IOP Conf. Series: Materials Science and Engineering **127** (2016) 012028 doi:10.1088/1757-899X/127/1/012028

Parametric Modeling as a Technology of Rapid Prototyping in Light Industry

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Abstract. The paper deals with the parametric modeling method of virtual mannequins for the purposes of design automation in clothing industry. The described approach includes the steps of generation of the basic model on the ground of the initial one (obtained in 3D-scanning process), its parameterization and deformation. The complex surfaces are presented by the wireframe model. The modeling results are evaluated with the set of similarity factors. Deformed models are compared with their virtual prototypes. The results of modeling are estimated by the standard deviation factor.

1. Introduction

Prototyping is compulsory in the design of a new article. Design of a quality prototype which is maximally alike the future article is a complex scientific and practical problem. Technologies of rapid prototyping have become popular recently [1]. A prototype is generally made on the basis of a solid CAD-model or a model with closed surface contours. Herewith parameterization is of a great importance. Parametric modeling is not as expensive as alternative methods of virtualization and enables to develop new models interactively by changing set parameters. Formally, this approach can be written as follows: development of a new model Ω by deforming an average base model Ψ according to the set of specified parameters ρ. Thus, a new model Ω, after being deformed is to satisfy a set of parameters ρ [2].

For parameterization of objects with a complex geometric shape and presented as wireframe models special technologies are required which take into consideration the information on form and metric characteristics accepted in the object domain. Mannequins used in clothes production are among these objects. The existing CADs of clothes are applied by designers mainly for laying-out and enable to view articles in 2D dimensions only. Systems of three-dimensional scanning and data bases of real object prototypes (man is included [3]) which are being rapidly developed in recent years could be widely applied in clothing industry right up to individual customizing of clothes. However, there are two hindrances obstacle problems. First, the prices of scanning systems are too high for clothing industry. Second, these systems are not integrated into CADs of clothes well enough. On the other hand, models obtained by scanning of real objects have a lot of empirical data and can be applied as the basis for parameterization followed by the design adjusted to the needs of a particular customer.

This approach demands for the development of methods and ways of getting information on the form of the object under modeling. Therefore, the problem of complex object parameterization is an urgent one and needs to be solved by generating new models on the ground of semantic information and evaluation of modeling quality [4, 5].

Thus, two interrelated problems are to be solved: complex objects need to be presented parametrically with further evaluation of parameterization results in order to define the efficiency. Formally, the problem can be stated as follows: there are two original models γ_1 and γ_2, on their basis models α_1 and α_2 are to be developed and specified by parameters π_1 and π_2 respectively; an undefined model α_1', meeting the parameters π_2 is to be developed, and proximity of models α_1' and α_2 is to be evaluated.

2. Description of solution procedure

The basic information for development of a basic model includes 3D model of a female mannequin with a standard form – a right trunk. The model is obtained by three-dimensional scanning with Artec MH 3D Scanner hand scanner [6, 7], providing accuracy of order 10^{-2} mm. The delivery set includes ZScan Lite software, which enables to evaluate the results of scanning and export data into the most accepted format. The most wide-spread format is STL. It is used to keep three-dimensional models of objects in technologies of rapid prototyping, import into the systems of three-dimensional modeling and send to the three-dimensional printer. Figure 1 shows the photos of the object and the result of scanning.

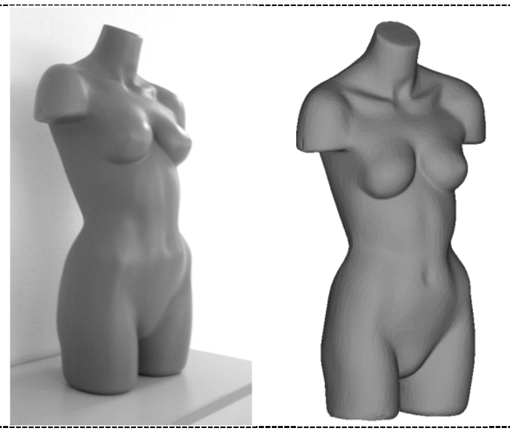

Figure 1. The photo of the objects (on the left), the result of three-dimensional scanning, 10 000 polygons (on the right)

The basic model has a polygon structure: set of points $t_{ij}(x_{ij}, y_{ij}, z_{ij})$, connected into triangular polygons $p_i = (t_{i1}, t_{i2}, t_{i3})$, $i = \overline{1,N}$, $j = \overline{1,3}$, where N – number of polygons. The model doesn't have internal polygons, polygon crosses and holes. The centre-of-mass coordinate of the model $C(x_m, y_m, z_m)$ coincides with the coordinates of origin of the global coordinate system O, when:

$$x_m = \frac{1}{3N}\sum_{i=1}^{N}\sum_{j=1}^{3} x_{ij}\ ,\ y_m = \frac{1}{3N}\sum_{i=1}^{N}\sum_{j=1}^{3} y_{ij}\ ,\ z_m = \frac{1}{3N}\sum_{i=1}^{N}\sum_{j=1}^{3} z_{ij} \tag{1}$$

The model is oriented in such a way, that the horizontal plane xOy divides the upper and the low parts of the mannequin, the vertical plane yOz separates the front part from the rear one, and the vertical plane xOz divides the mannequin into two parts along the symmetry axis.

The base model under the deformation is a three-dimensional wireframe model with topology: a set of horizontal sections h_i with the same quantity of equidistant apices $\{v_{ij}\}$ sorted out according to the polar angles: $i=\overline{1,N}$, $j=\overline{1,M}$, where N – number of sections, M – number of points in the sections. The sections are on the levels: $z_i = z_{i-1} + \Delta z$, $z_1 = z_{\min}$, $\Delta z = (z_{\max} - z_{\min})/N$, $i=\overline{2,N}$, where $z_{\max}$ – level of neck base from behind, $z_{\min}$ – level of perineum, N – number of sections. Thereupon, the points of each i section from h_i are arranged in such a way to meet the condition: $\varphi_1 < \varphi_2 < \ldots < \varphi_j < \ldots < \varphi_{M_i}$, where φ_j – is a polar angle of j point of i section.

One of the basic peculiarities of a mannequin form is xOz plane symmetry; therefore, the basic sections are subjected to the symmetrization – calculation of the averages between the left and right halves relative to the axis of symmetry, with the further smoothing – interpolation by third-order splines.

The parameterization of a human body is usually based on anthropometric or medical information: anthropometrical points [2], parameters of clothing industry [4], points of acupuncture [8], and types of spinal curvature [3] and so on. The results of anthropometric research and standards of clothing industry are referred to in paper [2], according to these data the main parameters of human body are height, chest, girth of hips and waist. Measured parameters 1–10 are showed in Fig. 2. To calculate them additional sections $c_k = \{c_{kj}\}$, $j=\overline{1,M}$, $k=\overline{1,5}$ and their girths (4–6) are determined besides the basic ones h_i. The set of anthropometric points is applied for this purpose. Axial displacements Ox (7–9) and Oy (1–3) enable to follow up the position of spinal column. The number of parameters can be increased by making additional sections through the needed anthropometric points.

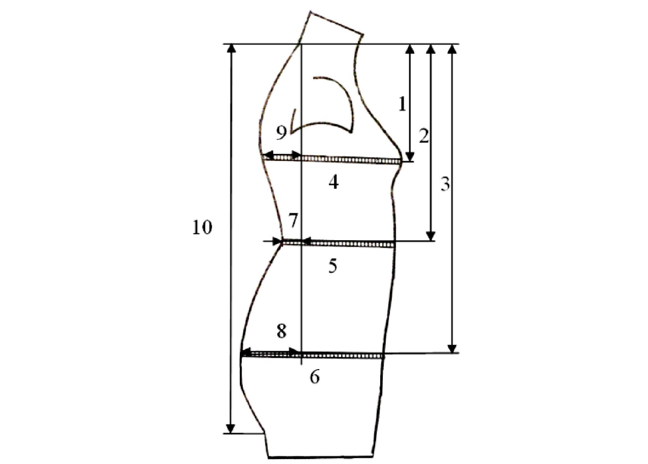

Figure 2. Positioning of the measured parameters

As a girth we see a perimeter of a minimal convex hull of additional section points. K section girth is calculated according to Graham algorithm. The deformation is seen as a change in the position and forms of base sections according to the similar change of additional sections. The deformation process includes several phases.

Axial displacement Oz of base sections proportionally to the changing parameter 10. The distances between base sections remain the same.

Axial displacement Oz of additional sections relative to the neck point according to parameters 1–3.

Scaling of additional sections according to parameters 4–6. Scaling is carried out in the section planes, for this purpose an optimization problem with efficiency function is solved:

$$F(s) = | G'_k - f(q_k \cdot S(s)) | \to \min, \quad (2)$$

where G'_k – a new girth, f – function of section girth calculation, q_k – range of k additional section points, $S(s)$ – matrix of scaling on the plane, s – scaling factor. The optimization problem is solved by coordinatewise descent.

Axial displacement Oy of additional sections relative to the neck point according to parameters 7 – 9.

Scaling of base sections according to the new form of additional ones. The base sections which are between sections c_{k-1} and c_{k+1}, are scaled for each k additional section, and herewith, the scale factor s decreases linearly from zero upwards and downwards relative to section c_k.

Developing the surface of quadrangular grid by connecting corresponding apices of adjacent sections, that is by adding edges $\{(v_{ij}, v_{i+1j})\}$, $i=\overline{1,N}$, $j=\overline{1,M}$, where N – number of sections, M – number of points in i-section.

3. Results and Discussion

The results of modeling are evaluated by comparing the base model of an object with the model of another object deformed according to the parameters of the base model. The approaches of three-dimensional object evaluation usually differ in the method of object form description and in the metric, which is to define the degree of similarity. Analyzing the models of a particular class their comparison gets more efficient in terms of peculiarities of this class models. From this point of view the mannequin models are presented quite well by the set of horizontal parallel sections, which are smooth, symmetrical figures. Therefore, to evaluate the model forms 4 factors are applied, which are calculated for each half-section h'_i: perimeter of half-section $S^v{}_i$, perimeter of half-section girth $S^w{}_i$, descriptor of form D_i, area of half-section A_i. The factor, based on the shape function, is also considered [4, 7], that describes the model form on the whole and it is calculated not in view of random points on the surface of mannequin, but according to the points of sections h_i. In this case it is not difficult to choose points on the surfaces of compared models.

Perimeter of i half-section:

$$S^v = \sum_{j=1}^{M'-1} \sqrt{(x_j - x_{j+1})^2 + (y_j - y_{j+1})^2}, \tag{3}$$

where M' – number of half-section points, $v_j(x_j, y_j)$ – j point of half-section.

Perimeter of i half-section girth:

$$S^w = \sum_{k=1}^{K-1} \sqrt{(x_k - x_{k+1})^2 + (y_k - y_{k+1})^2}, \tag{4}$$

where K – number of girth points, $w_k(x_k, y_k)$ – k point of girth.

Descriptor of i half-section form:

$$D_i = \sum_{j=1}^{M'-1} L_j \cos\alpha_j,\ L_j = \left|\overline{O_i v_j}\right|,\ \alpha_j = \left|\frac{180j}{M'} - \chi_j\right|,\ j=\overline{1,M'}, \tag{5}$$

where M' – number of points in a half-section, where χ_j – angle between radius-vector $\overline{O_i v_j}$ and axis $O_i x$ of the coordinate system $yO_i x$ of i section, v_j – j point of half-section, O_i – pole of the coordinate system $yO_i x$ of i section, here $\overline{OO_i} = \frac{1}{M}\sum_{j=1}^{M}\overline{Ov_{ij}}$, where M – number of points in a section.

The axes of the coordinate system of i section $yO_i x$ are parallel to the axes of the global coordinate system yOx.

Area of i half-section:

$$A = \frac{1}{2}\sum_{j=1}^{M'-1} L_j{}^2 \varphi_j \ , \ L_j = \left|\overline{O_i v_j}\right|, \tag{6}$$

where M' – number of points in a half-section, φ_j – angle between vectors $\overline{O_i v_j}$ and $\overline{O_i v_{j+1}}$, $j = \overline{1, M'-1}$.

Shape function – a set of Euclidian distances $\{\psi_s\}$ between all pairs of points in sections h_i, $s = \overline{1, S}$, $S = NM\,(NM-1)/2$, where N – number of sections, M – number of points in sections. The compared factor is a density diagram F of the set of Euclidian distances $\{\psi_s\}$.

The factors are compared by calculating the standard deviation of each factor:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(P^I{}_i - P^{II}{}_i)^2}\,, \tag{7}$$

where $P^I{}_i$ – i value of factor for the first model, $P^{II}{}_i$ – i value of factor for the second model, n – for shape function – number of intervals in density diagram, in other cases – number of sections.

The algorithms presented in the paper are applied to the models of female mannequins (Fig. 3), containing 50 sections, each section has 200 points. The number of intervals in density diagrams makes 100. Each model was deformed according to the parameters of two others, then the models were compared pair-wise to evaluate the deformation.

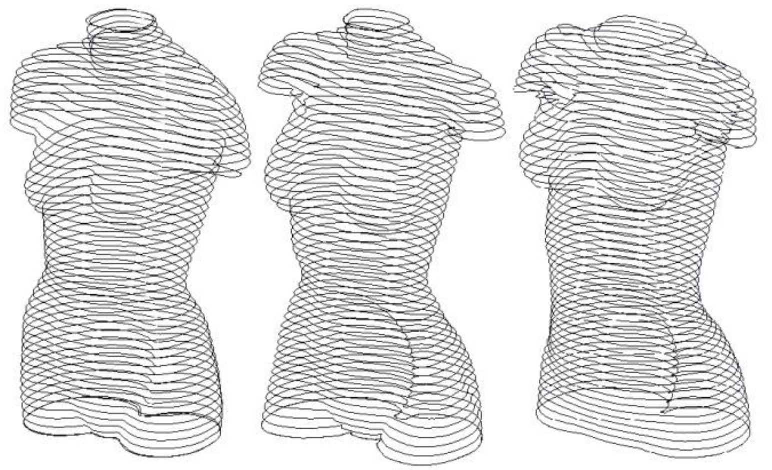

Figure 3. Base models I, II, III (from L to R) of the compared mannequins

The results of factor calculation before and after deformation are shown in Table 1. The obtained results help to conclude that forms of the models after deformation are much more similar to the model-prototypes because of the decreasing standard deviation.

Table 1. Evaluation factors before and after deformation

Pair of compared models	Criterion of comparison (SD) according to the factors				
	S^v	S^w	D	A	F
	Before deformation				
I – II	0.3581	0.3381	9.6928	15.4229	15829.7847
I – III	0.3268	0.2798	8.0335	12.4381	11412.6043
II – III	0.3405	0.3042	9.3217	14.2123	10315.3431

Pair of compared models	Criterion of comparison (SD) according to the factors				
	S^v	S^w	D	A	F
Change after deformation (in factor values)					
I – II	-0.0716	-0.0532	-0.5869	-1.0777	-4565.5172
II– I	-0.0724	-0.0624	-1.5681	-3.0487	-839.8100
I – III	-0.1029	-0.0650	-1.8809	-2.3758	-4304.8324
III – I	-0.0835	-0.0578	-1.7882	-2.6710	-1103.0592
II – III	-0.0159	-0.0652	-3.4951	-4.2805	-3029.4424
III – II	-0.0437	-0.0746	-2.8760	-3.5257	-3854.9402
Change after deformation (% from the original value)					
I – II	-20.0106	-15.7399	-6.0551	-6.9877	-28.8413
II– I	-20.2189	-18.4673	-16.1786	-19.7676	-5.3052
I – III	-31.5014	-23.2600	-23.4129	-19.1016	-37.71998
III – I	-25.5703	-20.6653	-22.2602	-21.4743	-9.6652
II – III	-4.6961	-21.4486	-37.4945	-30.1187	-29.3683
III – II	-12.8452	-24.5481	-30.8533	-24.8077	-37.3709

Conclusion

The paper provides the description of the approach of development of a base model with the set structure in view of polygon model of the original object. The original parameterization keeping the geometrics of a three-dimensional object model with a complex structure is investigated on the ground of clothing industry parameters and anthropometric research. Factors for evaluation of wireframe models similarity are suggested, models of female mannequins are compared in view of these factors. The described approach can be applied to develop virtual mannequins for the purposes of clothing industry.

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