3D Adaptive Morphotype Mannequin for Target Population

Balkiss Hamad*, Moez Hamad, Sébastien Thomassey and Pascal Bruniaux
ENSIAIT, GEMTEX – Laboratoire de Génie et Matériaux Textiles, F-59000 Lille, France

Abstract

The aim of this paper is to present a design methodology to obtain parametric geometrical model of 3D virtual mannequin representing the human bodies of a target population. The morphological evolution of these bodies depends on the chosen sizes imposed by the needs of the apparel industry. The population is composed of a representative sample of 5108 women aged 18-65 years from the French measurement campaign in 2003. These women have been measured by a 3D body scanner to detect with a good precision the measurements of the bodies. The proposed method starts by choosing a person representing the morphology nearest to the morphotype of the population. The morphotype is characterized by specific measurements from the standard size of the measurement chart. A geometrical model associated with reverse engineering techniques has been realized to generate the 3D virtual parametric mannequin from the 3D body scanned of the morphotype. Then, the volume of the parametric mannequin is managed by the morphological evolution rules extracted from the measurement chart of the classification. These rules are directly applied on the di erent morphological curves which are either located on the anthropometric points or managed by anthropometric and proportion rules. These two sets of parameters are directly applied on the 3D human mannequin in order to manage his volume according to the different sizes with a good precision. Finally, the 3D shape of the mannequin is a surface model hung to a morphological curves network. This process guarantees a maximum efficiency and an exceptional morphological similarity of the morphotype when the parametric mannequin evolves from one size to another size.

Keywords: 3D adaptive mannequin; Morphotype; Measurement campaign; Body scanner; 3D CAD system

Introduction

The new dynamics of global trade such as globalization, mass customization, rapid change in fashion trends, new media, the morphological evolution of populations, requires crucial changes in traditional methods of design, with a complex and fluctuating environment, apparel industry is facing a new reality. Therefore, company competitiveness depends on its ability to optimize the management of their resources, according to these new issues. This optimization could be achieved by the use of virtual reality technologies enabling 3D visualization of the garment worn by the consumer. However, this visualisation technique requires strong changes in traditional fashion methods of design and represents an additional challenge for global apparel industry. The first step to reach this digital area of fashion design is to develop adaptive morphotype mannequins.

Modeling of the human body in 3D is a critical and complex task at the same time for the apparel industry. Several modeling methods are proposed in the literature that can be categorised in two approaches: the creative approach (used for example in video games) and the reconstructive approach (used for example in the textile and clothing industry) (Figure 1).

Among the works that seem most interesting of the creative approach, three types of modeling can be extracted. The first method is focused on the anatomy of the human body. Anatomically based modelers [1,2] can simulate underlying muscles, bones, and generalized tissue. The interactive design is allowed in the anatomy-based modelers. However, these modelers require a long time to be produced and may are not suitable for the clothing industry due to fastidious implementation which require some notions about the human anatomy, and extensive knowledge in computer graphics [3]. Some attempts have been made to automatically build 3D geometry of human by capturing existing shape [4].

As mentioned by Seo and Magnenat-Thalmann [5], the disadvantage of these techniques is summarized in difficult to automatically modify the reconstructed models to different shapes following user ends. Example-based shape modeling technique [5,6] is an alternative to overcome this drawback. Ma and He [7] presented an approach to shape a single B-spline surface with a cloud of points, their work is further enhanced on fitting a hybrid mathematical model of B-spline surfaces. Sienz et al. [8] developed a fitting technique to generate computational geometric models of 3D objects defined in the form of a point cloud.

All the above approaches are oriented-geometry and result in the loss of morphological features. Recognized features on the scanned cloud points would benefit the surface parameterization and construction process. The second method relies on the scanning data of the human body. A low-cost 3D scanning technique for measuring subject-specific body segment parameters in an easy, fast, accurate and low-cost way was developed and validated by Pandis et al. [9]. The technology was able to scan an arm in less than 10s. This method has some limitations: the requirement for manual intervention to define the ends of the body segments and the image processing steps that includes de-noising and mesh merging. D’Apuzzo [10] used this concept in the context of the virtual fitting clothing for the apparel industry. Its results reveal a double interest for measurements taking. The first one is the short time of scanning, accuracy and high consistency of the measurements. The second interest is an alternative to the reuse of data from various measurement campaigns. The scan data is a boon for the apparel industry enriched by all these additional informations about the shape and volume of the human body. Admittedly, the 3D scanning methods [11,12] lead to highly accurate human body representation models, however they have not yet managed to solve three key issues: the extremely high cost equipment [3], the model parameterization and the high dependence on the quality and resolution of the 3D scanner. Schwarz [13] describes a newly developed positioning aid that stabilises...
the posture during the scanning process. The design incorporated the following features: Head fixture, Arm fixture, Hip support and Foot fixtures. The result of positioning aid showed that it effectively reduces postural variability for 3D body scanning systems and at the same time does not compromise scan quality. One of the limiting factors is the design process in finding the optimal distance to the body without limiting the fixation properties.

The third method, which aims to segment the human body into several parts. This method of segmentation is applied in many areas of computer vision, such as human posture classification, human body motion analysis, and modeling of human shapes [14]. By an implicit approach, Xiao et al. [15] proposed a modeling diagram from a scanned human body. Their final 3D model is composed of primitives deformable superquadrics, which each of them corresponds to a functional portion body scanned. However, because of the considerable needs in computer graphics knowledge and in human expertise, the method is complex to implement. Moreover, it leads to an animation model difficult to control interactively [16,17]. Moreover, it fails to model accurately the morphological details of the human shape. No methods by creative approaches lead to a real useful synthesis model for the apparel industry in the ready-to-wear sector. Indeed, these models cannot operate in two main values, ie: the stature and volume. Thus, the reconstructive approach appear as a solution to these problems.

There are two main methods of reconstruction: based sample modeling and based anthropometric characteristics modeling. The based sample techniques [5,11,18,19] adapt the parametric surfaces or the morphological curves (including dimensions) of an adaptive model (original model) to the cloud points of a human model. It’s a good alternative to address the problems of creative approaches, specifically in the case of anatomical models and implicit models.

The based anthropometric characteristics techniques proposed by [20] present another human body modeling strategy based on a parametric approach. From a parametrized wired model, the author finds the topological graph of the human body. For this, it predisposes the characteristic points of the wired network on the mesh of the scanned human body. The curves of the network represent then, the morphological contours near of it on which are created different faces. These are then deformed using patches of Gregory interpolation to approximate the body via deformability of mesh of each of them [20]. Koo et al. [21] presents a novel example-based statistical modeling framework to carry out the parametric modeling of 3D human body shapes from linear anthropometric parameters. This framework encompasses three phases: construction of a training database, statistical analysis of human body shapes and model generation.

In Cho et al. [22], authors showed very promising results for interactive modeling of the human body based on a parametric model. From a parametrized wired model, the author finds the topological graph of the human body. For this, it predisposes the characteristic points of the wired network on the mesh of the scanned human body. The curves of the network represent then, the morphological contours near of it on which are created different faces. These are then deformed using patches of Gregory interpolation to approximate the body via deformability of mesh of each of them [20]. Koo et al. [21] presents a novel example-based statistical modeling framework to carry out the parametric modeling of 3D human body shapes from linear anthropometric parameters. This framework encompasses three phases: construction of a training database, statistical analysis of human body shapes and model generation.

In this paper, an approach for the parametric design of human models is developed. Before defining the adaptive morphotype mannequin, there is a crucial need to choose a morphotype representing the human bodies of a target population. The 3D database of these human bodies has been extracted the French measurement campaign. The population sample used is composed of 5108 women aged 18-65 years, measured by a 3D body scanner in order to detect with a good precision the measurements of the bodies. At the end of this measurement campaign, different measurement charts were defined in order to overcome the problems of fitting garment. We chose the one that corresponds to the population sample. A person representing the morphology nearest to the morphotype has been selected from among the population in function of the measurements of the standard size of his measurement chart [23].

The following section presents the development of an adaptive model based on the measurement charts and their morphotypes associated.

### Methodology

The human body cannot be considered like a simple object on which some landmarks and some curves are taken regularly to create the similar shape, on which basic laws are applied to adjust it in function of different parameters. Therefore, the human body analysis and its development must follow anthropometric and morphological rules guided by numerous criteria (golden number, aesthetic canon). These criteria led us to capture the geometric features of morphotype in order to reconstruct an identical morphology for the morphotype mannequin, by increasing locally the discretization in certain areas to take account of atypical morphologies. The creation of an adaptive morphotype mannequin has three operations. The first operation is the selection and extraction of the morphological and dimensional informations on the morphotype to create an identical mannequin. The idea is to respect totally the morphology (more or less muscles or fat). The second operation is the adjustment of this mannequin so that these morphological contours take the dimensions imposed by the measurement chart of the classification. The idea is to respect the volume and the stature given by the standard size. The third operation is to manage the volume of the mannequin in order to adjust it to the different sizes of the measurement table. The idea is to adjust the measure of all the morphological contours in function of each column of the measurement chart representing the different sizes of the consumer.

The parametric morphotype mannequin proposed in this work is a surface model defined by a network of human body.

The quality of the mannequin realistic rendering is guaranteed by the wise choice of these curves, their positions, their settings, the relationship between them and the link with the measurement campaign data. Reverse engineering and modeling software are used to generate a CAD model from scanned data of the subject. To achieve this task we used the DC3D software edited by Lectra Company. The different steps which allow the creation of the parametric morphotype mannequin, from the body scanned to the final result, can be described in eight steps.

### Data post-treatment

3D scan data are generally noisy data and presents defects from the inaccessibility of the hidden areas. The hidden areas are located generally in the tangential areas of the laser beam, i.e. the top of the head and shoulders, or the hidden areas of the body itself such as the
crotch and the underarm. Various operations for the posttreatment of data such as filtering, patching of holes are made on the mesh of the point cloud so that it can then be treated as a surface model represented by a set of faces.

Implementation of anthropometric database

All anthropometric contours of the morphotype should be marked vertically and in the direction of the arm and the forearm. For this we must parameterize this operation with a set of data according to the morphology. Anthropometric points, the golden number rule and the proportion rules of aesthetic canon [24] has been used to estimate initial position of each of these parameters, which were then adjusted from the visual position of the anthropometric curves obtained. For that, two types of contours have to be distinguished:

Primary contours: which respect the rule of the golden number and the proportion rules of aesthetic canon in relation with the feature lines of a garment. The position of these contours is managed by the stature $h$ of the person for the torso height and the leg and arm lengths.

Secondary contours: which represent further morphological curves, lead to the reproducibility of the shape of each muscle or fat mass. Each contour is calculated relatively to the primary contour associated with it.

Extraction of morphological contours

Before the extraction of morphological contours, it is necessary to check whether the person was scanned in a correct posture. A wrong posture will lead to an irretrievably volume error during the symmetrization of the reconstituted mannequin. To solve this problem, a crotch curve is firstly obtained by using the sagittal plane to cut the body surface. Then the lowest point of the crotch curve is detected as a pivot. The pivot permits to adjust the obtained morphological curves extracted from a scanned crotch curve repeatedly until the final crotch curve is located between the breasts and the middle of the nose (Figure 2). If the result shows that the person leans slightly to one side, a correction of the posture will be made by using the measurement of the angle between the sagittal planes of the normal people and the people with leans slightly to one side. Also, a similar operation will be carried out for solving the problem of the person has rotated about its vertical axis.

For the next step mainly 5 points have to be located on the body scan such as left and right Axilla (Armpit), Crotch, Left and Right Acromion, Cervical, Adam’s Apple (Infrahyroid). These points are sufficient to extract morphological key contours (Figure 3).

Left and right axilla (Armpit): We used the same algorithm of locating the armpit point which has been developed in the work of Wang and Lu [21,10]. The goal of this algorithm is to define the armpit points as where the arm starts to attach the body torso (underarm). This approach extracts the key features by using horizontal cutting planes. From the intersection shapes of the three horizontal cutting planes as shown in Figure 4, the armpit points are determined once an horizontal plane with turning points is identified. Such an horizontal cutting plane from the top of the human mannequin downwards is searched. The turning points is identified when the angle on one point is “sharp” (Figure 4: curve 2).

Crotch: According to the Wang method, the algorithm defines the lowest point of the crotch curve as where the two leg curves of the crotch characteristic curve come together [25,26]. From the intersection shape of the three horizontal cutting plane in Figure 5, we can determine the position of the crotch characteristic curve: cutting the human body from the 1/2 height downwards (curve 1), once the intersection breaks up into two curves (curve 3), the crotch characteristic curve lies on a curve (curve 2) in the gap equidistance from both of them.

Side neck point: According to the study of Han et al. [27] they define the process of locating the shoulder point as follows;

Make a front silhouette between the bregma and shoulder point (bold line on Figure 6).

Draw a straight line by connecting the shoulder point and the height of the bregma on the silhouette. The mean of the difference
between the height of the armpit and the height of the shoulder point is obtained when a straight line is drawn, since the shoulder point (which is the base of the lowerside) has not yet been identified. The shoulder point is obtained by adding this mean to the height of the armpit.

Find the point with the largest perpendicular distance from the line on the silhouette. This point is referred to as the side neck point (Figure 6).

**Acromion**: The acromion is generally aligned with the navel and nipples. The Analysis of the proportion of the body in a context of beauty leads to this result [28]. It is possible to apply this technique on morphologies of middle-aged people. In our case, the morphotype that has been detected from our target population does not follow this morphological trend because the age group of our sample population within 50 and 60 years, it means atypical shape. According to Han et al. [27], the acromion is defined by the point maximum distance from the line joining the side neck point and the point on the outer arm on the line drawn from the armpit point perpendicular to the arm axis.

Based on morphological key contours, the next step is to perform a set of horizontal cuts, manage vertically with landmark configured by the anthropometric database in order to create the morphological contours of the leg and torso (Figure 7a-c). For the torso, a set of specifically tilted landmark was created to capture the contours perpendicularly to the axis of the torso (not parallel to the floor), in order to take account its misalignment. Concerning the arm (Figure 8), the 3 oblique sections provide a posture correction.
In order to accurately represent the muscular portion between the arm and torso (deltoid), three tilted cross-sections are set from 3 oriented landmarks (Figure 8a). One of them serves as a reference to the others and is obtained by the translation of the arm landmark on the armpit point. The translation distance is obtained by the measurement between the position of the armpits and the acromion point.

At this stage of the extraction process it is possible to correct the posture by pivoting all torso curves with its landmarks, arm curves with its landmarks and the three tilted cross-sections with its landmarks (Figure 8b). The rotation is centered on the pivot point of the crotch curve with the same angle which has been detected previously during the analysis of posture defect. The four curves of the chest, upper chest and lower chest should be adjusted to solve problems of collision between the arm and the torso (red lines on Figure 8b).

Creation of the homothetic axes and symmetry and distribution plans

All morphological contours are then translated to isolate the reconstruction of morphotype model in another nearby space. The goal is to compare the final results of both morphologies: morphotype, adaptive morphotype mannequin. This operation requires to translate the contours and landmarks of the leg (Figure 9a), the contours of the arm with the three tilted cross-sections (Figure 9b), their landmarks and associated axes, and finally the contours of the torso (Figure 10a).

The arm homothetic axis already made and represented by its two axes, it is necessary to design those of the leg and torso.

The homothetic axis of leg is achieved by creating centers of gravity of the two extreme contours (up and down) of the leg, (Figure 10a). These two points define the ends of the homothetic axis. For the torso, its axis is defined by the intersection of the sagittal plan and of the coronal plan. The sagittal plan is the body symmetry plan which has been detected during the analysis of the posture defect (Figure 10b). The coronal plan, body distribution plan, is perpendicular to the sagittal plane and passes through two points of the chest contour separating the front part from the back part in an proportion ratio of 35% and 65%. A distribution line, defined between two other points of the front/back resulting from the intersection between chest contour and the sagittal plan, must be created. This line serves as a support for projecting one of these two points in order to create a distribution point on which passes vertically the symmetry line (Figure 10b).

Symmetrization of the torso contours

In order to symmetrize the body, each morphological contour of the torso is separated in two parts through the sagittal plan (Figure 11a). Only half-contours from the right side are used to rebuild symmetrically.
Finally, each half-contour is sewn with its symmetrical one in order to create an only full contour (Figure 11b).

**Creation of the junction curves of arm-torso and leg-torso**

This step is very significant and delicate since it allows to create continuity in the junction of the future surfaces between the torso and the leg and arm. A common curve with a similar shape must exist. In the case of the arms, during the creation of the torso surface, this task causes the appearance of two shoulder stumps on which the arm junction curves can be realized. At this step, the cross-section of this overflow with a vertical plan located on the acromion landmark leads to the creation of the junction curve. This curve will be used to create the arm surface at its upper end (Figure 12a). For the leg, we rely on the half-contour of the crotch characteristic curve to create another contour which will be used to create the surface of the right leg to the top end (Figure 12a). The three tilted cross-sections of the deltoid have to be duplicated by translation for the adjusting of the curved surface continuity below the arm (Figure 12b).

**Creation of the surface model**

This step consists to create the surfaces of the right leg, torso and right arm. A copy by symmetry of the right leg and the right arm provides their symmetrical left (Figure 13a). The five surfaces are then stitched together into one surface. Measurements curves were created to control the measurements of our main contours in order to validate the results conformity with the standard size of the measurement chart (Figure 13b). These measurements show that they do not match. The morphology may be correct but the volume and the stature, must be slightly adjusted. We used the homothetic axes of the leg, torso and arm and forearm in order to obtain their new contours. For the arm, a translation of the contours on the new acromion has been done to take account of this volume change. According to a principle similar, all morphological contours have been moved vertically to respect the desired stature.

**Creation of an adaptive model morphotype**

The mannequin is now calibrated on the standard size, the goal is to parameterize it regarding the volume in order to fit the size system. For this, we proceed similarly to the previous volume change but with pre-calculated homothetic ratios in an Excel table.

The principle is to allocate new contours values to the mannequin (Table 1-col-New Value). To this, we add the measurements gaps (Table 1-col-Variation) to the standard size values (Table 1-col-Basic size) to calculate the new values. The measurements gaps are strategically calculated for each size (Table 1-col-36/40/44/48/52). For a given size, the key curves are parametrized by the key measurements gaps and the others curves are estimated proportionally by the neighbor
curves. By copying a size column in the variation column, the new values of morphological contours of the morphotype mannequin are automatically calculated.

An homothety of ratio New Value/Old Value (red curves − > pink curves) is performed on the torso (Figure 14a), on the legs (Figure 14b), on the arms (Figure 14c) for the chosen size. The right leg is translated before its symmetrization in order to adjust the continuity of the side surface. This task also avoids the collision problems of the leg surfaces at the crotch (Figure 14d). An adjustment of the arm junction plans is always necessary for the continuity of the surfaces between the torso and the arm (Figure 14d).

<table>
<thead>
<tr>
<th>Colonne 1</th>
<th>New Value</th>
<th>Basic size</th>
<th>Variation</th>
<th>36</th>
<th>40</th>
<th>44</th>
<th>48</th>
<th>52</th>
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<tbody>
<tr>
<td>Chest</td>
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<td>1020.43</td>
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<td>-162</td>
<td>-81</td>
<td>0</td>
<td>110</td>
<td>220</td>
</tr>
<tr>
<td>Crotch</td>
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<td>1056.99</td>
<td>0</td>
<td>-120</td>
<td>-60</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Belt</td>
<td>1025.44</td>
<td>1025.44</td>
<td>0</td>
<td>-111</td>
<td>-55</td>
<td>0</td>
<td>66</td>
<td>143</td>
</tr>
<tr>
<td>Hip</td>
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<td>1002.03</td>
<td>0</td>
<td>-137</td>
<td>-67</td>
<td>0</td>
<td>92</td>
<td>199</td>
</tr>
<tr>
<td>Belly</td>
<td>950.14</td>
<td>950.14</td>
<td>0</td>
<td>-164</td>
<td>-82</td>
<td>0</td>
<td>103</td>
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<tr>
<td>Waist</td>
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<td>-169</td>
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<td>0</td>
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<tr>
<td>Front shoulder breadth</td>
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<td>Back shoulder breadth</td>
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<td>-210</td>
<td>-105</td>
<td>0</td>
<td>45</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 1: Table of the mannequin control.
The superimposing of the initial morphotype (gray on Figure 15a) with the new parametric mannequin fitted with the good measurements (yellow on Figure 15a) shows the quality of morphological resemblance given by our method. The parametric mannequin was also measured to verify the key measurements imposed by the standard size. The Table 1 shows negligible errors for the application envisaged (Figure 15b).

Results Synthesis

Figure 16 shows the different morphologies that were generated by the mannequin set in relation to different sizes imposed by the measurement chart of Table 1. These results show that the morphology of the different mannequins follows the initial shape of the morphotype whatever the volume desired. Among other things, the table of the Table 2 shows that the key measurements taken for each of the mannequin is compliant with those required by the measurement chart. These morphologies were also presented and validated by the professionals from the apparel industry whose customers fit this population target.

Conclusion and Discussion

Nowadays, the apparel industry uses CAD software to validate the fit of the new garments belonging to the collection. During the simulation step of the 3D virtual try on, garments are worn by idealized virtual bodies not respecting the customer’s morphology, notably his imperfections. The goal of our work has been to solve this problem by the creation of an import gateway of human bodies whose the morphologies are compliant with those required by the measurement charts of the measurement campaigns. For this, we recreated an identical morphology to the morphotype of the targeted population by selecting the key morphological contours of the most representative customer of the population. From this morphology, we have implemented a method for varying the mannequin obtained. The goal was to adjust to the stature and the volume imposed by the standard size of the measurement chart. The next step was to create an adaptive mannequin from these results. The peculiarity of it is having the ability to change his volume depending on size imposed by the measurement chart while retaining the morphology of morphotype. The results has shown that the morphological tracking of the morphotype remains high quality during the evolution of sizes.

References


