

# A mixed human body modeling method based on 3D body scanning for clothing industry

Mixed human  
body modeling  
method

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## Abstract

**Purpose** – The purpose of this paper is to propose a relatively simple and rapid method to create a digital human model (DHM) to serve clothing industry.

**Design/methodology/approach** – Human body's point cloud is divided into hands, feet, head and torso. Then forward modeling method is used to model hands and feet, photo modeling method is used to model head and reverse modeling method is used to model torso. After that, hands, feet, head and torso are integrated together to get a static avatar. Next, virtual skeleton is bound to the avatar. Finally, a lifelike digital human body model is created by the mixed modeling method (MMM).

**Findings** – In allusion to the defect of the three-dimension original data of human body, this paper presented an MMM, with which we can get a realistic digital human body model with accurate body dimensions. The DHM can well meet the needs of fashion industry.

**Practical implications** – The DHM, which is got by the MMM, can be well applied in the field of virtual try on, virtual fashion design, virtual fashion show and so on.

**Originality/value** – The originality of the paper lies in the integration of forward modeling, reverse modeling and photo modeling to present a novel method of human body modeling.

**Keywords** Virtual reality, Body scanning, Digital human model, Mixed modeling, Reverse modeling

**Paper type** Technical paper



## 1. Introduction

The clothing industry as a traditional labor-intensive and low-technology industry (Scott, 2006) faces many difficulties in modern development and management. For example, the increasing labor cost and raw materials price (Li *et al.*, 2012), a variety of individual needs of consumers and the limitation of online shopping (Perea y Monsuwé *et al.*, 2004). Some scholars have devised solutions to these problems based on 3D and VR technologies. Virtual draping technology (Magenat-Thalmann and Volino, 2005; In Hwan and Tae Jin, 2006; Mesuda *et al.*, 2015) was developed to cut down fabric usage; virtual fashion design (Hinds and McCartney, 1990; Hardaker and Fozzard, 1998; Jin *et al.*, 2009; Decaudin *et al.*, 2006; Robson *et al.*, 2011; Tao and Bruniaux, 2013) was developed to improve design efficiency; virtual pattern design (Rodel *et al.*, 2001; Wang, Wang and Yuen, 2003; Petrak *et al.*, 2006a, b; Jeong *et al.*, 2006; Yunchu and Weiyuan, 2007; Cho *et al.*, 2010; Huang *et al.*, 2012) was developed to facilitate pattern making; virtual try-on technology (Kim and Forsythe, 2008; Meng *et al.*, 2010) was developed to simulate clothing sewing for reducing labor cost; virtual fashion show technology (Stylios *et al.*, 1996; Okada *et al.*, 2006) was developed to display fashion styles online. All of these applications of 3D and VR technology need a 3D digital human model (DHM).

As a branch of 3D modeling, human body modeling methods include among others: forward modeling method (FMM), reverse modeling method (RMM), parametric modeling method (PARMM) and photo modeling method (PMM).

FMM is used to construct a model according to the modeler's conception. It is a process from nil to existence. Some concrete implementation ways of FMM are wireframe modeling (Wilson, 1985), surface modeling (Terzopoulos *et al.*, 1987) and solid modeling (Requicha and Voelcker, 1983). 3D animators usually create all kinds of animated characters by FMM; however, this method asks for strong relevant skills, and a novice will probably take years of training to be competent. Moreover, the model's dimensions are not accurate by this method. Therefore, this method is not suitable for modeling human body for clothing industry.

RMM is used to construct a model according to point cloud data (Jones *et al.*, 1995; Seo *et al.*, 2001; Huang and Meng, 2003; Wang, Chang and Yuen, 2003; Andreetto *et al.*, 2004; Ke *et al.*, 2006; Li *et al.*, 2011; Wang *et al.*, 2012). This modeling concept combines wireframe modeling and surface modeling in essence. Mechanical engineers sometimes use a scanner to acquire 3D point cloud data, and then copy advanced models by reverse engineering. In the clothing industry, the point cloud data, which is obtained from 3D body scanning, is incomplete (Daanen and Ter Haar, 2013). Especially, the point cloud of hands, feet and head are fragmented. It is difficult to reconstruct these parts' models according to their point cloud data; therefore, it is not appropriate to only adopt RMM to model these parts.

By adjusting a few parameters known as features, PARMM can be used to construct a model (Shah, 1991; Salomons *et al.*, 1993). PARMM has been successfully applied in the clothing industry (Kim and Park, 2004; Wang, 2005; Cho *et al.*, 2005; Li and Chen, 2009; Park *et al.*, 2015); however, PARMM cannot be conveniently applied to made-to-measure because of some size discrepancies between the model and the real person.

PMM is used to construct a model based on photos (Zhou *et al.*, 2016). This is the quickest way to structure a lifelike model. But the model's dimensions are significantly different from the real persons'; therefore, this method has limitations in application in the clothing industry.

The fashion industry has some special requirements on DHM compared to other industries; the model's dimensions must be equal to real human dimensions as much as possible for purposes of garment fit and virtual try-on; the model should be able to make various movements for dynamic fitting evaluation and virtual fashion show; the model's appearance should be similar to the real person as much as possible for a high-quality

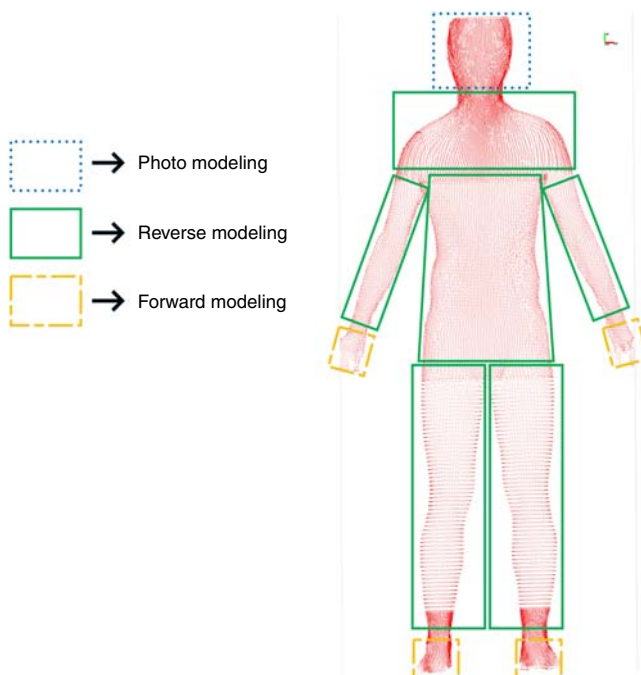
virtual fashion show and a good experience of virtual try-on online. However, so far, only professional companies can make a DHM to meet the requirements above. Moreover, creating a DHM is time consuming and extremely expensive; therefore, the current modeling methods hardly meet the requirements of fast fashion. This is one of the main factors that limit the application of 3D technology in the fashion industry.

The main goal of this research is to develop a relatively simple and rapid method to create a DHM for the clothing industry. In this paper, we propose a mixed modeling method (MMM) which integrates advantages of FMM, RMM and PMM. First, hands, feet, head and torso were constructed by different modeling methods respectively. Next, these parts' models were combined into a single static human model. Finally, a lifelike dynamic human model was created by binding a virtual human skeleton to the model.

## 2. Method

### 2.1 *The partitioning of human point cloud for modeling by MMM*

We used a 3D body scanner (TC<sup>2</sup>) to capture the point clouds of a 30-year-old male human body. As shown in Figure 1, we divided the point cloud into seven parts: head, shoulder, arms, middle torso, hands, legs and feet. In order to construct a DHM for clothing design, different modeling methods were adopted to construct the models of these parts. Owing to the fact that hands, feet and the head have no effect on the fitness of clothing, and that the point cloud of these parts are seriously defective, we used FMM to construct the model of hands and feet. In order to obtain a lifelike face model, the head was modeled by PMM. As the torso is needed for accurate dimensions for usage in fashion design, we modeled the torso by RMM.



**Figure 1.**  
The partitioning  
method of human  
body point cloud

2.2 Static human body modeling based on FMM, PMM and RMM

2.2.1 Modeling hands and feet by FMM. FMM was applied to model the hands and feet. As shown in Figure 2, three steps are needed:

- (1) a cuboid was created first (Figure 2(a));
- (2) the points, lines and surfaces of the cuboid were adjusted to make the cuboid-like hand as much as possible (Figure 2(b) and (c)); and
- (3) the polygons, which structure the hand model, were increased until the surface of the model gradually became smooth, and a vivid hand model was created finally (Figure 2(d)).

In addition, we constructed the feet model in the same way (Figure 2).

2.2.2 Modeling the head by PMM. PMM was applied to model the head by FaceGen Modeller 3.5.3 and Poser 2014 software. As shown in Figure 3, three steps are needed:

- (1) front and side photos of the face were taken, and then these two photos were input into the FaceGen Modeller 3.5.3 software;
- (2) the eye, nose and mouth of the photos were adjusted to overlap the corresponding marks. And then, a head model without hair was created automatically; and

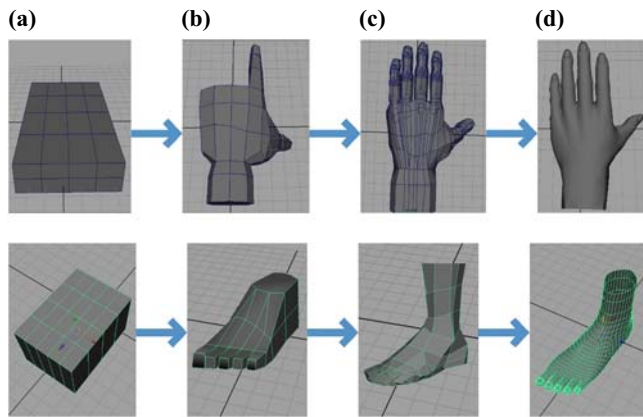


Figure 2.  
The hands and feet modeled by FMM

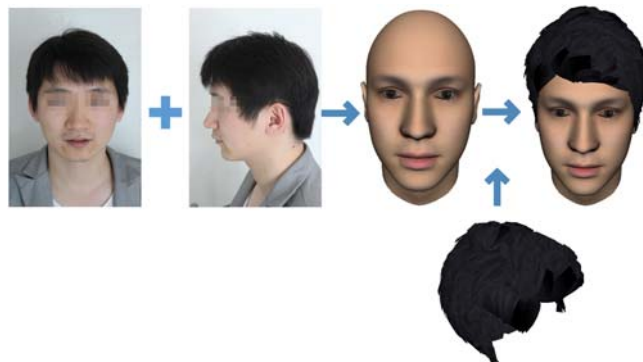


Figure 3.  
The head modeled by PMM

- (3) a hair model was created by Maya 2014. This hair model was then joined to the head model. A complete head model was created finally.

Actually, the head can be modeled by FMM; nevertheless, it is quite time consuming to create a vivid head model because there are many organs on the face, including eyes, nose and mouth.

**2.2.3 Modeling the torso by RMM.** The principle of RMM is that non-uniform rational b-splines (NURBS) curves are fitted according to point clouds, and then NURBS surfaces are fitted according to NURBS curves and point clouds; finally, a model is reconstructed based on NURBS surfaces. The human body has an approximate bilateral symmetry; therefore, we just need to construct half of the body model, and the other half can be created by symmetrical method. The torso modeling is one of the most important works in this research since clothing fitting is closely related to this part. RMM can keep as much as possible information of body shape according to the point cloud; therefore, RMM was selected to model the torso. As shown in Figure 1, the torso was subdivided into four parts: leg, arm, shoulder (from middle neck line to armpit line) and middle torso (armpit line to bottom crotch line). Next, we introduce how to reconstruct the models of these parts.

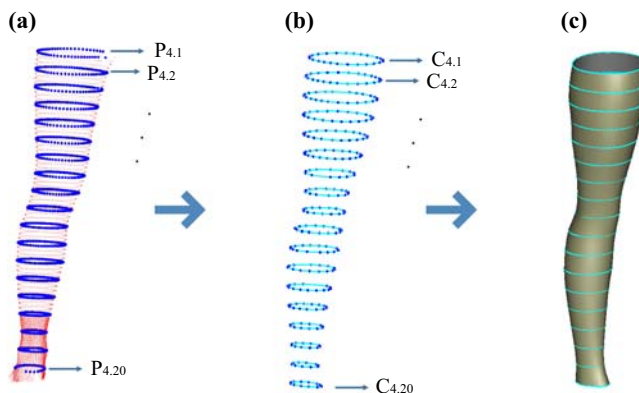
**2.2.3.1 Leg modeling.** As the shape of the leg is like a column, we conceived to model the shoulder by lofting method. Three steps were needed to achieve the above idea:

- (1) point clouds  $P_{4,1}, P_{4,2}, \dots, P_{4,20}$  were extracted from about 20 horizontal cross-sections of the leg (Figure 4(a));
- (2) circular curves  $C_{4,1}, C_{4,2}, \dots, C_{4,20}$  were fitted simultaneously according to the point clouds  $P_{4,1}, P_{4,2}, \dots, P_{4,20}$  (Figure 4(b)); and
- (3) finally, a leg model was reconstructed by lofting curves  $C_{4,1}, C_{4,2}, \dots, C_{4,20}$  (Figure 4(c)).

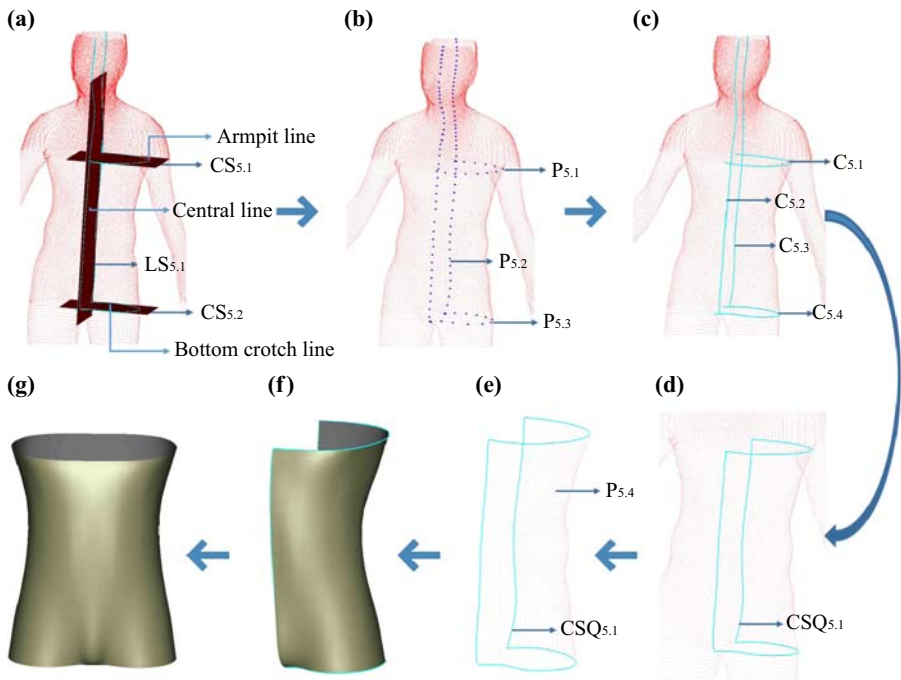
In general, the more the curves, the more accurate it is to model the leg by this method. But too many curves lead to rough surfaces of the model. We found that a leg model which is fitted by lofting 20-25 curves can meet the needs of fashion design very well through trial and error.

**2.2.3.2 Middle torso modeling.** In order to construct a middle torso model as accurately as possible, we adopted boundary lines and point clouds to fit surfaces. As shown in Figure 5, the construction of the middle torso requires five steps:

- (1) cross-sections  $CS_{5,1}$  and  $CS_{5,2}$  were cut according to the armpit line and bottom crotch line, and a longitudinal section  $LS_{5,1}$  was cut according to the central front line (Figure 5(a));
- (2) point clouds  $P_{5,1}, P_{5,3}$  and  $P_{5,2}$  were extracted from cross-sections  $CS_{5,1}, CS_{5,2}$  and the longitudinal section  $LS_{6,1}$ , respectively (Figure 5(b));



**Figure 4.**  
The leg modeled  
by RMM

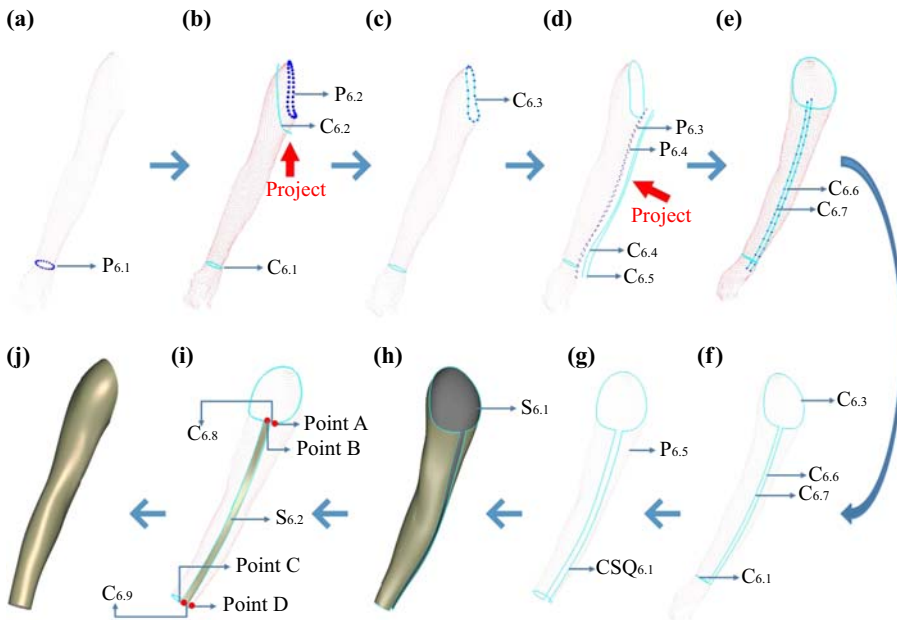


**Figure 5.**  
The upper torso  
modeled by RMM

- (3) armpit curve  $C_{5.1}$ , central front curve  $C_{5.2}$ , central back curve  $C_{5.3}$  and bottom curve  $C_{5.4}$  are fitted, respectively, according to point clouds  $P_{5.1}$ ,  $P_{5.3}$  and  $P_{5.2}$  (Figure 5(c));
- (4) curves  $C_{5.1}$ ,  $C_{5.2}$ ,  $C_{5.3}$  and  $C_{5.4}$  were trimmed to space quadrilateral  $CSQ_{5.1}$  (Figure 5(d) and (e)); and
- (5) NURBS surface  $S_{5.1}$  was fitted according to space quadrilateral  $CSQ_{5.1}$  and point cloud  $P_{5.4}$  (Figure 5(e) and (f)); finally, a whole middle torso was reconstructed by symmetrical method (Figure 5(g)).

2.2.3.3 Arm modeling. The shape of arm is similar to leg; therefore, we tried to model the arm using the same method applied for the leg. However, the result is less than perfect; because the arm is relatively slim, the arm's point cloud data are inadequate and irregularly distributed. Furthermore, the arm top is not a column but a triangular curve surface. We conceived another way to model the arm, involving eight steps:

- (1) Points cloud  $P_{6.1}$  was extracted from the cross-section, which passes through the wrist line (Figure 6(a)), and wrist curve  $C_{6.1}$  was fitted according to point cloud  $P_{6.1}$  (Figure 6(b)).
- (2) Curve  $C_{6.2}$  was created according to the shape of the arm hole, and then point cloud  $P_{6.2}$  was extracted by projecting Curve  $C_{6.2}$  (Figure 6(b)). Arm hole curve  $C_{6.3}$  was fitted according to the point cloud  $P_{6.2}$  (Figure 6(b) and (c)).
- (3) Curves  $C_{6.4}$  and  $C_{6.5}$  were created according to the outer seam of the arm (Figure 6(d)), and then point clouds  $P_{6.3}$  and  $P_{6.4}$  were extracted by projecting curves  $C_{6.4}$  and  $C_{6.5}$ ; next, outseam curves  $C_{6.6}$  and  $C_{6.7}$  were fitted according to point clouds  $P_{6.3}$  and  $P_{6.4}$  (Figure 6(e)).

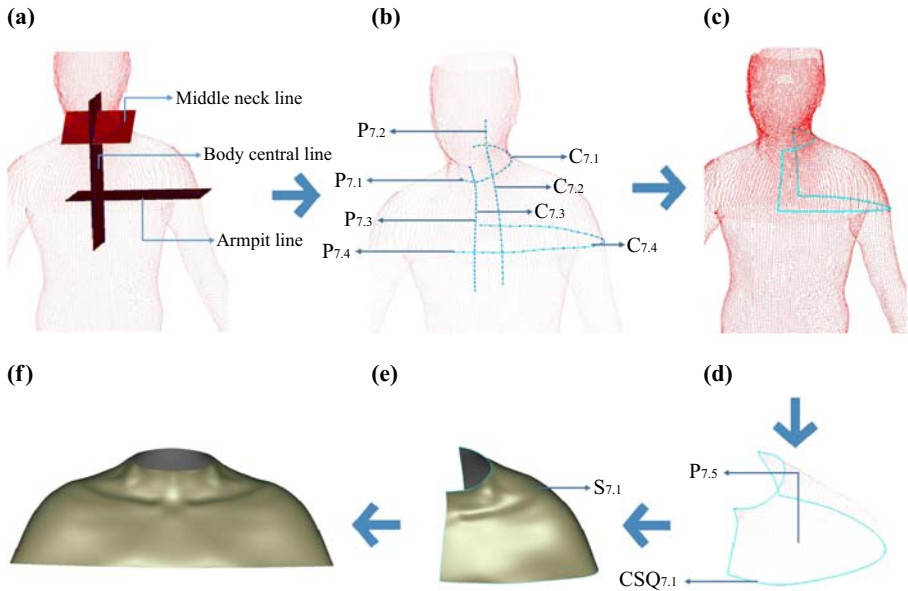


**Figure 6.**  
The arm molded  
by RMM

- (4) Curves  $C_{6.1}$ ,  $C_{6.3}$ ,  $C_{6.6}$  and  $C_{6.7}$  were trimmed (Figure 6(f)), and then closed space quadrilateral  $CSQ_{6.1}$  was formed by linking these trimmed curves end to end (Figure 6(g)).
- (5) Curve surface of arm  $S_{6.1}$  was fitted according to curves  $C_{6.1}$ ,  $C_{6.3}$ ,  $C_{6.6}$ ,  $C_{6.7}$  and point cloud  $P_{6.5}$  (Figure 6(f)-(h)).
- (6) Curve  $C_{6.8}$  was created by bridging point A and point B; curve  $C_{6.9}$  was created by bridging point C and point D (Figure 6(i)).
- (7) Curve surface  $S_{6.2}$  was fitted by bi-directional loft of curves  $C_{6.6}$ ,  $C_{6.7}$ ,  $C_{6.8}$  and  $C_{6.9}$  (Figure 6(i)).
- (8) An arm model was constructed by combining surface  $S_{6.1}$  and  $S_{6.2}$  (Figure 6(j)).

2.2.3.4 Shoulder modeling. In order to model the shoulder as accurately and easily as possible, we conceived a way to model shoulder based on border lines and point clouds. As shown in Figure 7, the shoulder model was reconstructed in six steps:

- (1) point clouds  $P_{7.1}$ ,  $P_{7.2}$ ,  $P_{7.3}$  and  $P_{7.4}$  were extracted from three cross-sections which pass through the middle neck line, body central line and armpit line, respectively (Figure 7(a) and (b));
- (2) curves  $C_{7.1}$ ,  $C_{7.2}$ ,  $C_{7.3}$  and  $C_{7.4}$  were fitted respectively according to point cloud  $P_{7.1}$ ,  $P_{7.2}$ ,  $P_{7.3}$  and  $P_{7.4}$  (Figure 7(b));
- (3) curves  $C_{7.1}$ ,  $C_{7.2}$ ,  $C_{7.3}$  and  $C_{7.4}$  were trimmed, and then closed space quadrilateral  $CSQ_{7.1}$  was formed by linking these trimmed curves end to end (Figure 7(c));
- (4) point cloud  $P_{7.5}$  which is in space quadrilateral  $CSQ_{7.1}$  was extracted (Figure 7(d));
- (5) curved surface  $S_{7.1}$  was fitted based on space quadrilateral  $CSQ_{7.1}$  and point cloud  $P_{7.5}$  (Figure 7(e)); and
- (6) a whole shoulder model was constructed by symmetry method (Figure 7(f)).

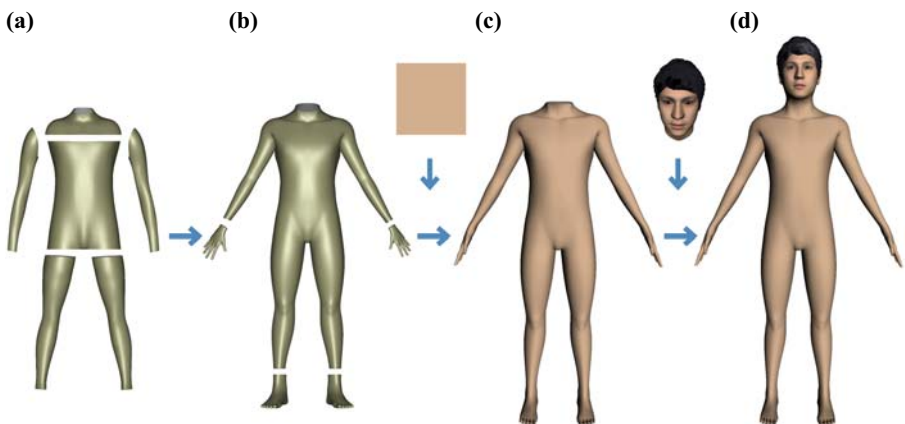


**Figure 7.**  
The shoulder modeled  
by MMM

*2.2.4 Whole body modeling by MMM.* In this section, we constructed a lifelike DHM by Maya 2013 and ZBrush. As shown in Figure 8, three steps are needed:

- (1) a DHM without head was combined by the model of hands, feet, arms, legs, shoulder and middle torso (Figure 8(a) and (b));
- (2) a skin picture was assigned to the DHM (Figure 8(c)); and
- (3) a DHM was constructed by combining the body and head (Figure 8(d)).

The above steps' operations are very time consuming; therefore, this part needs to be carried out automatically in the further research.



**Figure 8.**  
Whole body modeled  
by MMM

### 2.3 Dynamic human body modeling by binding a virtual human skeleton

**2.3.1 Human skeleton.** The human body has over 200 bones, and about 300 joints. These bones and joints constitute a complicated skeletal system which supports and drives our body in various body movements. It is very difficult to establish a virtual skeletal system exactly identical to the real skeleton. For the fashion industry, a 3D dynamic mannequin just needs to do several regular motions for dynamic evaluation of fitting, virtual fashion show and so on; therefore, we conceived a simple virtual skeletal system to be bound to the static human model. Finally, the real skeletal system was simplified to 19 bones and 15 joints (Figure 9(a)).

**2.3.2 Skeleton binding.** In this section, we bind a virtual human skeleton to a 3D human body model by Maya 2013 (Figure 9), involving three steps:

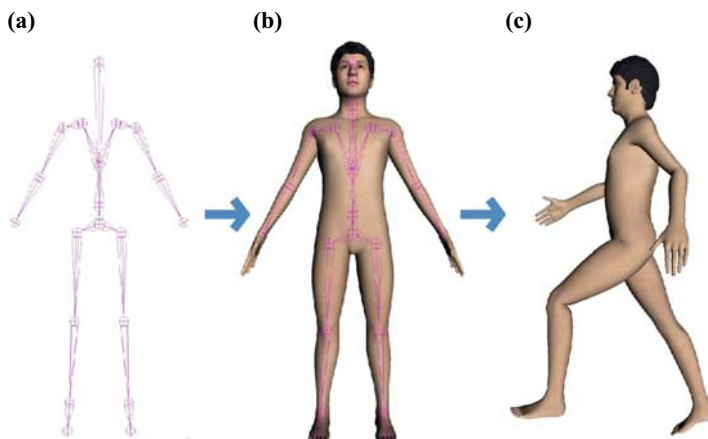
- (1) a virtual human skeleton was created by our simplified skeletal system (Figure 9(a));
- (2) adjusting bones and joints of the virtual human skeleton to corresponding places of the DHM, and then bonding the virtual human skeleton on the DHM (Figure 9(b)); and
- (3) the skinning weights were adjusted until the result was satisfactory, and a dynamic DHM was finally created (Figure 9(c)).

The above steps' operations are very time consuming and need repeated testing; therefore, this part needs to be carried out automatically in the further research.

## 3. Result and discussion

### 3.1 Comparing FMM, RMM, PMM, PARMM and MMM

Through human modeling experiments above, a DHM was constructed by MMM. Actually, each modeling method can be utilized to model human body independently, and the difference in these methods depends on difficulty, the length of time, cost and accuracy. The advantage of FMM is the diversity in possible models with less constraints; the disadvantage of this method is the time-consuming element and requirement of sophisticated skill. RMM has the advantages being fast and accurate; the disadvantage of this method is the inability to produce a model without point cloud data. The PARMM is simple and rapid, although with a disadvantage is that some parameters cannot be accurately represented in the model's information. The advantage of PMM is that it is very quick, and the disadvantage is dimension distortion. The MMM absorbs the merits of



**Figure 9.**  
The virtual human  
skeleton bonding

FMM, RMM, PMM and PARMM. The rate of model construction for MMM is quicker than FMM, and the accuracy of model construction in MMM is more precise than FMM, PMM and PARMM.

### 3.2 Comparing real and virtual body dimensions

In order to evaluate the accuracy of body dimensions of the model, we measured 24 dimensional items of real people. Each person's model was constructed three times using our method, and then an average was taken (Table I). These dimensions are closely related to garment fit. As shown in Table I, most of the virtual model's body dimensions on height direction are larger than for real people. This is mainly because the head and feet which influence height dimensions are modeled by PMM and FMM, respectively, and these head and feet models are created taller. On the other hand, most of the virtual model's body dimensions on girth direction are smaller than those of real people (Table I). This is mainly because people involved in the study wore underwear during this measurement. Actually, the dimensions of the feet and head have no influence on garment fit. The relative errors are negligible, except for crotch width and shoulder width (Table I); the shoulder point is difficult to find, hence the error, and the point cloud of the crotch lacks seriously. The differences in dimensions of real people and their virtual model are very negligible, and these differences are acceptable for fashion design, and made-to-measure items among others. So the MMM is entirely feasible to model the human body.

### 3.3 Limitation

There is significant previous research on human body modeling technology for the clothing industry. Our method has proved superior, feasible and more effective than others

No.	Item	BDRP (cm)	BDHM (cm)	AE (cm)	RE (%)
1	Stature	168.5	170.1	-1.6	-0.95
2	Cervical height	145.1	146.6	-1.3	-0.895
3	Bust height	125.7	126.4	-0.7	-0.557
4	Waist height	103.2	104.6	-1.4	-1.357
5	Hip height	82.7	82.3	0.4	0.484
6	Knee height	47	47.4	-0.4	-0.851
7	Abdomen height	96.5	97.9	0.6	0.609
8	Leg length	73.9	74.3	1.6	2.108
9	Arm length	56.7	55.9	0.8	1.411
10	Neck to waist length	43.6	44.2	-0.6	-1.376
11	Crotch length	71.5	69.7	1.8	2.517
12	Upper arm length	31.8	31.2	0.6	1.887
13	Bust	92.5	92	0.5	0.541
14	Waist	82.2	81.1	1.1	1.338
15	Hip	95.1	93.8	1.3	1.367
16	Abdomen	87.1	86.7	0.4	0.463
17	Thigh	57.8	57.2	0.6	1.054
18	Knee	36.9	36.2	0.7	1.897
19	Shoulder width	42.1	41.3	1.8	1.9
20	Maximal calf girth	36.8	36.4	0.4	1.087
21	Minimal calf girth	22	22.5	-0.5	-2.273
22	Front across	38.1	37.4	0.7	1.837
23	Back across	39.8	40.4	-0.6	-1.508
24	Crotch width	19.6	20.7	-1.1	-5.612

**Table I.**  
Comparison between  
real and virtual body  
dimensions

**Notes:** BDRP, body dimensions of real person; BDHM, body dimensions of human model; AE, absolute error; RE, relative error

discussed. The processes of combining the head, hand, foot, torso and head together, and skeletal binding and skinning took time and needed practiced skills, especially the boundary proceeding of two human body parts of the model. Moreover, the MMM is still carried out by manual operation through combining some commercial software. A new software application can be developed based on the principle of MMM in the future; thus, the modeling process can be carried out automatically by the developed software. In the real application, we can model the torso alone by RMM for made-to-measure, or model the upper body for upper clothing design, or model lower body for lower clothing design.

#### 4. Conclusion

Currently, 3D garment design becomes more and more popular. The first step of 3D garment design is to model 3D human body. After this, designers can design garment on the 3D human body model. Therefore, 3D human body model is very important for 3D garment design. There are several methods to construct 3D human body model currently; however, these methods mainly focus on 3D animation and rarely involve in how to model human body for clothing industry. As MMM models human body based on the body's point cloud collected by 3D body scanner, the human body model's dimensions equal to scanned body's dimensions. Thus, the 3D human body model constructed by MMM can meet 3D garment design well.

From the modeling experiments and discussion above, we draw the following conclusions: First, it is more simple and accurate to model human body by the MMM than the FMM, RMM or PMM alone. Second, the model which is constructed by the MMM can meet the requirements for virtual fashion design and other relevant industries.

Our technology has great potential for development and application. For example, a rapid model generation system can be designed based on our method of 3D human body modeling above for clothing industry in future work. With this model generation system, we only need to scan a wearer's body and take the front and side photos of their head, and then a 3D dynamic mannequin is automatically generated immediately. This technology will greatly enhance the efficiency of virtual garment design, virtual try on, virtual draping and related industries.

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