Designing Three-Dimensional Man Figure Mannequins

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Abstract. The article describes the method of designing dummies, based on the requirements for typical mannequins for clothing and the principles of geometric modeling of objects of complex volumetric shapes. The information component of the methodology is the data obtained by three-dimensional scanning of individual figures without clothes and in clothes. An important part of the process of designing new dummies is the knowledge base about the thickness of the package of materials of the underwear layer at different anthropometric levels on the front, side and rear surfaces of the virtual three-dimensional model. These data will allow to design dummies with a high degree of physical similarity of the dummy to the real figure of the consumer, take into account the thickness of the underwear layer when conducting a virtual fitting and assessing the quality of the finished clothing, ensure the personalization of the design process for garments and increase customer satisfaction with the finished clothing.

1. Introduction
An increasing number of factories, retailers, on-line shops are interested in obtaining 3D models, avatars and mannequins. When using such databases, it is possible to design new models of clothes, adjust new patterns according to individual consumer measurements and try on new clothes virtually.

2. Related work
In order to begin the construction of three-dimensional mannequins of figures, we can use three-dimensional scanning data or typical values of dimensional signs. For example, American and Korean scientists (Park SM, et al., 2011) [1] suggested a method for building an individual three-dimensional avatar using three-dimensional scanning data, which corresponds to the figures of anthropometric parameters. However, this method doesn’t reflect the changes in the surface of a figure for fitting a final product, as it doesn’t take into account the thickness of the underlying layer of materials. Scientists from the Technical University of Dresden (Hlaing E.C., Krzywinski S., Roedel H.) have proposed their technique of modelling trousers, which is based on 3D scanning data of various types of the lower part of female body [2]. The authors have assembled a database of virtual mannequins of the lower supporting surface of the figures, on the basis of which they intend to create frames and parametric models of three-dimensional virtual basic design of adjacent trousers. Researchers at the Institute of Textiles and Clothing of the Hong Kong Polytechnic University (Zhu S., Mok PY, Kwok YL) have also developed a method of self-customization of an avatar model to the individual parameters of the customer (an intelligent model customization method). It offers the possibility of reconstructing the characteristics of a consumer figure using his orthogonal photographs [3]. Basing
on the photograph of the consumer’s figure, the program selects a suitable virtual mannequin, more appropriate to the shape data according to the coincidence of the horizontal sections.

Figure 1. Conformity assessment of a virtual mannequin selected for designing clothes with three-dimensional scanning of a human figure.

The authors developed a system describing the shape of the human body, comprising a multi-level structure of geometric characteristics and curves. The system allows you to visually compare the coincidence of the shape of the surface of three-dimensional models using the color interpretation of the virtual alignment of the selected virtual mannequin and the 3D model of the figure obtained by 3D scanning.

However, in all the above-mentioned methods, the projected avatars reflect the similarity of the consumers’ figures, but do not take into account the peculiarities of the distribution of the bottoming layer, as we need to make an overmeasure, which is important for loose-fitting.

At Microsoft, the developers Peter-Pike J. Sloan, Charles F. Rose III, Michael F. Cohen [4] also create mannequins for animation. The scientists from Taiwan Polytechnic University Xiaozhi Li, Xiaozhi Li; Xiaojiu Li, Xiaojiu Li) have also offered a system for capturing and reconstructing a human body surface[5].

At Seoul National University, Korean scientists (In Hwan Sul, Tae Jin Kang) [6] obtain three-dimensional models using the implicit particle method to create animation mannequins (avatars). The problem of the study is to find anthropometric information from a scanned 3D model for the implementation of avatar movements.

Alexander Weiss and David Hirshberg [7] from Brown University are conducting experiments on the reconstruction and optimization of the 3D models to create realistic characters for animation. Data are obtained by using the Microsoft Kinect scanner. We have set up a system that optimizes 3D models, including an estimation of 252 parameters. Calculations take 65 minutes, which is significantly inferior to professional systems.

Virtually all of the precedent methods of producing three-dimensional mannequins, models or avatars tend to ensure the coincidence of the anthropometric characteristics of the figures, but they are not sufficiently working on the issue of conducting a virtual fitting with regard to the distribution of packages of materials of the underlying layer relative to the surface of the person body. Emerging technologies of three-dimensional scanning allow you to create an information database for accurate construction of three-dimensional anthropometric models of figures, which provides an opportunity to conduct research on the influence of human body features, a package of designed clothes and dynamic changes in dimensional features on the external shape of the mannequin surface. Moreover, they will help you to create a database, which will help you to develop theoretical models in accordance with the real picture.
3. Method
To improve the quality of the resulting three-dimensional models, many developers use infrared sensors, with the help of which it is possible to obtain three-dimensional models of figures with a greater accuracy of describing a three-dimensional surface. A 3D scanning system based on Microsoft Kinect sensors [8, 9] has been developed on the basis of the Light Industry Technology Department of MSUDT. The scanning system allows to obtain three-dimensional models of the torso of the figure for the subsequent design of mannequins for clothing (Fig. 2). The installation scheme consists of one Microsoft Kinect sensor, a turntable, a tripod for the sensor, a computer (laptop), software (Fig. 2a). In order to obtain data on the range of distances from the scanned object to the sensor, an experiment in which multiple scanning of the same figure was performed. The distance from the sensor was in the range of 0.7 m to 1.7 m. It was revealed, that an error of 0.1 cm of the obtained three-dimensional models can occur when the sensor is installed at a distance of 0.8 m to 1.0 m. The height of the sensor can be changed, depending on the person's height; and the waistline can be chosen as a guideline for determining the height of the sensor. Using the software Meshlab and SketchUp [10, 11] we can define the anthropometric characteristics, on the basis of which it is possible to build designs of clothing.

Figure 2. The stages of experimental research: a-scanning system based on a single Microsoft Kinect sensor; b - a fragment of a database of individual three-dimensional figures; in - a fragment of the database of individual mannequins and three-dimensional printing of the mannequin.

Using the described system, a study of 45 women aged from 18 to 35 years was performed. At the first stage, three-dimensional scanning of individual figures was performed and the figures were systematized by height, chest girth and hip girth.

At the next stage, a three-dimensional scan of the listed figures in the clothing of the first layer was performed. Underwear is used as the first layer of clothing - a T-shirt, made of knitted fabric. Then the figures were scanned in the clothes of the first and second layers. The T-shirt as the first layer, and as the second layer - knitted pullover. Then, a figure was scanned in a jacket, put above. Thus, the situation of building up the underlying layer of the material package for fitting the jacket was simulated. The process of obtaining three-dimensional models is performed in the following sequence:
- put the examined figure in the clothes of the first, second layer and jacket
- set on a turntable;
- scan a figure in a jacket;
- without changing the position of the figure, remove the jacket;
- scan the figure in the clothing of the second layer;
The given sequence provides a possibility for a more accurate positioning of three-dimensional models when combining three-dimensional models for the study of the formed values of the thickness of the underwear space.

Figure 3 shows the scheme of combining the contours of horizontal and vertical sections of the surface of an individual figure (dressed and naked). Basing on the information received, areas of the support surface of the figure are clearly marked: from the point of the base of the neck in front to the chest line, in the area of the protrusion of the abdomen, shoulder blades and buttocks.

The distribution of air gaps at chest level is calculated after finding the total area and the area of the back, armholes and shelves. Next, you need to determine the percentage of air gaps in each area at the level of chest, waist and hips.

**Figure 3.** Frontal and sagittal sections of stripped figures and dressed figures.

At the level of the chest (Fig. 4a), 4 areas are distinguished in the following way: 1 - right armhole, 2 - back, 3 - left armhole, 4 - before. The total area of the air gaps is 2892.9 mm$^2$; area 1: $S_1 = 317.7$ mm$^2$ at 1 site; area $S_2 = 826.8$ mm$^2$ at 2nd site; area $S_3 = 898.5$ mm$^2$ at area 3; $S_4 = 849$ area at 4, 9 mm$^2$. As a percentage, 11% fall to 1 section, 28.6% at 2, 31% at 3, and 29.4% at 4.

**Figure 4.** Distribution of air gaps at different anthropometric levels.

On the hip line (Fig. 4, c), there are gaps in 4 areas: 1 - right side, 2 - back, 3 - left side, 4 - in front. The total area of the air gaps is 3418.5 mm$^2$, on 1 plot the area $S_1 = 500.9$ mm$^2$, on the 2nd plot the area $S_2 = 440.5$ mm$^2$, on the 3rd plot the area $S_3 = 1243.6$ mm$^2$, on the 4 plot the area $S_4 = 1233$ , 5 mm$^2$. As a percentage, 14.6% falls on 1 section, 12.9% on 2, 36.4% on 3, and 36.1% on 4.
For this individual figure, a larger distribution of air gaps falls to the left side of the body - from the center of the bulge of the left shoulder blade to the left center of the chest. On the chest line, 3 stretches more than 1 to 20%, on the waistline 3 stretches more than 1 stretch by 15.8%, and on the hips line 3 stretches more than 1 stretch by 21.8%.

Also, the individual body shapes were fixed without clothes and in clothes on the waist, chest and hips lines. On the chest line, the girth without clothes is equal to CG3 = 82.0 cm, the girth in clothes CG3 = 88.6 cm. The increase IG3 = 3.3 cm. On the waistline, the girth without clothes varies From = 69.0 cm, the girth in clothes From = 72.6 cm. Increase IW = 1.8 cm. On the hips, the girth without clothes is HG = 92.7 cm, the girth in clothes is HG = 96.9 cm. The increase is IG = 2.1 cm.

Thus, new information was obtained on the distribution of the thickness of the underlying layer on the figure (Table 1).

| Line       | Degrees | 0    | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  |
|------------|---------|------|------|------|------|------|------|------|------|------|------|------|------|
| Chest      |         | 11,9 | 7,7  | 3,9  | 1,4  | 1,5  | 1,4  | 1,4  | 0,7  | 8,6  | 12,6 | 10,1 | 4,5  |
| Waist      |         | 9,4  | 6,9  | 7,4  | 7,8  | 8,8  | 10,8 | 12,0 | 11,6 | 8,1  | 5,1  | 4,2  | 2,8  |
| Hips       |         | 4,5  | 2,9  | 1,1  | 0,8  | 0,8  | 3,3  | 7,2  | 10,1 | 10,5 | 9,2  | 5,0  | 2,4  |
| Degrees    |         |      |      |      |      |      |      |      |      |      |      |      |      |
| Chest      | 120     | 130  | 140  | 150  | 160  | 170  | 180  | 190  | 200  | 210  | 220  | 230  |
| Waist      | 2,6    | 1,9  | 1,8  | 2,8  | 2,4  | 2,0  | 1,4  | 2,1  | 2,7  | 1,7  | 1,9  | 1,4  |
| Hips       | 0,5    | 0    | 8,9  | 6,8  | 1    | 0    | 0    | 0    | 0,1  | 9,1  | 15,4 | 6,2  |

To build a reliable individual figure mannequin it is necessary to increase the thickness of the bottom layer at different anthropometric levels. To do this, choose the chest line, waist line and hips line. From the center of the model, the plane is divided into rays in increments of 10 degrees (Fig. 5). The center of the figure is located in the center of the square, which is obtained by crossing 4 lines: 2 horizontal lines are located at the level of the posterior and anterior angles of the armpit, 2 vertical lines pass through the teat points of the left and right breasts. Then find the values of air gaps.

| Line       | Degrees | 0    | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  | 110  |
|------------|---------|------|------|------|------|------|------|------|------|------|------|------|------|
| Chest      | 0       | 1,3  | 5,3  | 3,4  | 5,2  | 0,1  | 0,4  | 0,6  | 0,6  | 0,5  | 5,4  | 9,8  |
| Waist      | 2,2    | 2,4  | 2,2  | 1,5  | 1    | 3,6  | 6,3  | 4,3  | 3    | 1,2  | 2,2  | 8,9  |
| Hips       | 4,1    | 0,1  | 0    | 3,9  | 7    | 5,2  | 1,6  | 0,8  | 0,9  | 1,4  | 1,3  | 5,5  |

Figure 5. Anthropometric figure levels.

4. Results
The database of three-dimensional models of figures of individual consumers aged from 18 to 35 years, obtained at the first stage, was transferred to a database of individual three-dimensional mannequins using software processing. The resulting mannequins are mannequins of the internal form.
of clothing and can be used to conduct a virtual and real jacket fitting. The shape of the surface of the developed mannequins was created taking into account the experimental values obtained for the distribution of the thickness of the underlying layer in relation to different parts of the surface of the figure.

The database of three-dimensional individual mannequins is systematized in accordance with the most important dimensional features. Moreover, a system of additions was suggested. It takes into account the merchandise line that will provide the consumer with an opportunity for choice. The external shape of the mannequin can be corrected in compliance with the specified assortment of clothing [12].

A method of designing a mannequin of uniform is proposed. It includes the following steps:

Stage 1. While working on an anthropometric three-dimensional model specialists do the following:
- perform an individual figure scan;
- remove excess information about the surface of a person’s figure (head, arms, legs);
- specify the area of the dark zone in the axillae.

Stage 2 Designing the shape of the surface of the mannequin, they do the following:
- determine the purpose of the mannequin;
- determine the mathematical dependencies of the distribution of the increment values over the surface areas of the figure, depending on the thickness of the pack material of the underlying layer;
- increase the thickness of the material of the underlying layer on the working anthropometric shape and form the surface of the mannequin.

The resulting three-dimensional virtual models of mannequins can be made using 3D printing technology.

5. Conclusions
A method of designing mannequins, based on the requirements for typical mannequins for clothing and the principles of geometric modeling of objects of complex volumetric shapes has been developed. The information component of the methodology is the data on the external shape of the original surface, obtained by three-dimensional scanning of individual figures. An important part of the process of designing new mannequins is the knowledge base about the thickness of the package of materials of the underwear layer at different anthropometric levels on the front, side and rear surfaces of the virtual three-dimensional model. Such data will allow designing mannequins with a high degree of physical similarity of the mannequin to the real figure of the consumer; to take into account the thickness of the underwear layer when conducting a virtual fitting and assessing the quality of the finished clothing; to ensure personalization of the garment design process and to boost customer satisfaction with the end product.

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