the inseam dimension range, then look for the point with the normal vector in the y-direction that has the maximum value. Next, the height from the floor to this maximum value is calculated (Figure 13). This is the inseam dimension height.
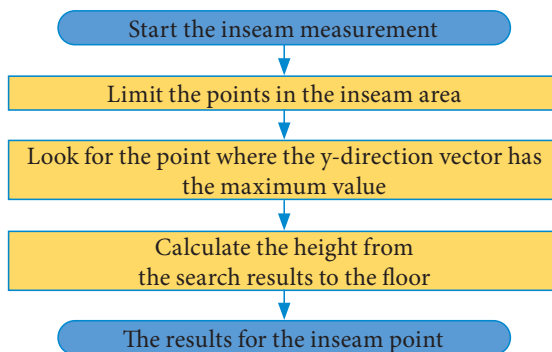

Figure 13: The algorithm to estimate the inseam dimension

3.6 The result of the automation for extracting the size and the shape

Table 3 shows the results of automating the neck size and inseam calculation algorithm used to extract size and body shape from 30 samples of 3D scan data, with two cases for neck girth estimation. Three different scenarios are shown. In the first example, the results are identical. The scanned samples have the correct standing posture; the chin is parallel to the ground and the head is kept straight (Figure 14, a). In the second instance, the results are different from the data because of an incorrect standing posture, such as the altered head position due to leaning forward or leaning back, a hunched

back or skewed shoulders (Figure 14, b). In the third instance, the results show no size and no body shape group. For results with no size, this was mainly because the measurements of the neck girth were taken outside the boundary conditions, or due to an incorrect sample standing posture, or an altered head position due to leaning forward or backward, a hunched back, or skewed shoulders (Figure 14, c).

4 Conclusion

The study focused on using an automated system to extract the size and body shape in order to establish an algorithm model to extract them according to the simulation method on the Matlab software with two input variables, neck girth and inseam height. The first case is to perform a scan of the neck area through the scan angle created by the plane containing the neck hollow point and the plane of the floor. The second case is to scan the area of the neck through the scan angle created by the plane containing the shoulder's peak point intersecting the floor's plane. Also, the study analyzed the results of comparing the automation method with the simulation method. The results have shown that the scan samples with the correct scanning standing posture will give the same results. On the contrary, there are different results due to incorrect scanning positions of the sample. There are samples with small size deviations. The methods used in the research content of the paper include principal component analysis, factor analysis, and an ANOVA test to establish the sizing system tables. Moreover, the fuzzy logic technique is used to set up the numerical size extraction algorithm. The optimal search method is used to extract the size and body shape. The control test method is used to check the algorithm results again. This research proposes a way of selecting a fit size of garment for the human body. Furthermore, it may be applied to other fields in garment technology.

*Table 3: The results of dimensions and extraction body size/shape by the method of inputting data directly into the simulation program and the automating method*

3D object	Neck size (3D Object)	Neck size (Case 1)	Neck size (Case 2)	Inseam (3D Object)	Inseam (automatic)	Size/Shape (Simulink)	Size/Shape (Case 1)	Size/Shape (Case 2)
1	40.05	40.57	36.33	67.6	67.51	7/2	7/2	0.5/0.5
2	40.8	41.01	39.18	71.03	71.34	8/2	8/2	6/1
3	40.34	37.28	35.76	71.26	71.73	7/2	0.5/0.5	0.5/0.5
4	39.08	39.59	37.82	70.48	70.49	6/1	6/1	5/1
5	43.27	44.56	41.19	73.38	74.19	0.5/0.5	0.5/0.5	13/2
6	37.77	37.48	36.05	68.55	68.78	0.5/0.5	0.5/0.5	0.5/0.5
7	38.84	39.22	46.31	72.86	73.48	10/1	10/1	0.5/0.5
8	41.16	40.04	41.85	74.76	75.59	13/2	11/1	13/2
9	38.85	42.82	38.82	70.88	69.6	6/1	0.5/0.5	6/1
10	44.09	38.85	31.26	80.24	79.94	0.5/0.5	15/1	0.5/0.5
11	46.13	38.53	40.05	73.09	72.90	0.5/0.5	10/1	11/1
12	42.84	51.91	35.11	75.05	74.98	14/4	0.5/0.5	0.5/0.5
13	40.81	40.47	38.26	75.96	75.67	12/2	12/2	0.5/0.5
14	37.99	41.01	35.22	70.19	70.22	5/1	8/2	0.5/0.5
15	41.85	36.35	37.32	75.7	76.26	13/2	0.5/0.5	0.5/0.5
16	41.06	40.92	40.92	71.68	71.99	8/2	8/2	0.5/0.5
17	36.1	49.61	37.21	83.85	83.21	0.5/0.5	0.5/0.5	0.5/0.5
18	38.44	38.46	39.36	73.3	72.72	10/1	10/1	11/1
19	38.83	39.14	37.6	77.54	77.63	15/1	15/1	0.5/0.5
20	41.31	41.53	40.63	73.58	73.35	13/2	13/2	12/2
21	38.14	38.87	51.26	73.55	74.14	0.5/0.5	10/1	0.5/0.5
22	40.05	40.42	39.38	79.16	79.2	16/1	16/1	15/1
23	46.84	33.67	37.05	71.59	72.6	0.5/0.5	0.5/0.5	0.5/0.5
24	36.35	35.95	34.75	65.45	65.55	0.5/0.5	0.5/0.5	0.5/0.5
25	43.01	46.37	43.03	77.32	77.18	0.5/0.5	0.5/0.5	0.5/0.5
26	37.54	36.78	38.8	69.81	69.88	0.5/0.5	0.5/0.5	6/1
27	38.65	34.61	41.72	75.42	75.75	10/1	0.5/0.5	13/2
28	43.03	36.5	45.29	81.64	83.25	19/4	0.5/0.5	0.5/0.5
29	38.95	32.31	33.67	72.14	72.62	6/1	0.5/0.5	0.5/0.5
30	41.2	45.39	41.43	72.58	72.69	13/2	0.5/0.5	13/2
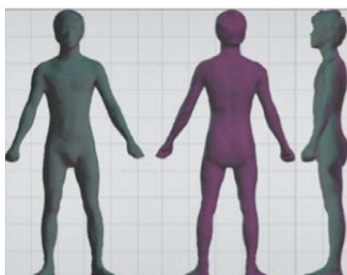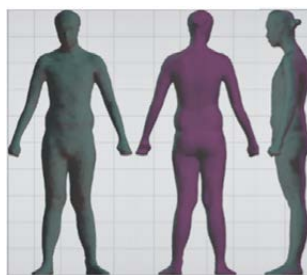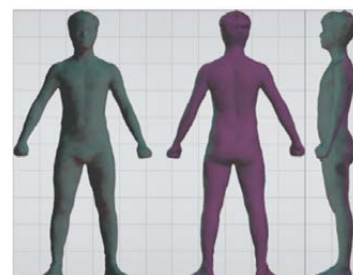
| a) | b) | c) |

Figure 14: a) The sample's images in boundary conditions,
b) The sample's images with a forward-leaning head, c) The sample's images in boundary conditions

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