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ФОРМООБРАЗОВАНИЕ ЦИФРОВЫХ ДВОЙНИКОВ МАЛООБЪЕМНОЙ ОДЕЖДЫ

SHAPING DIGITAL TWINS OF TIGHT-FITTING CLOTHES

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Цифровые двойники – быстроразвивающаяся концепция в рамках цифровизации швейной промышленности. В статье представлен метод формообразования виртуальных двойников малообъемной одежды, базирующийся на аппроксимации участков поверхности аватара эллипсоидами относительно плоскостей, проведенных через антропометрические точки. Метод развертывания поверхности и новый математический аппарат позволяют моделировать вытачки одежды. Разработана антропометрическая база данных для фигур ASTM с 34 до 52 размера, содержащая параметры аппроксимирующих эллипсоидов и нагрудных вытачек. Проверка метода осуществлена средствами компьютерного моделирования процесса формообразования мужской одежды с различной степенью прилегания.

“Digital twins” is a rapidly developing concept in digitisation of apparel industry. The article introduces a new method for reproducing shaping of convex areas of tight-fitting clothes in a virtual environment. It bases on 3D approximation of areas of the avatar with ellipsoids. The areas are bounded by planes drawn through anthropometric points. Surface development methods and related calculations were employed to model a dart that reproduces clothes shaping. A new anthropometric dataset covering ASTM body sizes from 34 to 52 was developed. The dataset contains parameters of approximating ellipsoids and darts for chest area shaping. The data was used to analyse the shaping area and describe the variability of its contours within the sizing system. The efficiency of the method was accessed by experimental computer modelling which shown that the method reproduces tight, semi-tight and loose clothes shaping within the chest area.

Ключевые слова: цифровой двойник, вытачка, виртуальная примерка, формообразование одежды, аватар, 3D аппроксимация.

Keywords: digital twin, dart, virtual try on, clothes shaping, avatar, 3D approximation.

Introduction

The concept of digital twins, which was introduced by M. Grieves in 2002 [1], opens new ways for technological modernisation of apparel industry. Digital twins are intended to reflect the physical objects by means of reproducing each step of apparel manufacturing in a virtual environment. Those include shaping, i.e., a transformation of flat parts of the garment into a 3D twin.

This study aims to develop a method of tight-fitting clothes shaping through geometrical modelling in convex areas of digital twins. Only several methods have accessed 3D geometrical modelling and shaping of clothes in relation with avatars. STAPRIM system utilises truncated cones to approximate the 3D garment and converts them into a flat layout from which the block pattern is formed [2]. However, the incisions of the cone development and its segments are hidden from the user and cannot be used to control the apparel shape. Bust CAD [3] employs UV-mapping technology to flatten tight-fitting garments. The algorithm, though, does not take into account air gaps between the avatar and the garment. This shortcoming is addressed in Look Stailor X [4] software, which, however, requires a number of subjective post-processing operations in order to produce a flat pattern. The same technology was used ([5]-[8]) to reproduce garment shaping by using darts. However, this approach has not instrumented for darts calculating. Virtual try-on software, such as Clo3D [9] and Assyst Vidya [10], provide 3D-2D mapping functions to convert 3D shape of an avatar into a 2D pattern. Those, nevertheless, could not be applied to virtual garments because does not take into account an air gaps and the result will depend completely on the user's experience.

The avatar contains important information about the surface of the body which is crucial for clothes shaping. However, none of the abovementioned methods provides a generic approach to extracting target areas from a highly detailed avatar and using them for parametric modelling of tight-fitting clothes in a virtual environment.

Methods

Our approach is based on 3D approximation of convex areas of human body important for clothes shaping. Those are bounded by planes which are drawn through anthropometric points. The resulted segments of the surface are represented with ellipsoids. The ellipsoid is modified in order to model air gaps between two virtual twins – the avatar and the garment – and to reproduce different shaping levels, such as tight, semi-tight and loose. A method of surface approximation and a new mathematical apparatus are employed to calculate a dart to obtain the desirable fit. The dart reproduces clothes shaping and can be used instead of textile materials deformation. Fig. 1 shows the flowchart of the developed method.

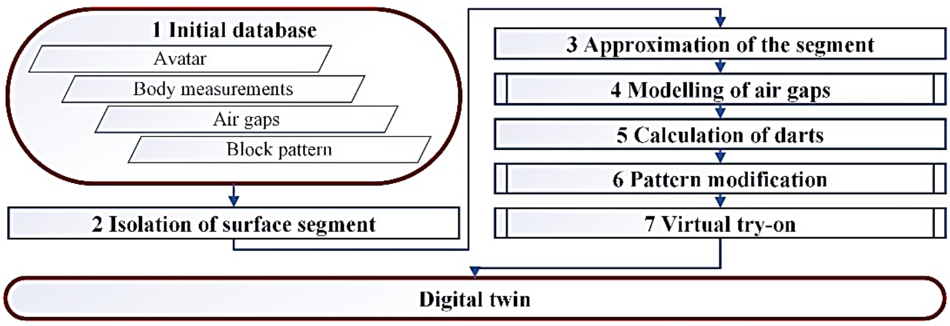


Fig. 1

As can be seen in Fig. 1, the method includes seven steps, which are as follows.

1. Creation of the initial database. The data required to present the mechanism of shaping techniques. It includes information about pattern block, surface of the avatar, avatar dimensions and air gaps located between the avatar and the garment.

2. Analysis of the surfaces of the both objects - the garment and the avatar - in terms of its segments involved in garment shaping. This step aims to render the position of cutting planes relatively to anthropometric points.

3. Approximation of the segments with ellipsoids in accordance with the avatar shape, anthropometric points and cutting planes.

4. Ellipsoid modification. The ellipsoids are scaled along their axes in order to reproduce air gaps between the body and the garment.

5. Calculation of the dart that deforms the edge of the garment in accordance with its shape.

6. Pattern modification, which integrates of the dart into garment construction.

7. Generation of the digital twins by means of computer simulations, i.e. the transition from the 2D pattern to the 3D digital object.

The list of required software programs includes a virtual try-on system (Clo3D, Marvelous Designer, Optitex, Assyst Vidya, etc.) and a 3D graphics package (3dsMax, Maya, Cinema4D, Blender, etc.).

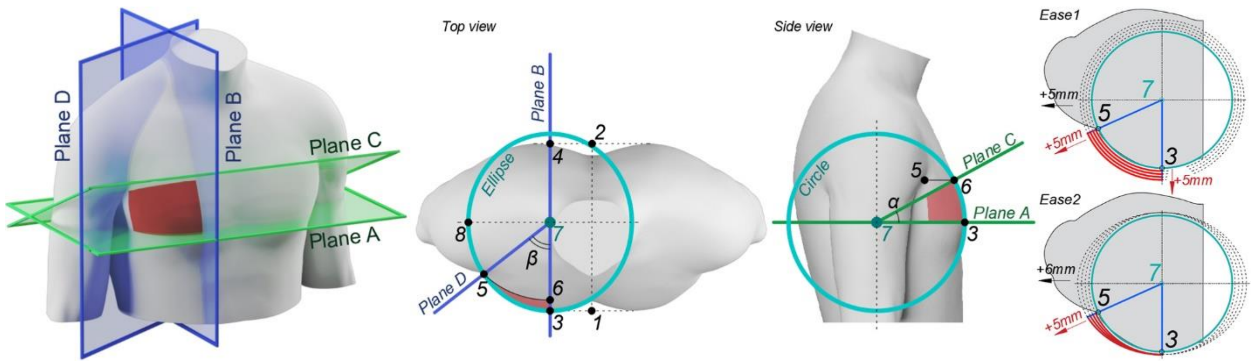
This study employed Clo3D [11] and 3dsMax [12] which are complemented with Substance painter [13]. The latter was used for analysing the surface of virtual clothes.

The chest area of the body was chosen as the research object since it is one of the most important shaping areas for men's clothing. Fig. 2 (a) shows a mannequin and the scheme for isolating the segment of the surface by four planes through three steps, which are as follows.

1) Auxiliary lines are drawn in top and side views (Fig. 2, b, c) under the following restrictions: point 1 is the centre of the chest girth; line 1-2 lies on the sagittal plane; point 3 is the most protruding point of the chest girth; line 3-4 is parallel to line 1-2; point 5 is the front corner of the axillary hollow; line 5-6 is horizontal. Anthropometric points correspond to ISO 85559-1:2017 [14].

2) The chest contour in the side view is approximated with a circle. The circle with the centre in point 7 (Fig. 2, c) passes through points 3 and 6. Point 7 lies on line 3-4. The chest contour in the top view is approximated with an ellipse. Its centre coincides with the centre of the circle in point 7 (Fig. 2, b) and its longitudinal diameter coincides with diameter 7-3 of the circle (Fig. 2, b). The transverse diameter of the ellipse,7-8, (Fig. 2, b) is adjusted in such a way as to ensure its contour runs through point 5.

3) Four planes are drawn to isolate the target segment. Plane A is horizontal and passes through the chest level. Plane B is vertical and passes through line 7-3. Plane C is drawn through line 7-6 perpendicularly to plane B. Plane D is oriented vertically and passes through line 7-5.



a) b) c) d)

Fig. 2

The circle and the ellipse could be presented as an ellipsoid, namely a spheroid, with two equal semi-diameters. The segment of the ellipsoid bounded by *planes A, B, C and D* (Fig. 2, a) represents the shape of the chest area. The same segment is able to reproduce the shape of the garment covering the chest. The transition from the surface of the body to the surface of clothes requires two adjustments (Fig. 2, d) in accordance with the fit of the garment. Firstly, the ellipsoid should be increased proportionally to the air gap between the body and the garment (Fig. 2, d). Secondly, the transverse diameter of the ellipsoid is increased in order to enlarge the air gap at the front corner of the axillary hollow and thereby to flatten the shape of the garment. For example, *ease 2* is 5 mm in point *5* and becomes nil in point *3* (Fig. 2, d). When the transverse diameter of the ellipsoid tends to infinity, the segment has the cylindrical shape which results in the absence of shaping.

The presented approach can be projected onto other convex shaping areas, such as stomach, scapula and shoulder. Stomach is approximated with a single ellipsoid, the transverse and the vertical diameters of which are equal and lies on the frontal plane. Scapula area is represented by an ellipsoid, similar to the one in Fig. 2, drawn by using the horizontal cross section of the body at scapula level and the back corner of the axillary hollow. The shoulder ellipse can be drawn by employing the shoulder anthropometric point, the front and the back corners of the axillary hollow, the upper arm axis and its cross sections.

In order to find the most suitable way to shape clothes, we compared several approaches by using 3dsMax software and the Unwrap UVW modifier [15]. Fig.3 (a, b) shows an ellipsoid and its rectangular segment. In terms of the presented approach, the segment is considered a geometrical model of the chest area.

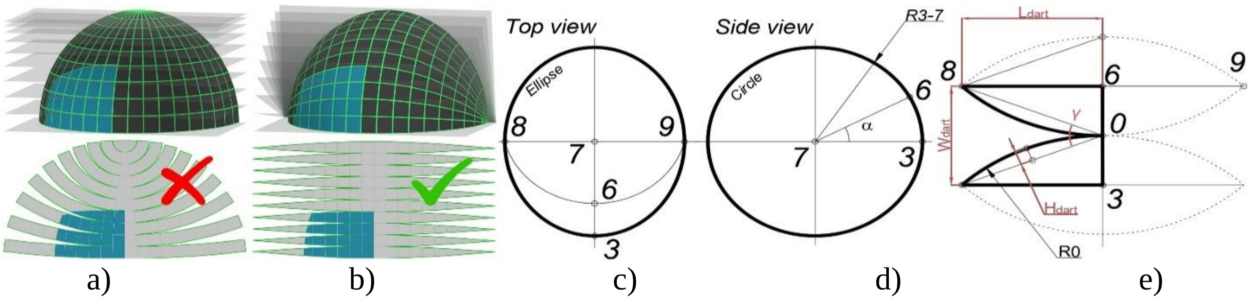


Fig. 3

Two methods were considered in our study. The first one, called “Zone method” [16], uses horizontal planes to cut the object into truncated cones (Fig. 3 a). The second one, so-called “Gore method” [17], employs intersected planes running through the axis of the primitive to cut it into leaf-shaped pieces (Fig. 3, b). In both methods, trapezoidal segments are laid out flat to render a 2D layout. As can be seen from Fig. 3 (a, b), the two developments for the small segment are similar. The difference lies in darts which located on the sides of the flattened shape. The zone method results in unparallel and unequal darts. The gore method forms darts that are parallel and equal. The second layout (Fig. 3, b) is more suitable for reproducing clothes shaping because the darts are perpendicular to the edge of the garment part and the number of darts does not affect their direction.

The key point of the developed method is to apply the darts instead of nonpredictable treatment by shortening of garment edges and textile materials during garment shaping. This study presents a new mathematical apparatus that allows to determine the required parameters in accordance with the chosen surface (Fig.2). The four parameters include length (L_{dart}), width (W_{dart}), deflection (H_{dart}) of the sides of the dart and the angle (γ) between them (Fig. 3, e).

Fig.3 (c, d, e) shows two projections of a sphere and a leaf-shaped segment of its flat layout. In accordance with Fig. 3 (c, d, e), the parameters of the dart are interlinked with those of the ellipsoid that approximates the avatar. Thus, the latter can be used to calculate the dart by applying standard methods [18, 19], trigonometric functions [20] and Ramanujan approximation [21] of ellipse circumference (1…5):

$$W_{dart} = 3\_6 = \frac{\alpha 2\pi R_{3-7}}{180n} = \frac{\alpha 2\pi |3\_7|}{180n}, \quad (1)$$

$$L_{dart} = \frown 3\_8 = \frac{\pi}{4}\Big(3(|3\_7| + |7\_8|) - \\ -\sqrt{(3|3\_7| + |7\_8|)(|3\_7| + 3|7\_8|)}\Big), \quad (2)$$

$$R_0 = \frac{\left(\frac{(2L_{dart})^2}{4} + \left(\frac{W_{dart}}{2}\right)^2\right)}{2\left(\frac{W_{dart}}{2}\right)^2}, \quad (3)$$

$$H_{dart} = R_0 - \sqrt{R_0^2 - \frac{\left(\frac{2L_{dart}}{2}\right)^2}{4}}, \quad (4)$$

$$\gamma = 2\mathrm{arctg}\left(\frac{0.5W_{dart}}{L_{dart}}\right). \quad (5)$$

where n is the number of darts within the segmentandR_0 is the length of the side of the leaf-shaped segment (Fig. 3, e). This study uses one dart for clothes shaping (n=1).

Results and discussion

Ten avatars presented in the Clo3D software library and covering ASTM body sizes from 34 to 52 were analysed. Their shapes were approximated with ellipsoids in accordance with Fig. 2. The parameters of the ellipsoids which are sufficient for their reproduction were measured. Those include the transverse shift, the longitudinal radius, the transverse radius, the horizontal angle, and the sagittal angle.

Table 1 shows new anthropometric dataset. The absolute approximation error D_a was estimated as the distances measured between two surfaces along normal vector in nine points and averaged as the arithmetic mean. The relative error D_r was calculated as $D_a$divided by the longitudinal radius (3-7). The geometric parameters of the darts, namely, length L, width W, deflection D and angleγ, were calculated by (1-5). The approximation was carried out four times by using different values of *Ease1* and *Ease2* as the table shows. The dataset was used to analyse the shaping area.

Table 1

Parameter	Values for ASTM body sizes*									
	34	36	38	40	**42**	44	46	48	50	52
Body										
Heigh, mm	**1778**									
Chest girth, mm	864	914	965	1016	**1067**	1118	1168	1219	1270	1321
Waist girth, mm	724	775	826	876	**927**	978	1041	1105	1168	1232
*Body mimicking surface: Ease1 = 0 mm; Ease2 = 0 mm***										
Ellipsoid										
Transverse shift (1-3), mm	61	64	67	69	71	74	78	82	86	89
Longitudinal radius (3-7), mm	156	142	133	123	114	111	105	102	98	95
Transverse radius (7-8), mm	121	117	112	115	118	119	120	121	122	123
Horizontal angle (β), deg.	44,12	52,17	59,83	62,04	65,51	67,92	72,1	75,64	77,81	79,92
Sagittal angle (α), deg.	29,53	32,61	36,76	40,98	45,06	48,31	51,34	52,9	55,19	57,98
Absolute error (D_a), mm	2,9	2,7	2,8	3,0	3,1	3,1	3,6	3,9	4,5	4,7
Relative error (D_r), %	1,9	1,9	2,1	2,4	2,7	2,8	3,4	3,8	4,6	4,9
Dart										
Length (L_{dart}), mm	218	203	192	186	182	180	176	175	172	171
Width (W_{dart}), mm	80	80	85	88	90	93	94	94	94	96
Deflection (H_{dart}), mm	18	18	18	19	19	19	19	19	19	19
Dart angle (γ), deg.	20,87	22,39	24,92	26,48	27,70	29,04	29,85	29,97	30,46	31,22

Continue of tabl. 1

*Tight fit (level 1): Ease1 = 5 mm; Ease2 = 0 mm***										
Ellipsoid										
Longitudinal radius (3-7), mm	161	147	138	128	**119**	116	110	107	103	100
Transverse radius (7-8), mm	126	122	117	120	**123**	124	125	126	127	128
Dart										
Length (L_{dart}), mm	225	211	200	194	**190**	188	184	183	180	179
Width (W_{dart}), mm	83	83	88	91	**94**	97	99	98	99	101
Deflection (H_{dart}), mm	19	19	19	19	**20**	20	20	20	20	20
Dart angle (γ), deg.	20,79	22,32	24,85	26,45	**27,72**	29,08	29,94	30,09	30,62	31,43
*Semi-tight fit (level 2): Ease1 = 10 mm; Ease2 = 30 mm***										
Ellipsoid										
Longitudinal radius (3-7), mm	166	152	143	133	**124**	121	115	112	108	105
Transverse radius (7-8), mm	171	167	162	165	**168**	169	170	171	172	173
Dart										
Length (L_{dart}), mm	264	250	239	234	**230**	228	225	224	222	221
Width (W_{dart}), mm	85	86	91	95	**97**	102	103	103	103	106
Deflection (H_{dart}), mm	20	20	21	21	**21**	22	22	22	22	22
Dart angle (γ), deg.	18,36	19,55	21,62	22,90	**23,92**	25,07	25,74	25,85	26,26	26,93
*Loose fit (level 3): Ease1 = 15 mm; Ease2 = 60 mm***										
Ellipsoid										
Longitudinal radius (3-7), mm	171	157	148	138	**129**	126	120	117	113	110
Transverse radius (7-8), mm	223	219	214	217	**220**	221	222	223	224	225
Dart										
Length (L_{dart}), mm	310	297	286	281	**278**	277	274	273	271	270
Width (W_{dart}), mm	88	89	95	98	**101**	106	107	108	108	111
Deflection (H_{dart}), mm	21	21	22	22	**23**	24	24	24	24	24
Dart angle (γ), deg.	16,13	17,06	18,77	19,82	**20,66**	21,64	22,19	22,27	22,60	23,18

Fig. 4 summarises body measurements, dimensions of the ellipsoids and darts parameters for ASTM 34-52avatars.

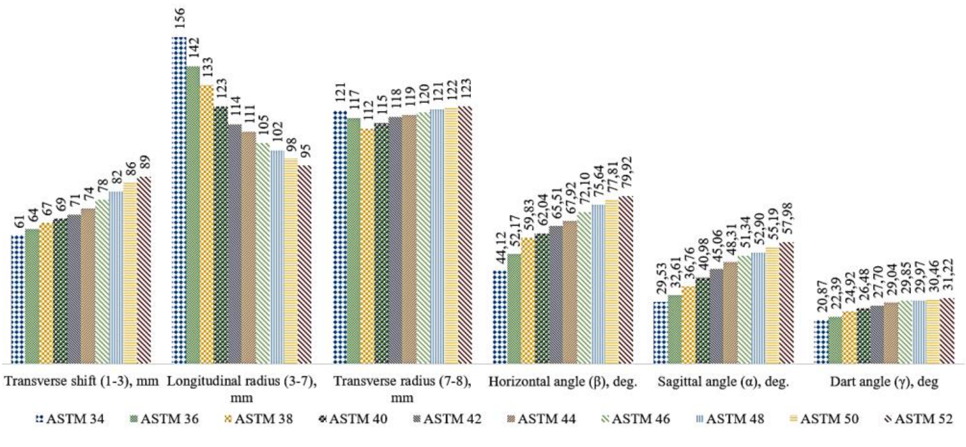


Fig. 4

As can be seen in Fig. 4, the parameters of the ellipsoid changes with increasing size. The transverse shift, i.e., the distance between the approximated surface and the sagittal plane, increases from 61 to 89 mm. Likewise, the horizontal angle significantly increases from 44° up to 80°. This is in line with body sizing be-cause as the chest girth grows all its segments lengthen. On the contrary, longitudinal radius decreases from 156 to 95 mm with increasing size. Thus, the profile projection of the ellipsoid becomes smaller, its centre moves closer to the body surface and the approximated area becomes more convex. In order to keep the size of the shaping area, the sagittal angle increases from 29° to 58°. The transverse radius drops from 121 to 112 mm in sizes 34-38 and rises back up to 123 mm in size 52. This indicates that the horizontal projection of the chest area is most pointed for 38 size and becomes smoother for smaller and larger sizes. It is worth mentioning that in 34-40 sizes longitudinal radius is larger than the transverse radius. The horizontal contour of the approximated area for these sizes is more convex than the profile contour. Vice versa, within 42-52 sizes profile contour of the chest is more curved than the horizontal one. All the above-mentioned data, taken together, result in the dart angle that proportionately increases from 20,87° in size 34 to 31,22° in size 52.

To prove the efficiency of our method, the experimental modelling of clothes was done. The ASTM avatar with 42 size was chosen. The basic front part was constructed in accordance with a pattern drafting system [22, p.24]. Three different darts were drawn by using the values marked in Table 1 to generate tight, semi-tight and loose fit. Fig.5 shows how the darts were integrated into the initial construction.

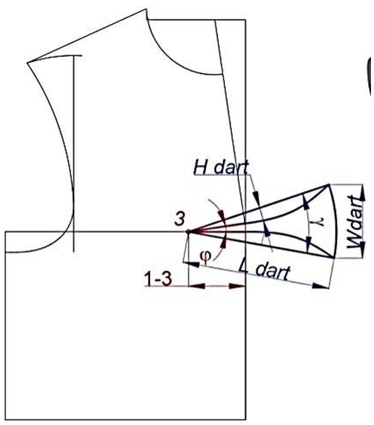
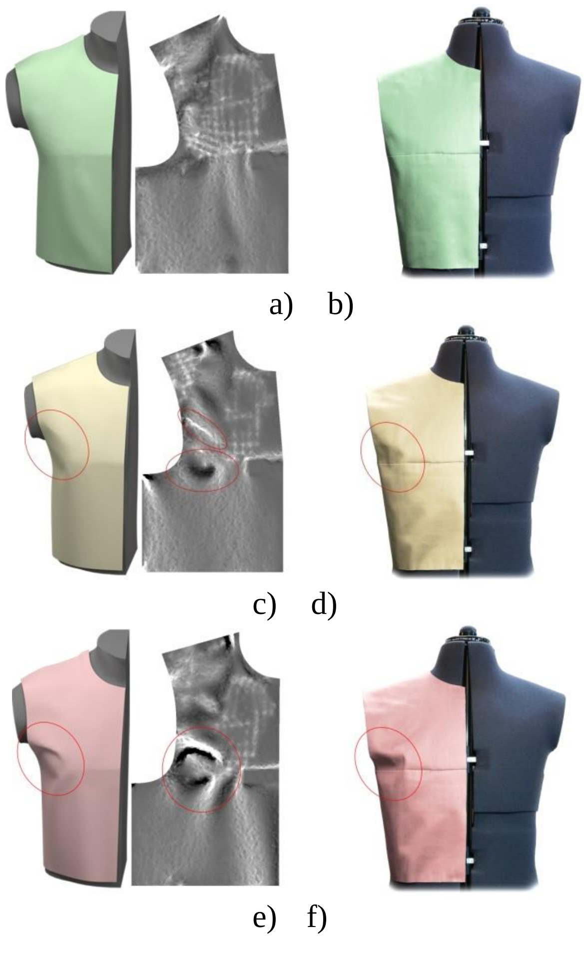


Fig. 5

As can be seen in Fig. 5, the top of dart was overlapped with point *3* at the chest level. The sides of the dart were shortened to the centre line of the garment part. Thus, the dart angle was reduced from γ to *φ*. The obtained values of *φ* were 8,75°, 6,24° and 3,45° for tight, semi-tight and loose fitting.

Three virtual twins were modelled in Clo3D software. Cotton oxford virtual textile material (id=FCL1PSC011, fibre content is cotton 100%, density is 182 g/m^2, thickness is 0,36 mm) was used for simulations due to its ability to render rigid folds similar to mock-up fabrics. A reasonably high level of simulation quality was set up (particle distance is 3 mm, minimal air gap is 1 mm, iteration count is 50). The curvature map of Substance painter software was employed [23] to generate concave and convex information related to the mesh. It calculated angles formed by neighbouring polygons and painted the surface in shades of grey.

In parallel the same fronts were made from real textile material with similar properties as virtual one and presented on an adjustable ASTM standard mannequin.



a) b)

c) d)

e) f)

Fig. 6

Fig.6 (a,c,d) shows the curvature maps for all three digital twins in different colours: grey colour represents flat areas, black and white colours represent the concave and the convex areas respectively. Therefore, black and white areas visualised the folds. The first twin (Fig.6, a) has not visible black or white areas because the front shape smoothly bends around the avatar and chest area has minimal air gaps. The real front has similar surface (Fig.6,b).

The second twin and its map (Fig.6, c) reveals weakly expressed wrinkles which are natural for semi-tight clothes.

The third variant (Fig. 6, e, d) shows strong folds around the chest similar to ones visible on the surface of loose fitting garments. In this case the both looks - virtual and real - have the similar relief of surface.

Thus, the developed method reproduces different degrees of clothes shaping within the chest area.

CONCLUSIONS

The article introduces a method for reproducing clothes shaping in a virtual environment by means of darts. The results of the study are as follows.

1. A new approach to digital clothes shaping was developed based on geometric modelling of the human body by means of approximates convex areas of spheroids. The modelling areas are bounded by four planes through anthropometric points. Surface development methods and related calculations are employed to model a dart which used for clothes shaping.
2. A new anthropometric dataset was developed. The dataset contains parameters of the approximating ellipsoids for chest area ASTM men body sizes 34 to 52 and the darts of front of clothes.
3. The efficiency of the method was accessed by experimental computer and real modelling of three basic shapes of men's clothes. The folds on the surface were visualised by using computer generated curvature maps to reproduce tight, semi-tight and loose clothes.

The developed method has its limitations. Firstly, it uses convex 3D primitives to approximate the body. Thus, concave shapes of body, such as sides and back out of the scope and its application. Secondly, the body varies significantly in different sizing standards and 3D avatars. Therefore, more 3D shapes should be studied in order to establish widely applicable and precise approximation techniques.

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