Algorithm Research on Virtual Individualized 3D Mannequin

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***Abstract*—This article presented a new approach for the research of virtual individualized 3D mannequin. First, the author summarized and analyzed the current research methods and pointed out the shortage of these methods. Second, the author took an example to illustrate the originality of the research method. In this part, the author studied the algorithm of the bust dart and the waist dart distribution with the new research methods and then point out that they will study all of the characters in a certain field of human body separately and ultimatly integrated these research findings into a whole body model to generate an individual mannequin, which will reflecte the subtle difference of different human body and guarantee the realization of individuation. Finally, the author made conclusions to explain the algorithm and their applications to build the virtual individualized 3D mannequin in further research.**

***Index Terms*—three dimensions, individualized mannequin, GCAD, algorithm**

I. Introduction

The virtual individual 3D mannequin, which is also called parameterized human body model or deformable constructing human body model, is the model to disply the shape of somatotype that constructed by computers and could adjust its shape by changing the deformable parameters through human-machine interface. The virtual individual 3D mannequin is the essential research for GCAD (Garment-CAD) industy, spaceflight industry, automotive industry, house and home industry and etc., which can accelerate the respective design and development of research in each special field.

Because that it can display the subtle characters distinction between differnt people, the individual 3D mannequin can help the designer illustrate the virtual design and exhibition as real as possible and satisfy the consumers online with good impression of high fitting quality, therefore, it is one of the most important focuses of GCAD researches.

So far, researchers have studied more on the computer simulation of Standard 3D mannequin, but studied less on Individual 3D mannequin, however, the latter is more important for the GCAD and E-business of fashion.

Traditionally, there are two types of methods to construct the 3D human body model as following:

1) By the universal modelling software, such as Poser, Maya, 3DSMax and etc. Lin De Jing in ref. [1] carried out their research on 3D mannequin by using Poser software, they analyzed the feasibility of the construction of the apparel pattern communication platform based on Poser. Their experiment results showed that the obtained platform could improve the pattern productivity of clothing business. But there exists a prolem that the original models in this special software are congenital defectiveness of no somatotype, that is to say the results of modelling by this software are inaccurate and unreliable, which cannot reflect the subtle difference between different people.

2) By the data of human body surface through 3D human body scanner. Wang Mei in ref. [5] presented an easy way to construct personalized manikin from scanned body data. The feature points of scanned body are adjusted to the right position. Based on these points, cutting planes are allocated to get section contours of scanned body, and the triangle mesh of manikin with uniform sizes and regular topology are regenerated. Deng Wei Yan in ref [4] studied with BP neutral network. By making use of scanned body data, cutting planes were allocated to get the feature points of section contours of scanned body, and the training samples of the neck, bust, waist and hip were obtained. Based on section loops which generate from neural network, a 3D mannequin was regenerated. In their research above, we found a problem that there are millions of points in even one of point-clouds data, we have to deal the data with different methods to reduce the points and reconstruct the surface of human body by recondite computing and modelling, which need special programming methods and would cost

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more to achieve the results and it is always an impassable obstacle for fashion designer.

Although lots of modelling algorithms of 3D human body have been studied and achieved in the past, it is always a problem that how to construct and deform the virtual individual human body model that can reflect the sutle differece in different field of human body.

In our research team, we got hundreds of point-clouds data by Symcad 3D Human Body Scanner and got directly the feature measurements by reverse engineering software Imageware from the point-clouds data and finally achieved the algorithms to construct the individual 3D mannequin. What make us special is that we studied all of the characters in a certain field of human body separately and integrated the research findings into a whole individual model, which will reflecte the subtle difference of different human body and guarantee the realization of individuation.

II. Experiments

We divided the whole bodice human body into three parts to study separately, they are the bust part, the neck/armhole part and the shoulder part. In the following contents of this paper, we will introduce our research method on the bust part to show our research methods and its specialness, the other two parts was omitted because the space is limited.

First, the point-clouds data of hundreds of young women's body was got by non-contact body scanner Symcad. After optimizing the point-clouds data, the 3D scanned body was rebuilt by reverse engineering software Imageware.

Second, we studied two contents: the algorithm of the bust dart and the waist dart distribution to embody our idea of individuation. In content one, we studied the algorithm of bust dart. In content two, we studied the algorithm of waist darts distribution.

Third, in each part of research, the conditions and experimental data were separately analyzed by SPSS according to the principle of spatial geometric.

Subjects

In the whole research of this paper, two hundred and ninety three healthy young female college students took part in our test. The subjects were all wearing thin fitted bra and briefs.

Equipments

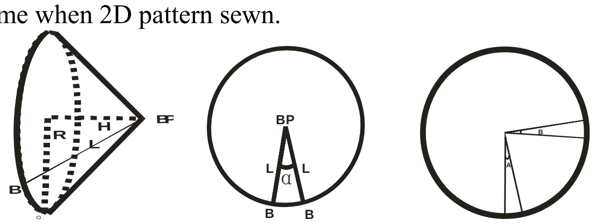
German non-contact body scanner Symcad was used in this experiment. It can export the point cloud data of the human body surface with the information of three-dimensional coordination.The point-clouds data and corresponding 3D scanned bodies were reconstructed by Imageware.

Algorithm of Bust Darts

A. Principles

We imaged the women's breast as a cone and the radius R and tallness H of the cone will determine its shape, as shown in Fig. 1(a). When a 3D cone is flattening to 2D pattern, a sector will be occured. The cleft angle of the sector, α, is the angle of bust dart of garment pattern shown in Fig. 1 (b).

According to the transfer theory of bust dart, for the same cone, if the summation of angles round BP keep equal to the breast dart angle, α, the chest style will be the same when 2D pattern sewn.

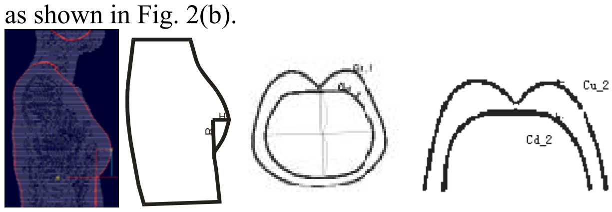


(a) (b) (c)

Figure 1. Cone and spreading sector of cone

B. Measurement of 3D Scanned Body

Six key data were measured accurately by Imageware: H, R, Cu_1, and Cu_2, Cd_1, Cd_2. H is the height of breast; R is the radius of breast, as shown in Fig. 2(a). Cu_1 is the chest circumference; Cd_1 is the lower chest circumference, as shown in Fig. 2 (b). Cd_2 is the front arc length of the lower chest; Cd_2 is beginning and ending at the lower chest depth, as shown in Fig. 2 (c). The starting and ending points of Cd_2 are the intersection points of Cd_1 and the horizontal line which passes through half of the lower chest depth, as shown in Fig. 2(b). Cu_2 is the front arc length of the chest, as shown in Fig. 2(c). The starting and ending points of Cu_2 is the intersection points of Cu_1 and the horizontal line which passes through half of the lower chest depth, as shown in Fig. 2(b).



(a) （b） （c）

Figure 2. Measurement of chest

C. Data Treatment

By (1)~(-4), four data are calculated, which affect the shape of women's breast.

D_1 is the difference between Cu_1 and Cd_1. D_2 is the difference between Cu_2 and Cd_2. L is the length of bust dart [Fig.1.b]. Ang_1, α, is the bust dart angle of 2D garment pattern.

$$D\_1= (Cu\_1-Cd\_1)/2. \quad (1)$$

$$D\_2= (Cu\_2-Cd\_2)/2. \quad (2)$$

$$L= (R^2+H^2)1/2. \quad (3)$$

$$Ang\_1= 360*(D\_2/2\pi*L). \quad (4)$$

D. Data Analysis and Discussion

Table 1 is the correlation analysis of the 293 subjects by SPSS. Ang_1 has significant correlation with D_2, H/R, H and D_1. Meanwhile, D_2 is the most significant correlation with Ang_1. H/R is the next most significant correlation with Ang_1. The change of the back thickness makes the effect of D_1 on Ang_1 complex, and D_2 does not include the change of the back thickness, so D_2 has better correlation with Ang_1 than D_1. Ang_1 is not significant correlation with R, so H has greater influence in Ang_1.

TABLE I. CORRELATION ANALYSIS OF THE WHOLE PEOPLE

Data		Ang_1
H	Pearson Correlation	.360(**)
	Sig.(2-tailed)	.000
R	Pearson Correlation	-.002
	Sig.(2-tailed)	.973
D_2	Pearson Correlation	.831(**)
	Sig.(2-tailed)	.000
D_1	Pearson Correlation	.260(**)
	Sig.(2-tailed)	.000
H/R	Pearson Correlation	.413(**)
	Sig.(2-tailed)	.000

*** the 0.001 level (2-tailed).
** the 0.01 level (2-tailed).
* the 0.05 level (2-tailed).

E. Mathematical Modelling Graded by H/R

According to the Chiese National Standards (GB1335-91), somatotype are classified to Y, A, B, and C four grades. The previous researches showed that the effects of mathematical modelling graded by this standard is not good because bust-waist difference does not indicate the difference of women's figure well, the shape of breast is regardless in this standard at all.

In our research, H ang R restrict the cone medel of women's breast, and in Table 1 Ang_1 is significant correlation with H/R, so the subjects are classified by H/R. The distribution range of H/R is from 0.2 to 1.1. The subjects are classified to 9 grades and the grade difference is 0.1. The distribution of the number of person in grades is seperately 5, 31, 68, 63, 80, 26, 12, 6 and 2. The modelling process is as follows:

（1）Because the first and ninth grades have lesser subjects, the two grades are omitted. The percentage of the left grades is 97.9%.

（2）In order to find the independent variables which have significant correlation of Ang_1, this article analyzed the correlation of Ang_1 with H, R, D_1, H/R and D_2 the left seven grades by SPSS.

The results showed that, in the second grade, the irrelevant probability of D_2 with Ang_1, sig (2-tailed), is 0.00. The correlation of Ang_1 with D_2 is significant. The correlation of Ang_1 with H, R, and D_1 is not significant. In the other seven grades, the correlation of Ang_1 with D_2 is significant.

（3）According to the result of the correlation analysis above, there is some regression analysis by SPSS for each grade as follows (1) ~ (7). It is assumed that Ang_2 is the predicting bust dart angle graded by H/R. Then, the mathematical model from the second grade to the eighth grade classified by H/R is built. In the mathematical model, D_2 is the independent variable, and Ang_2 is the dependent variable.

The second grade: Ang_2=4.732+7.326*D_2. （1）

The third grade: Ang_2=14.877+4.401*D_2. （2）

The forth grade: Ang_2=10.527+5.573*D_2. （3）

The fifth grade: Ang_2=12.557+4.787*D_2. （4）

The sixth grade: Ang_2=9.958+5.521*D_2. （5）

The seventh grade: Ang_2=21.870+3.207*D_2. （6）

The eighth grade: Ang_2=11.904+4.567*D_2. （7）

TABLE II. INDEPENDENT VARIABLES WHICH HAS SIGNIFICANT CORRELATION WITH ANG_1

Grades	Significant correlation with Ang_1
The third grade	R(**) ; D_2(**)
The forth grade	R(***); D_2(***) ; H(***)
The fifth grade	R(***); H(***); D_1(***)
The sixth grade	R(***); H/R(***); D_2(***)

*** the 0.001 level (2-tailed).
** the 0.01 level (2-tailed).
* the 0.05 level (2-tailed).

F. Mathematical Modelling Graded by D_2

In the above mathematical modelling graded by H/R, the number of the predicting subjects has wide range, and this method predicts the trend of Ang_1 well. This method needs 3 variables: H, R, and D_2. H and R are difficult to get, however, the body circumferences are easy to get, and D_2 is the most significant correlation with Ang_1. So the subjects are classified by D_2 in our further research. The distribution range of D_2 is from 0 to 9cm. The subjects (254 persons) are classified to 9 grades and the grade difference is 1cm. The distribution of the number of subjects in grades is separately 1, 8, 27, 78, 78, 41, 13, 6 and 2. The modelling process is as following:

(1) Because the 1, 2, 7, 8 and 9 grades have lesser subjects, the five grades are omitted. The percetage of the left 3, 4, 5 and 6 grades is 76.4%.

(2) In order to find the independent variables which have significant correlation of Ang_1, we analyzed the correlation of Ang_1 with H, R, D_1 of the left four grades by SPSS. Table 2 shows independent variables which has significant correlation with Ang_1. In the four grades, Ang_1 has significant correlation with R, but it is complex to measure. Ang_1 has significant correlation with the circumference difference D_2 and D_1. The

circumference is easy to get, so it is advantageous to use circumference difference to build the mathematical model.

(3) According to the result of the correlation analysis above, there is regression analysis by SPSS for the left four grades as follows (1) ~ (4). It is assumed that Ang_3 is the predicting bust dart angle graded by D_2. Then, the mathematical model from the third grade to the sixth grade classified by D_2 was built. In this model, the circumference difference D_2 or D_1 is one independent variable, and Ang_3 is another independent variable.

The third grade: Ang_3=-3.782+10.965*D_2. (1)

The forth grade: Ang_3=-6.289+10.338*D_2. (2)

The fifth grade: Ang_3=44.933-1.589*D_1. (3)

The sixth grade: Ang_3=9.726+5.39*D_2. (4)

G. Verification of Bust Darts

As shown in Fig. 3, Ang_2 predicts the trend of the Ang_1 well. The percentage of subjects, whose difference between Ang_2 and Ang_1 is ±5°, is 83.6%.

As shown in Fig. 4, Ang_3 predicts the trend of the Ang_1 well. The percentage of subjects, whose difference between Ang_3 and Ang_1 is between -5°and 5°, is 84.0%. Ang_3 is a little more exact than Ang_2. But Ang_2 has wider range than Ang_3.

The next step is to do further verification whether Ang_3 can replace Ang_2 to predict the bust dart angle of Ang_1. There is independent-samples T test by SPSS of Ang_3 and Ang_2. The results are that t=0.619 and sig. (2-tailed) = 0.404. That means Ang_2 has no significant differences with Ang_3. In a word, Ang_3 can replace Ang_2 to predict the bust dart angle of Ang_1.

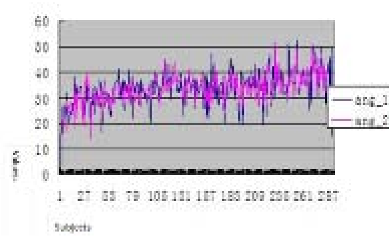


Figure 3. Compared line graph of Ang_1 and Ang_2

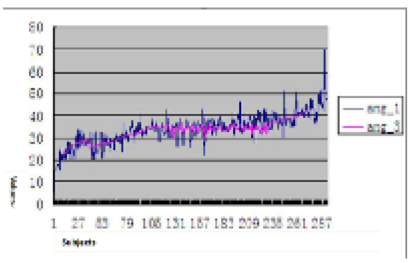


Figure 4. Compared line graph of Ang_1 and Ang_3

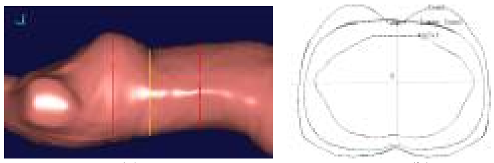
Algorithm of Waist Dart Distribution

A. Measurements of 3D Scanned Body

In this content, we will study the dart of the front lower chest -front waist and the dart of the back chest-back waist.

Fig. 5. (b) is the planform of the chest circumference lower chest circumference and waist circumference, which were intercepted from the 3D scanned body (Fig.5. (a)).

In this content, the horizontal line was across half of the chest depth. That line divided the chest circumference into two parts, the front and the back chest circumference. That line divided the lower chest circumference into two parts, the front and the back lower chest circumference.



(a) (b)

Figure 5. Reconstructed model and section loops.

B. Data Treatment

Part A: Measurement of front lower chest-front waist

(1) As shown in Fig. 6, a vertical line, across the BP, intersected the front waist at the point J.

(2) The extended line of OJ intersected the front lower bust circumference at the point K.

(3) L1 is the angular bisector of∠KOQ. L1 separately intersected the front waist and the front lower bust circumference at the points N and M.

(4) Simulated 3D b-spline curves MR, NS, QM and TN by Imageware.

(5) Because the circumference of the front lower bust and the front waist, in the process of 3D flattening to 2D pattern, the dart of front lower bust - the front waist formed. In this experiment, this front waist dart is divided into two parts D1 and D2. D1 is the difference of arc length MR and NS. D2 is one part of latasuture dart. D2 is the difference of arc length QM and TN.

Part B: Measurement of back chest-back waist

(1) As shown in Fig. 7, the vertical line across the bust point intersected the back chest at the point C.

(2) The extended line of OC intersected the front lower bust circumference at the point D.

(3) L2 and L3 is the trisection line of ∠COU. L2 and L3 separately intersected the back waist and the back bust circumference at the points I, H, F and E.

(4) Simulated 3D b-spline curves AC, CH, HU, BD, DI and IT by Imageware.

(5) The back waist dart is divided into three parts D3, D4 and D5. D3, D4 and D5 are as follows (1)~(3).

D3=arc CA –arc DB. （1）

D4=arc CH –arc DI. （2）

D5=arc HU –arc IT. （3）

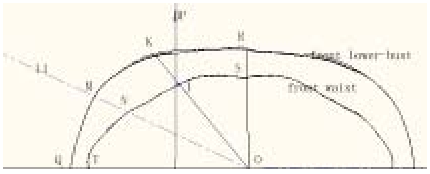


Figure 6. Front lower chest-front waist.

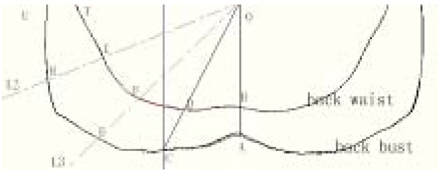


Figure 7. Back chest-back waist.

For the following analysis, several data are added. X is half of the back bust circumference. Y is half of the back waist circumference. H is the ratio of back waist and back bust circumference. K is the difference of back bust and back waist circumference. P3, P4 and P5 are percentage of D3, D4 and D5 in K. Equations are listed as (4) ~ (8).

$$H=Y/X. \quad (4)$$

$$K=X-Y. \quad (5)$$

$$P3=D3/K. \quad (6)$$

$$P4=D4/K. \quad (7)$$

$$P5=D5/K. \quad (8)$$

C. Data Analysis and Discussion

Part A: Front lower chest-front waist

The research result showed that, in the part of front lower bust-front waist, 88% of the subjects'dart is less than 1cm. This front waist dart is divided into two parts D1 and D2. 77.8% of subjects'D1 is less than 0.5cm. 85% of subjects'D2 is less than 0.5cm.

Because the waist is supported by muscle and the lower bust is supported by human skeleton, the shape of waist is irregular, different subject's waist shape changes a lot. In the platform (Fig. 5.(b)), 95% of the subjects'waist circumference is not in the lower bust circumference and Arc MS intersect with arc NS, which leads that 77.8% of subjects'D1 is less than 0.5cm. The platform (Fig. 6), though 98.2% arc TN waist is in arc QM (Fig 6), the bending of arc TN is bigger than arc QM, which leads to 85% of subjects D2 is less than 0.5cm. So it is unnecessary to distribute darts to D1 and D2 in the part of front lower bust-front waist.

Part B: Back chest-back waist

In this paper, the back waist dart is divided into three parts D3, D4 and D5. Because the shapes of human bodies are not the same, nine subjects D3, D4 or D5 is less than 0cm, so these data are omitted.

The correlation analysis of the subjects was carried out with SPSS. The back waist dart is divided into three parts D3, D4 and D5. D3 has significant correlation with X, Y, H and K, so do D4 and D5, but P3, P4 and P5 do not have such significant correlation with X, Y, H and K.

D. Mathematical modelling

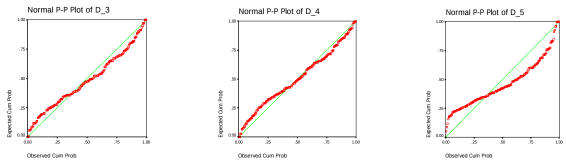
Fig. 8 showed the normal probability distribution graph of D3, D4 and D5. D3 and D4 are normal probability distribution, but D5 is not. At the same time, D3 and D4 have significant correlation with X, Y, H and K, so D3 and D4 are chosen to simulate the dart distribution.

By the former analysis, mathematical model of D3 and D4 are got by linear analysis of SPSS as follows (9) ~ (10). D5 (11) is gained by the predicted value D3 and D4.

$$D3=-8.692-0.142Y+12.309*Y/X+0.655*(X-Y). \quad (9)$$

$$D4=27.522+0.368Y-35.375\,Y/X-0.79*(X-Y). \quad (10)$$

$$D5=(X-Y)-D3-D4. \quad (11)$$



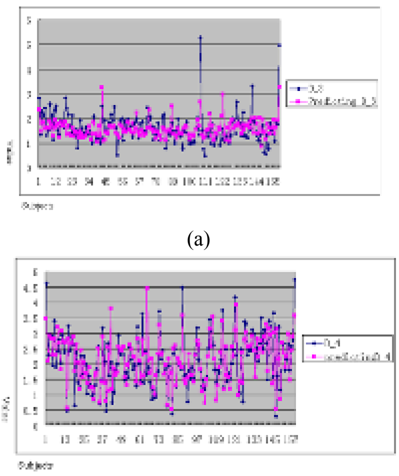
(a) (b) (c)

Figure 8. Normal probability distribution (D3 ~ D5).

E. Verification of Waist Dart Distribution

In order to separately compare the predicted values with the measured values of D3 and D4, some chart are used by Excel.

As shown in Fig.9 (a), predicted value predicts measured value of D3 well, except six extreme values. The difference between predicted D3 and measured D3 from -0.5cm to 0.5cm is 82.4%. As shown in Fig. 9 (b), predicted value predicts measured value of D4 well. The difference between predicted D4 and measured D4 from -0.5cm to 0.5cm is 81.8%.



(a)

(b)

Figure 9. Comparison between mearements and predicted data of D3 and D4.

III. CONCLUSIONS

In the content of algorithm of bust darts, we focused on the study of angle of bust darts.

(1)This article chooses two method to build the mathematical model Ang_2 and Ang_3 to predict Ang_1, the bust dart angle of 2D garment pattern.

(2)In mathematical modelling graded by H/R, the mathematical model Ang_2 is built to predict the bust dart angle, Ang_1. Ang_2 has wider range of the whole subjects than Ang_3.Ang_2 predicts the trend of the Ang_1 well. The percentage of subjects, whose difference between Ang_2 and Ang_1 is between -5°and 5° is 83.6%. But this model needs 3 variables, H, R and D_2. It is difficult to measure H and R.

(3)In mathematical modelling graded by D_2, the mathematical model Ang_3 is built to predict the bust dart angle, Ang_1. Ang_3 predicts the trend of the Ang_1 well. The percentage of subjects, whose difference between Ang_3 and Ang_1 from -5° to 5°, is 84.0%. It is a little more than the percentage of Ang_2. This model needs two variables, D_1 and D_2 .It is easy to measure them. At the same time, Ang_2 has no significant differences with Ang_3.In a word, Ang_3 can replace Ang_2 to predict the angle of bust dart.

In the content of algorithm of waist dart distribution, we focused on the waist dart distribution.

(4) The waist dart distribution, the lower bust-front waist and back bust-back waist, are discussed.

(5) In the part of front lower bust-front waist, 88% of the subjects' dart is less than 1cm. This front waist dart is divided into two parts D1 and D2. And 77.8% of subjects' D1 is less than 0.5cm as well as 85% of subjects' D2 is less than 0.5cm. So it is unnecessary to insert darts in the part of front lower bust- front waist.

(6) In the part of the back bust-back waist, dart is divided into three parts D3, D4 and D5. D3 and D4 got good mathematical models.

In the further research, we will studied the neck/armhole part and the shoulder part with the same methods, and finally we will integrate all of the partial research findings into a whole achievement to make the integrated algorithm which will produce the preconceived individualized 3D mannequin.

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