Intelligent Clothing Size and Fit Recommendations based on Human Model Customisation Technology

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ABSTRACT

E-commerce and mobile commerce have become part of our lives; the growth of online sales has continuously outpaced that of through traditional retail channels. However, even though nearly everyone now shops online, it is still challenging to sell clothes online. One of the major reasons is that size selection and clothing fit are still difficult to address within the current online platforms; this is reflected by the alarming return rate, between 20% and 40%, of online purchased clothes. New technology recently becomes available to create accurate 3D human models for individual customers by taking two photos using smart phone. The resulting models have accurate size and detailed local shape characteristics. The accuracy of the resulting models is comparable to scan, meeting the size tolerance of the clothing industry. Extending from this photo-based precise human modelling technology, we propose new solutions in this paper to advise suitable clothing sizes for individual customers, and to visualise virtual try-on effects of clothing on customised human models for online fit and size evaluation. We verify the size and fit recommendation solutions by experiment on clothing items of dress and shirt in this paper. With these novel sizing and fitting solutions, fashion brands can better serve their customers by attracting, engaging and delighting them with a brand new shopping experience.

Keywords

Human modelling, virtual try-on, clothing simulation, size and fit evaluation

1. INTRODUCTION

During the past five to ten years, e-commerce and mobile commerce have become part of our lives. According to China Internet Network Information Centre (CNNICC) [1], clothing, shoes and hats are among the top five product categories that people shop online. Despite the large online sale figures, selling clothes online is still challenging because clothing fit is difficult to address. It is not uncommon that people find the clothing products ordered online do not fit them at all when orders are received, and they have to arrange for exchange or return. Research studies [2,3] reported that most complaints about online clothing purchases are related to size and fit, and ‘fit’ is one of the major reasons for purchase return. In addition, uncertainty of clothing fit not only causes high return rate, but also affects customers’ overall satisfactions towards the e-stores/brands, leading to loss of sales. It is thus important to research on new solutions for online fitting suggestions and size recommendations.

Recent developments in computer graphics and virtual reality have brought about new possible solutions to facilitate fit analysis in online shopping, that is, virtual garment fitting on human models. Existing one fitting processes usually start from creating avatars using subject’s body measurements, followed by a number of interactive 3D operations for selecting and positioning clothing pattern pieces around avatars and virtual sewing in order to generate the final virtual try-on results. Virtual try-on applications enable users to visualise the wearing effects without physically trying on garments, improving shopping efficiency [4] and reducing product return rates [5].

The research work of virtual try-on are mainly focused on better modelling and rendering the time-varying geometrical and mechanical behaviours of clothing and its interaction with human models. Geometry-based simulation and physics-based simulation are the two categories of methods in virtual try-on or clothing simulation. Although previous research efforts have successfully modelled the clothing models in accordance with the physical laws and ensured attractive rendering results, virtual fit evaluation is still difficult to address. One of the main reasons is that human shapes vary substantially, while the existing try-on simulation are not on individual shapes, but avatars with average figure shape. We propose in paper a complete pipeline that integrates virtual fitting and human model customisation technologies to realize fit and size recommendation, facilitating online shopping of clothes. The rest of the paper is organised as follows. We first review the related work in virtual simulation and human modelling technologies in Section 2. We next explain our proposed pipeline in Section 3. We conduct experiment in Section 4 to demonstrate the proposed pipeline by trying on a dress model onto three female subjects, and trying on a shirt model onto three male subjects. After physical draping, collision detection, response and rendering, the result provides visual references for fitting analysis on different figures or body shapes.

2. RELATED WORK

Virtual fitting solution has aroused much research attentions in recent years. In general, a typical virtual fitting system consists of three subsystems, namely, body-shape modelling system, clothing simulation system, and interactive 3D exhibition room [6]. Fitting a 3D garment model onto an individual human model requires a perfect match between the two models and a minimal distortion of the garment model. Therefore, typical virtual fitting solutions must address to two problems [7]: garment simulation and human modelling technologies.

2.1 Clothing Simulation Technology

Garment simulation or draping means computing the shape of a piece of cloth under the control of gravity [8]. Traditional virtual try-on simulations have two approaches: either sewing 2D patterns around a 3D character [20,21] or fitting 3D garment models directly onto a 3D human model [7,22]. Comparing with other 3D simulation, garment simulation is unique and challenging for two reasons: garment fabric is soft and human body is usually in movements.

Normally, a garment on human body can be classified into fit part and fashion part [9,10]: the former is in direct contact with the human model and the latter is draped freely to create aesthetic appearance. The fit part can be directly determined by semantic features on a body model [11], while the fashion part is simulated according to the physical properties of garment materials.

Before the pioneer work of Prof. Nadia Magnenat-Thalmann, little has been done on realistic garment simulation [12,13]. Only simple scenes such as blowing flag could be simulated. In the last two decades, many efficient simulation models were proposed, with which customers can visualise the realism of virtual try-on [8].

Garment simulation methods can be divided into two classes − geometric based and physical based methods. Geometric methods describe complex geometric details by mathematical models, such as wrinkles and folds [14]. It treats garment as developable surfaces. Developable surface means that the materials cannot be stretched or torn during the process of virtual sewing and simulation. Considering that most textiles have little stretch in physics, the geometric model could indeed achieve acceptable level of accuracy. On the other hand, in physical based simulation, the mechanical properties of fabrics are calculated, leading to higher level of simulation accuracy. However, its computing speed is much slower than the geometric methods. Many physical models were proposed, such as the mass-spring models [15,16], the particle models [17] and the elasticity-based models. To take advantages of the merits of both geometric methods and physical based method, to be specific, the speed of the geometrical methods and the accuracy of physical methods, some researchers proposed hybrid models [18,19] for clothing simulation.

2.2 Human Modelling Technology

3D human body modelling technology has been widely studied by engineers and researchers in computer graphics area. Body-scanning technology enables each individual to be the centre of garment development and enhances experience in size and fit [23]. In most cases, 3D body scanners capture subject’s body surfaces using optical techniques [24]. Body scanning has been applied in sizing and mass customisation. Scan-based methods have known drawbacks such as high cost and privacy concerns [25,26]. Other fitting tools usually build virtual avatars based on users’ body measurement input [27]. However, inaccurate body measurements are often input by general consumers [28]. Moreover, measurement-driven deformable models are often established by example-based methods, which create realistic average figures, but cannot capture detailed local shape characteristics of individuals.

In the age of smartphones, It is appealing if accurate 3D models of individuals can be created by taking photos. To this end, various image-based reconstruction methods were proposed. Traditional image-based reconstructions require a set of images to be simultaneously taken for body dimensions analysis. Moreover, subjects are asked to take photos against a mono-color background. For example in [29], two photographs were taken and verified, after which 36 landmarks were identified manually to define for collecting body dimensions. However, model generation process is time consuming in the method of [29]. [25] used a segmentation method to accelerate extraction of 2D body contours from front-view and right-view photographs. However, there are known shape approximation errors in their method of constructing 3D body shape.

Recently, a new model customisation method was recently developed by segmenting raw contours of the human subject from images, from which to construct 3D shape representation for the subject using trained relationships between 2D profiles and 3D shape representation, and the shape representation guides the detailed shape deformation for subjects dressed in tight-fit clothing [26], in arbitrary clothing, or even loose-fit clothing [30]. A subject's 3D body model can be customised in a few seconds, and the output models have accurate sizes and realistic shape details. However, their method does require some manual work in image feature definitions.

3. SOLUTION TO THE PROBLEM

This paper proposes a virtual clothing simulation system that integrates human model customisation technology with virtual try-on simulation, as shown in Figure 1.

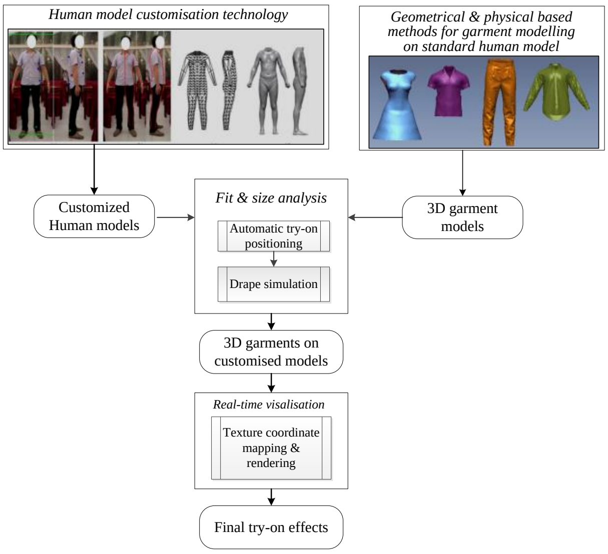

Figure 1. Virtual fitting flow chart

We will first describe briefly the human model customisation technology in section 3.1, which is based on our previous work [26,30]. Next, we briefly discuss two approaches to obtain 3D garment models in section 3.2. The key contribution of this paper lies in the part fit and size analysis by automatically trying on 3D garment models onto different customised human models and carrying out drape simulations. For simplicity, virtual garments are simulated using particle system model. Although particle model-based simulation may have deviation on the final try-on effects because of the simplification in the simulation computation, our method does visualise the garment and body relationship before the simulation. The geometrical relationship better illustrates the clothing 'fit'. We demonstrate that this approach can be used for efficient near real-time size recommendations and fit evaluation. After the drape simulation, the final garment shapes on customised models are shown to customers. By pre-computing texture coordinate mapping, users can be shown with the rendering results of different colours and texture choices on the final garments in real time.

3.1 Human Model Customisation

Although previous studies have attempted to use virtual try-on to analyse fit, most previous studies of clothing simulation use standard virtual dummy instead of customised human models for the simulation. One of the reasons is that clothing simulation is computational expensive, it is difficult, if not impossible, to simulate the try-on effects in real time when a clothing is selected. All simulations must be done beforehand and the final simulation results are recorded at the database for visualisation. Another reason, more critical one, is that most existing human modelling methods cannot create a very accurate body shape model for individual customers.

We proposed to apply the human model customisation method [26,30] for online virtual try-on and fit evaluation. We propose complete automatic pipeline to obtain accurate measurements and have 3D body models customised using two photographs. The human modelling method has the following advantages: (1) customised models have high resolution details and realistic appearance; (2) customised models are very accurate (in terms of sizes), comparable to scan; (3) the modelling process is efficient, meeting the requirement on real-time application; (4) the user involvement is simple and easy to handle, just by taking two photographs without restrictive clothing conditions.

Our method create accurate body models under clothing based on customer's photos. Photos only contain 2D information, we define customer's 2D feature as body profiles – front-view and side-view profiles. Since most parts of body profile are covered by clothing in the photos, the most challenging task is to predict a complete under-the-clothes profile based on some cues not being covered by clothing.

To do so, we first establish a database of normalized body profiles. The profiles are extracted from scans of human subjects with different body shapes. The database covers a wide range of body shapes; some example profiles are shown in Figure 2.

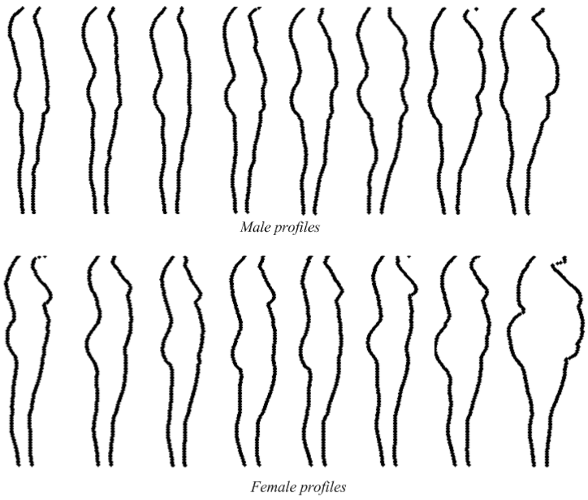

Figure 2. Example profiles in the profile database

We used the state-of-the-art semantic segmentation technology [31] to identify the human from the image background by training a fully convolution network (FCN), as shown in Figure 3. We then synthesise the under-the-clothes body profiles (Figure 4) of the subject with patented method [32] by taking advantage of the large profile database.

Figure 3. Human parsing

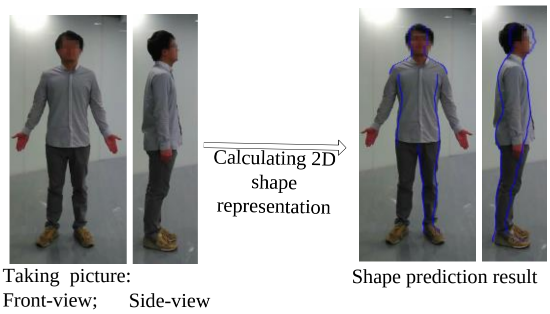

Figure 4. Body profile calculation

With the 2D profiles, we can use them to predict and construct 3D shape representation for the subject in the photos. To do so, we identify a number of body features (such as chest, waist, hips, crotch, shoulder, etc.) from the synthesise profiles using anthropometric knowledge. The corresponding width and depth of each body features are obtained and input to relationship models trained between 2D features and 3D shape, so as to generate the cross-sectional 3D shape at these feature levels. The predicted cross-sectional 3D shapes are used to reconstruct a large mesh model as a 3D shape representation of the subject (Figure 5). It is important to note that our 3D shape representation is feature aligned mesh, consist of parallel cross-sectional features. Each layer represents a cross-sectional shape of the subject's body corresponding the girth of to a feature. By defining the body shape in parallel cross-sections, we characterize different body figure types. The relative positions of these cross-sectional body features in fact describe the overall shape of the body, so they define the body model's global features. A layered structure with parallel cross-sections is an effective shape representation, because such a structure aligns with the clothing size definition. The parallel cross-sections characterize local features of the body in terms of shape and size, as some cross-sections indeed correspond to important body girth measurements, such as the bust, waist, and hip. The shape of these cross-sections gives detailed information on where the body has developed fat, for instance the shape of the waist girth. With these detailed shape representation, we can deform detailed 3D models by deforming a template using deformation algorithm [26,30].

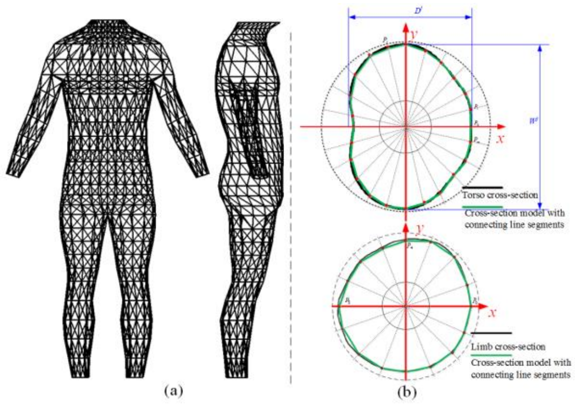

Figure 5. 3D shape representation

3.2 Garment Modelling

We used both two methods [33,34] to generate 3D garment model from 2D pattern pieces. Our system first imports pattern pieces in dxf format, and triangulates the 2D pattern pieces as mesh models by the constrained delaunay method (see Figure 6(a)).

3.2.1 Physical-based simulation model

Traditionally, 2D pattern pieces are place around human model in 3D space, and simulate garment try-on effect by physical-based method [33], as shown in the example of Figure 6(b). We used particle system to simulate clothing's physical properties, in which each vertex of the cloth mesh is treated as a particle, and its positions and velocities are updated under different forces acting on the particle. The particle system can simulate highly deformable objects like clothing. A particle system mainly employs Newton's second law,

$$F(t) = M\frac{d^2P}{dt^2} \qquad (1)$$

where the vector $\boldsymbol{P}$ represents the particle position, $\boldsymbol{M}$ denotes the geometric state and mass distribution of the cloth, $\boldsymbol{F}$ is the sum of the forces (air-drag, contact and constraint forces, internal damping, and so forth) exerted to the particle.

Combining all forces into a force vector f_i, the acceleration a_i of the ith particle is simply defined by $a_i = \frac{f_i}{m_i}$, where m_i is the ith particle's mass. Given the known position $\boldsymbol{P}(t_0)$ and velocity $\boldsymbol{v}(t_0)$ of the system at time t_0, our goal is to determine a new position at each time step.

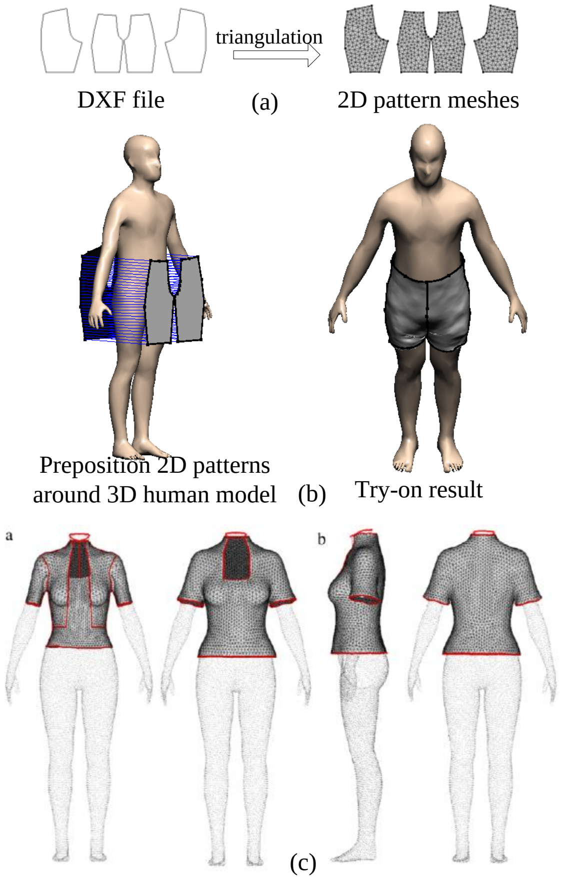

Figure 6 (a). Triangulation of pattern pieces; (b) modelling 3D garment by physical-based simulation [33]; (c) geometrical garment modelling method [34]

Physical-based simulation may generate slightly different garment models each time. One of the reasons is that pattern pieces are manually arranged around the human model before the simulation in most physical-based simulation. The preposition of 2D pattern pieces in relation to the 3D human model determines the final appearance of garment. In general, pattern pieces should be arranged as close as possible for better results. The output 3D garments will have folds and gathers formed in the physical drape simulation.

Another approach to generate 3D garments is by geometrical-based surface parameterisation [34], involving two steps (see Figure 6(c)).

Step one is to obtain an initial form of 3D garment and correspondence mapping relationship between human model of clothing. This is done by first defining corresponding feature points on both the human mesh model and the clothing pattern pieces. Next, the human mesh model is segmented to several patches to match with the patterns. Finally, a cross parameterization procedure is carried out by duplex mapping scheme.

Step two is to restore the desired shape and size of the 3D garment from its initial form. Iterative hybrid pop-up method is employed to deform the initial garment. First, the silhouette of initial form of garment (i.e. girth measurement at the hem level) is adjusted to the size of corresponding pattern pieces. A physical simulation is performed along the normal direction to update the garment length. As a result, the position of the boundary vertices is changed. Finally, the rest vertices are updated by the geometrical reconstruction with the use of pyramid coordinates. The pyramid coordinate of vertex v^{3d} is calculated as weight parameter ω_i^{3d} by:

$$\omega_i^{3d} = \omega_i^{2d}(1 - \cos\theta_i) \qquad (2)$$

where ω_i^{2d} is the mean value coordinates weight, it is defined by its neighbour angle α_i and length l_i as follows:

$$\omega_i^{2d} = \frac{\tan(\alpha_i/2) + \tan(\alpha_{i+1}/2)}{l_i} \qquad (3)$$

where $l_i = |v^{2d} - v_i^{2d}|$.

$$\theta_i = (\arcsin\frac{l}{|v^{3d} - v_i^{3d}|} + \arcsin\frac{l}{|v^{2d} - v_i^{2d}|})/2 \qquad (4)$$

where $|v^{3d} - v_i^{3d}|$ is the length between v^{3d} and its neighbour v_i^{3d} on the 3D shape of the current reconstruction iteration, $|v^{2d} - v_i^{2d}|$ is the corresponding length on the 2D pattern, l is the length parameter value for the local coordinate of the current reconstruction iteration.

Geometrical models obtained by this approach are with smooth garment surfaces. We later obtain drape simulation by a numerical method, which involves Non-linear CG integrator and can solve particles' position and velocity at each time step due to gravity, stretch force, bend forces, and vertex/face and edge/edge collisions.

In this paper, we use the 3D shape representation constructed in the stage of human model customisation for automatic preposition of garment models. Each 3D shape representation has all feature positions known, which can be used to define the relative position of garment models.

4. EXPERIMENT

A garment try-on experiment was conducted involving three male subjects and three female subjects in The Hong Kong Polytechnic University. Firstly, we prepared 3D garment models of dress and polo shirt, which were not draped on human models, but could represent basic geometrical 3D clothing shape. We used the described human modelling method to obtain 3D customised human models for the three males and three females. All subjects were taken front-view and side-view photographs for model customisations.

4.1 Result

To illustrate experimental results, the following part will show the key steps in Figures 7 to 10. In these figures, garment model and customised human models are inputs to the system, the preposition and drape results are shown in blue, and the rendered results are presented in red.

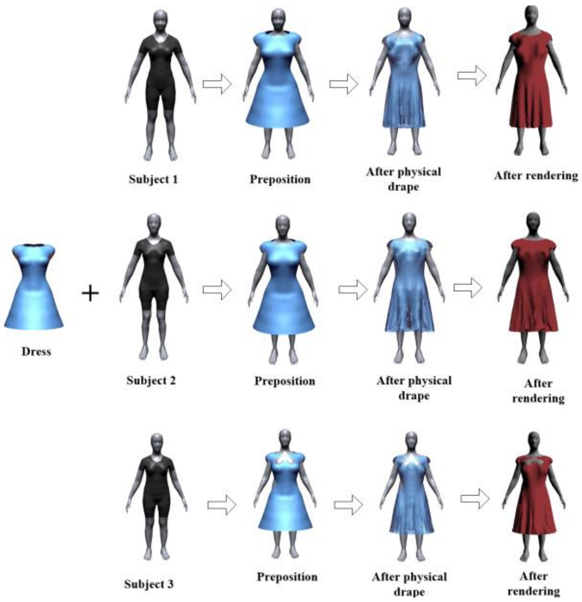

Figure 7. Dress try-on customised female models

Figure 7 demonstrates the results of virtual try-on dress experiment. After obtaining pictures and height information from three female subjects, their customised human models were created. From the prepositioned results where garment model are mapped to different human models automatically, we can found that the dress is fit for subject 2, but too large for subject 1, and relatively too small at bust for subject 3.

We compared the (a) before drape and (b) after drape results of dress on subject 2 in Figure 8. It is shown that the dress is rigid and relatively stiff before drape, and the dress has folds and wrinkles after drape.

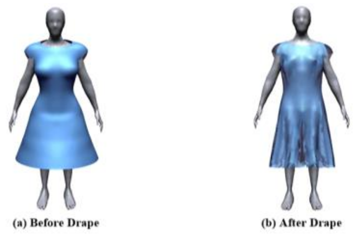

Figure 8. Subject 2's dress wearing effects (a) before drape and (b) after drape simulations.

The final rendered try-on simulation effects for subjects 1, 2 and 3 are shown in Figure 9.

Figure 9. Rendered result for dress on female subjects

We simulate a polo shirt on three male subjects with different body shapes, and the results are shown in Figures 10 to 12.

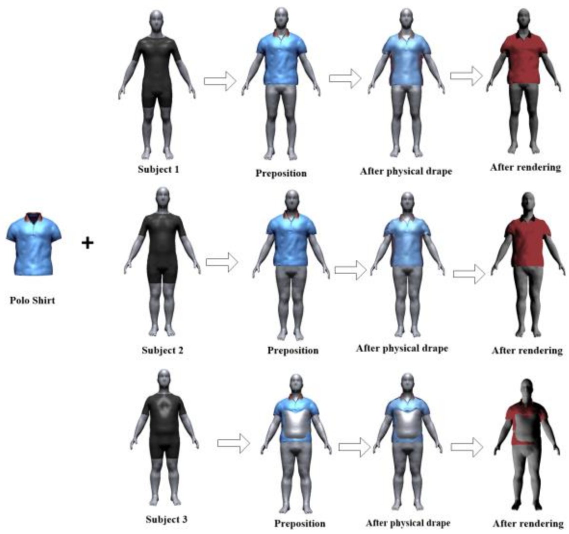

Figure 10. Polo-shirt try-on customised male models

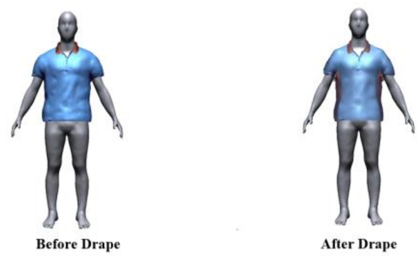

Figure 11. Subject 1's shirt wearing effects of (a) before drape and (b) after drape simulations

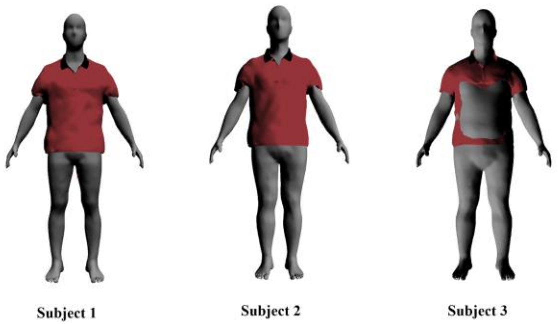

Figure 12. Rendered results for male subjects

4.2 Size and Fit Recommendations

By using virtual garment try-on technology and human model customisation, the experimental results show that subjects with different body sizes and shapes obtain different wearing effects. In addition, the system provides subjects with visual cues for size and fit evaluations.

4.2.1 Dress size recommendation:

As shown in Figure 7, the dress is loose at the waist and the bust for female subject 1. She might need to consider a smaller size. For the dress is fit for female subject 2, and the dress is obviously too small for subject 3.

4.2.2 Polo size recommendation:

As shown in both preposition and drape simulation results in Figure 10, the polo shirt fit for both male subjects 1 and 2, because the polo keeps nice appearance on these human models. The polo shirt is too tight for subject 3, he might is recommended to change to a bigger size.

We can conclude that by visualised simulation results, indirect information on fit and size are given to users.

5. CONCLUSION

In this paper, we explain the clothing industrial need on virtual fitting solutions. We propose complete pipeline obtain fit clothes using virtual fitting solution on the basis of human model customisation technology. We can conclude that customised human models are important for obtaining useful and reliable results in online fit evaluations.

In the future, clothing mechanical properties will be considered for size and fit recommendations. In practice, designers can distinguish fit from the folds and wrinkles of clothing. In the virtual environment, if clothing mechanical properties can be properly modelled the nonlinearities and deformations appearing on the virtual clothing in forms of 'winkles and folds' can be used for more detailed fit evaluations.

6. ACKNOWLEDGMENTS

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