Method of optimization of geometric transformations of design surfaces of a man's jacket

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Abstract. The article considers the mechanism of combining 3D and 2D-design methods based on the combination of modules of 3D-digital modification of the morphological structure of the body and 2D-generation of sweep details of the jacket. The mechanism of formation of the integrated design system for transformation of a surface of a body into silhouette designs on the basis of geometrical modeling has been offered. The selection of optimal divisions of the mannequin surface on the basis of identification of zones of stable deformations of the grid with regular topology is theoretically substantiated. Has been shown that the maximum compression deformation in the range of overall dimensions characterizes the parametric levels of darts in the product design. The affine transformations by the operation "shift" of the mannequin surface scan into three basic silhouettes of the jacket design were experimentally investigated. Parametrical transformation of silhouette designs have been realized by schemes of designs and the reference book of standard movements. Homogeneity of details’ construction of the sketch project of interchangeable models system has been estimated by coefficients of constructive homogeneity of silhouette designs and technological homogeneity of model functional knots. The algorithm of formation of the integrated design system of 3D and 2D-design is developed and its practical application on an example of the development of a series of interchangeable models of a jacket is shown.

Keywords: geometric features, mannequin surface, jacket, silhouette design, affine shift, displacement, modification parameters, 3D-2D design.

1. Introduction

Modernization of the process of forming clothes from flat materials on the basis of the introduction of information and computer technologies involves the application of fundamentally new approaches to the problems of engineering and spatial design [1,2]. The concept of combining 2D and 3D clothing design methods [3] is based on the use of graphic vector programs (Corol Draw, AutoCAD, etc.) in the construction of scans, followed by importing drawings into programs to create a three-dimensional model (3DS MAX, Zbrush, Maja and others). The use of interactive genetic algorithm (IGA) and fuzzy clustering method [4] will provide the formation of key modules for the development of reference books for digital modification of the morphological structure of the body in the generation of 2D-image contours of the structure [5].
2. Discussing ideas
Experimental design through the strategy of emotional branding is focused on creating your own style by developing a morphological map of combinations of basic and additional features of the product look [6]. Thematic studies of technical characteristics, namely, attributes, features, properties, determine the comfort of the product through a set of quality indicators laid down in the design stages. The use of affine transformation "shift" in the informative points of the design provides a consistent increase in the volume of the jacket corresponding to the body surface by continuous mappings [3].

The idea of visualizing the values of pressure and stress points in areas of tight fit to the body, using virtual technology of three-dimensional clothing (3D) [7] allows you to determine the objective pressure of the product in daily movements. The algorithm of level distribution of pressure on a body provides comparison of results with subjective perception of the consumer and definition of parameters of deformations of design parts in a dimensional scale on property of dynamic co-dimensionality.

Gender differences in consumer attitudes to fashion comfort are due to the need for uniqueness and social identity [8]. The need for uniqueness is inherent in both sexes. However, men are more interested in social identity, which explains the stability of the range and a certain conservatism of typical characteristics of jacket designs, both among ordinary consumers and celebrities [9].

The social certainty of the attributes of the jacket affects the choice of methods for optimizing 2D-design on the basis of engineering design.

To identify the parameters of geometric transformations of the system "measurements – detail’s design" it is advisable to use a block-modular approach in combination with 3D-digital modification of the electronic mannequin and 2D-generation of the design of the jacket. This requires the following actions:
- to develop key modules of 3D-digital modification of a mannequin surface and 2D-generation of scans of a jacket’s details;
- to justify the use of the topological operation "shift" for geometric modification of the structure silhouette;
- to import a method of silhouette modification of a jacket design in the module of construction of CAD Julivi patterns.

3. Methods
Theoretical principles of engineering design of the clothing surface are based on a combination of information models of the body surface and the jacket's sweep.

Techniques of 3D-modeling of clothes provide a new level of project activity through the use of graphic software packages for modeling 3D-space and 3D-printing of design objects [10]. Based on the use of planar 2D-design methods of clothing, which contain experience in working with textile materials, it is advisable to use scenarios for designing products of different three-dimensional shapes by combining 2D and 3D-design methods in the form of an integrated design system.

Since the spatial silhouette shape of a modern jacket is reproduced in a silhouette design [11], it is advisable to use a geometric model of the surface of a typical mannequin to graphically reproduce the smoothed surface of the body [12]. The latest versions of Auto CAD allow you to build both mesh surfaces and surface models (figure 1).
Figure 1. Model of the mannequin surface: a - surface; b - visual image.

The frame of the mannequin surface in the form of a grid with a regular topology (polygon mesh) is built on the basis of a two-parameter (MXN) array of vertices (figure 2).

Figure 2. Fragment of the coding of the grid vertices at M = 36, N = 70.

Smoothing the surface of the mannequin is performed by cubic splines (see figure 1, b). For the population of men of the younger age group, 176-92-80 was chosen as the representative size of a typical mannequin. The basic set of Auto CAD includes the AVE module, which, with the help of the Strethen command, performs anthropometric adjustment of the manikin surface by the difference between the anthropometric measurements of the real figure and the control measurements of a typical mannequin.

The engineering method of constructing a scan of a rigid surface by using a grid of geodetic parallels is based on the gradient method of solving extreme problems for each cell of a three-dimensional grid (figure 3) and described (1):

$$|B_{0,0} - A_{1,0}| = \sqrt{(x_1-x_0)^2 + (y_1-y_0)^2 + (z_1-z_0)^2}.$$  \hspace{1cm} (1)

Figure 3. Scheme of calculation of the cell of a three-dimensional grid.
To determine the true angle between the sides of a cell of a three-dimensional grid, the cosine theorem of rectilinear trigonometry is applied (2):

$$BC^2 = AC^2 + AB^2 - 2AC \times AB \cos \alpha,$$

from which:

$$\alpha = \arccos \left( \frac{AC^2 + AB^2 - BC^2}{2AC \times AB} \right),$$

$$\beta = \arccos \left( \frac{BC^2 + AB^2 - AC^2}{2BC \times AB} \right),$$

where BC, AC, AB are the sides of an arbitrary triangle;
\(\alpha\) - opposite angle to the BC side;
\(\beta\) - is the opposite angle to the AC side.

To characterize the stability of the deformation of the scans in the mannequin’s dimensions the authors used a method of fixing the zones of compression and extension relative to the chest line (Figure 4). The sign "+" corresponds to the stretching of the cell, the sign "-" means compression. Maximum stretching is observed at the waist line (G27).

**Figure 4.** Deformation grid of the mannequin surface scan.

The places of stretching the grid in the areas of the armpits, thighs, compression in the lateral areas of the back, foreparts, shoulder blades confirm the need to introduce partitioning of the original model structure to fix a stable three-dimensional shape, taking into account the recommendations of EMKO REV.

To identify the cross sections of the mesh frame in the optimal position of the partitioning lines, 7 vertical and 8 horizontal lines are used, which determine the parameters of geometric modules for the procedure of laying structural zones of parts in surface scan patterns (figure 5).
Consecutive increase of the silhouette volume of the jacket relative to the surface of the mannequin is provided by the EMKO REV allowance system, which contains structured modules of design allowances and technological allowances for four types of information: constant, normative, conditional-typical, variable.

The mathematical model of the process of construction of scans of structural parts by Zermelo’s theorem is described by mathematical models of continuous mappings of group structure of geometric modules of mannequin surface $\phi$ in constructive zones of details’ design $\theta$ (5):

$$\theta \div G \times G \rightarrow G \ GMsd,$$

$$\phi \div G \times G \rightarrow GKJ_0.$$

Observance of the condition of equivalence of mappings $\phi$ and $\theta$ ensures the transitivity of the structural points of the parts’ contours to the nodal points of the mesh frame of the mannequin: $\phi G = \theta G$ and characterizes the original matrix structure $S_{i0}$. Modifications of silhouette designs are provided by both direct and inverse affine transformation. For direct - $S_{i1} \rightarrow S_{i2} \rightarrow S_{i3}$, for the inverse - $S_{i3} \rightarrow S_{i2} \rightarrow S_{i1}$.

4. Experimental

To ensure the transition from the scanning of the manikin surface in the form of vertical stripes to the matrix structure $Cu0$, 6 vertical blocks are generated taking into account the structural elements of the reliefs for shaping (see Figure 5). The deviation of the indentations in the vertical divisions along the waist line is 71.1 mm, the breast - 2.717 mm, landing on the convex shape of the shoulder in the area of

Figure 5. Laying of constructive zones on a breast line.
a sleeve’s cap - 27.02 mm. The obtained parameters are the limit in the control of calculations for silhouette structures.

Experimental study of the system "mannequin surface scan - silhouette design of a man's jacket" takes into account the design characteristics of popular "lines", in particular English - a, French - b, American - c, Italian - d, German - d [13, 14] (figure 6).

![Figure 6. "Fashion lines" of modern jackets: a - English; b - French; c - American; g - Italian; d – German.](image)

The choice of construction method is primarily influenced by the silhouette shape and features of the surface of the product [15]. Since the silhouette shape of the jacket refers to stable characteristics and the partitioning of the surface by details to mobile features, to analyze the look’s features statistics for a period of four years is sufficient.

Photos from magazines of the first decade [16-19] and electronic resources of the second decade [20, 21] serve as a source of information about the look of 50 jacket’s models of the XXI century.

The first group of artistic and design characteristics takes into account:
1.1 - silhouette: 1.1.1 - adjacent, 1.1.2 - semi-adjacent;
1.2 - the number of divisions of the state: 1.2.1 – a 5- stitch; 1.2.2 - darts;
1.3 - sleeve cut: long, sewn two-stitch;
1.4 - type of fastener: 1.4.1 - central: 1.4.1.1 – one-button, 1.4.1.2 - two-button, 1.4.1.3 – three-button, 1.4.1.4 – four- button; 1.4.2 - offset;
1.5 - collar: 1.5.1 - jacket, 1.5.2 - shawl;
1.6 - length of the product: 1.6.1 - short, 1.6.2 - medium, 1.6.3 - long.

The second group takes into account additional characteristics:
2.1 - shape of lapels: 2.1.1 - narrow, 2.1.2 - medium, 2.1.3 - wide, 2.1.4 - combined;
2.2 - design of the bottom of the side: 2.2.1 - straight, 2.2.2 – with displacement; 2.2.3 - rounded;
2.3 - type of an upper pocket: 2.3.1 – slash welt pocket, 2.3.2 – a patch pocket, 2.3.3 - in the frame;
2.4 - type of a lower pocket: 2.4.1 - in the frame, 2.4.2 - with valve and trim, 2.4.3 – patch pocket with a valve;
2.5 - back slot: 2.5.1 - absent, 2.5.2 - in the middle seam, 2.5.3 - in the side seam;
2.6 - decorative elements: 2.6.1 - finishing stitch, 2.6.2 - buttons, 2.6.3 - lapels, 2.6.4 - ribbon, 2.6.5 - additional pockets, 2.6.6 - contrasting loops, 2.6.7 - figured fastening, 2.6.8 - wide valves.

Diagrams of the occurrence of individual characteristics are presented in figure 7-11.
Based on the results of the development of the morphological map of combinations in the models of the man's jacket, the codes of the features of the typical design have been compiled: 1.1.1; 1.2.1; 1.2.2; 1.3; 1.4.1.2; 1.5.1; 1.6.2; 2.1.2; 2.2.3; 2.3.1; 2.4.2; 2.5.2.

Code of modification features: 1.1.2; 1.4.1.1; 1.6.3; 2.1.3; 2.2.2; 2.4.1; 2.4.3; 2.5.3; 2.6.2.

The selection of models for the sketch project is focused on a highly developed style of consumption, which is confirmed by the lexicon of advanced fashionistas. Among them, only an ubersexual (a real, normal, "balanced" man) creates his own style [19].

The sketch design of the system of interchangeable models of the jacket according to fashion trends [20, 21] is presented in table 1.

**Table 1.** Preliminary design of the system of models of interchangeable models of a men's jacket.

| Model code | Drawings of the main details | Model details |
|------------|-----------------------------|---------------|
|             | back | side part | front | sleeve | collar |               |
| Model AB1   | B1   | Sp1      | F1    | S11    | Col1   | Lap1, Val1, Cas1 |
| Model AB2   | B2   | Sp2      | F2    | S12    | Col2   | Lap1, Lea1, Val1, Cas1 |
| Model AB3   | B2   | Sp2      | F2    | S12    | Col2   | Lap2, Lea1, Val1, Cas1 |
| Model AB4   | B2   | Sp2      | F2    | S12    | Col2   | Lap2, Val1, Cas1 |
| Model AB5   | B2   | Sp1      | F1    | S11    | Col1   | Lap2, Val1, Cas1 |
Structural homogeneity of silhouette constructions is estimated by the coefficient of use of identical basic details. The average coefficient of homogeneity \( K_{k.o.} = 0.62 \) confirms the principles of interchangeability of series models.

To highlight technologically homogeneous parts, the coefficients of repetition of unified parts of functional units, namely pockets, fasteners and collar are calculated: \( K_{t.o.ser.} = 0.88 \). This creates the preconditions for the development of a catalog of unified parts.

Experimental verification of the combinations of matrix \( Si_0 \) and silhouette \( Si_1 \) structures confirmed the uneven displacement of the main structural points due to the peculiarities of the distribution of the composite allowance within the silhouette shape (figure 12).

![Figure 12. Scheme of combination of \( Si_0 \) and \( Si_1 \) constructions.](image)

The use of topological shift operation provides the transition from \( Si_0 \) to \( Si_1 \):

\[
N1(x_1; y_1) \rightarrow [(x_0 + \Delta x_0); (y_0 + \Delta y_0)]
\]

(6)

where \( x_0, y_0 \) are the coordinates of the constructive points \( Si_0 \);
\( \Delta x_0, \Delta y_0 \) — values of displacements of structural points from the silhouette 0.

The detailed affine transformation (see Figure 12) at the informative points of the structure is illustrated by figure 13.

![Figure 13. Affinity transformation of the contour of the shoulder area of the back.](image)
The addition to the base takes into account the following changes relative to the armhole: 62% belongs to the back, 38% - to the forepart, which explains the uneven displacement of the side line and the middle lines, respectively.

The parametric system of increments used in EMKO REV [5] provides a silhouette transformation of the design’s contours of a classic man’s jacket (tables 2-4).

Table 2. Values of increases on silhouettes for a man’s jacket, ASi.

| Silhouette     | Absolute values of allowances A Si along the lines, sm |
|----------------|--------------------------------------------------------|
|                | chest | waist | thigh | shoulder girth |
| null           | 2,0   | 2,0   | 2,0   | 2,6            |
| adjacent       | 6,0   | 5,0   | 5,0   | 5,0            |
| semi-adjacent  | 7,0-9,0 | 6,0-8,0 | 6,0-8,0 | 5,0-7,0       |

Table 3. The values of allowances to the design segments for men’s clothing.

| System number | Segment | BA | A Si1 | A Si2 |
|---------------|---------|----|-------|-------|
| 6             | 31-37   | 2,0 | 6,0   | 8,0   |
| 7             | 31-33   | 0,5 | 0,6   | 1,2   |
| 8             | 33-35   | 1,0 | 3,1   | 3,9   |
| 9             | 35-37   | 0,5 | 2,3   | 2,9   |
| 13            | 33-13   | 0,3 | -     | -     |
| 14            | 35-15   | 0,3 | -     | -     |
| 29            | 12-121  | 0,3 | -     | -     |
| 52            | 36-16   | 0   | -     | -     |
| 61            | 411-470 | 2,0 | 5,0   | 7,5   |
| 62            | 511-571 | 1,0 | 5,0   | 7,5   |

Table 4. The values of increases and allowances of the silhouette design of the men's jacket adjacent (Si1), semi-adjacent (Si2) silhouettes.

| System number | Constructive segment | to freedom FA | to package PA CA = Σ SA, PA | Technological allowance TA | Allowance is general A = Σ CA,TA |
|---------------|----------------------|---------------|-----------------------------|---------------------------|---------------------------------|
| 1             | 11-91                | 1,2           | 1,2                         | 0,4                       | 1,6                             | 1,4                           | 2,7,4                          | 2,7,4                          |
| 2             | 11-21                | 1,2           | 1,2                         | 0,4                       | 1,6                             | 1,6                           | 0,23                           | 1,83                          | 1,83                          |
| 3             | 11-31                | 1,2           | 1,2                         | 0,4                       | 1,6                             | 1,6                           | 0,35                           | 1,95                          | 1,95                          |
| 4             | 11-31                | 1,2           | 1,2                         | 0,4                       | 1,6                             | 1,6                           | 0,71                           | 2,31                          | 2,31                          |
| 5             | 41-51                | -             | -                           | -                         | -                               | -                             | 0,28                           | 0,28                          | 0,28                          |
| 6             | 31-33                | 0,2           | 0,8                         | 0,4                       | 0,6                             | 1,2                           | 0,22                           | 0,82                          | 1,42                          |
| 7             | 33-35                | 2,25          | 3,05                        | 0,85                      | 3,1                             | 3,9                           | 0,16                           | 3,26                          | 4,06                          |
| 8             | 35-37                | 1,3           | 1,9                         | 1,0                       | 2,3                             | 2,9                           | 0,21                           | 2,51                          | 3,11                          |
| 9             | 31-37                | 5,0           | 5,0                         | 2,25                      | 7,25                            | 7,25                          | 0,59                           | 7,8                           | 7,8                           |
| 10            | 37-47                | -             | -                           | -                         | -                               | -                             | 0,48                           | 0,48                          | 0,48                          |
| 11            | 47-57                | -             | -                           | -                         | -                               | -                             | 0,38                           | 0,38                          | 0,38                          |
| 12            | 47-97                | 1,0           | 1,0                         | 1,0                       | 1,0                             | 1,0                           | 0,6                            | 1,6                           | 1,6                           |
| 13            | 33-13                | 0,2           | 0,2                         | 1,35                      | 1,55                            | 1,55                          | 0,2                            | 1,75                          | 1,75                          |
| 14            | 35-15                | 0,2           | 0,2                         | 1,6                       | 1,8                             | 1,8                           | 0,36                           | 2,16                          | 2,16                          |
| 15            | 33-331               | 2,0           | 2,5                         | 1,5                       | 3,5                             | 4,0                           | -                              | 3,5                           | 4,0                           |
As it can be seen from table 3,4, the values of allowances vary on the structural segments of the lines of the chest, waist and hips. On other structural segments they remain unchanged.

Silhouette modification of the state (figure 14) is performed by superimposing the constructed structures Si1, Si2, Si3 relative to the original lines: vertically - the side line, horizontally - the chest line.

|   | 16   | 27   | 29   | 32   | 45   | 47   | 49   | 50   | 51   | 52   | 54   | 61   | 62   | 71   |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|   | 35-331 | 111-12 | 12-121 | 31-32 | 471-46 | 47-36 | 36-372 | 372-372' | 371'-361 | 36-16 | 16-161 | 411-470 | 51-570 | 351-333 |
|   | 2.0  | 0.3  | -0.9 | -  | -    | 0.4   | -    | -    | 0.3   | 0.3   | 0.4   | 0.75  | 2.7  | 3.05  |
|   | 2.5  | 0.3  | -0.9 | -  | -    | 0.4   | -    | -    | 0.3   | 0.3   | 0.4   | 0.75  | 5.2  | 4.05  |
|   | 1.5  | 0.45 | 0.25 | -  | -    | 0.75  | 0.4  | -    | 0.45  | 0.45  | 0.45  | 0.75  | 2.3  | 0.65  |
|   | 3.5  | 0.75 | -0.55| -  | -    | 0.75  | 0.4  | -    | 0.85  | 0.85  | 0.85  | 0.85  | 5.0  | 3.7   |
|   | 4.0  | -0.25| -0.55| -  | -    | 0.5   | 0.4  | -    | 0.85  | 0.85  | 0.85  | 0.85  | 7.5  | 4.7   |
|   | -    | 0.5  | -0.55| -  | -    | 0.5   | 0.4  | -    | -     | 0.56  | 0.56  | 0.56  | 5.1  | 0.21  |
|   | 3.5  | -    | -0.55| -  | -    | 0.5   | 0.4  | -    | -     | 0.56  | 0.56  | 0.56  | 5.1  | 3.91  |
|   | 4.0  | -    | -0.55| -  | -    | 0.5   | 0.4  | -    | -     | 0.56  | 0.56  | 0.56  | 5.1  | 4.91  |

Figure 14. Silhouette modification of the design of a man's jacket state Si1 (adjacent) - Si2 (semi-adjacent) - Si3 (straight).

The values and directions of movement of structural points are determined on the basis of layered drawings using the command "Dimensions ordinate" (table 5).
| Designation of a constructive point | Si0→Si1 Horizontally | Vertically | Si1→Si2 Horizontally | Vertically | Si1→Si3 Horizontally | Vertically |
|------------------------------------|----------------------|------------|----------------------|------------|----------------------|------------|
| 11                                 | -2.5                 | +1.9       | -1.1                 | 0          | -2.2                 | 0          |
| 121                                | -2.1                 | +1.3       | -1.1                 | 0          | -2.2                 | 0          |
| 123’                               | +2.2                 | +1.5       | -0.9                 | 0          | -1.7                 | 0          |
| 22                                 | -1.7                 | +0.8       | -1.0                 | 0          | -2.0                 | 0          |
| 123                                | -2.0                 | +1.6       | -0.9                 | 0          | -1.7                 | +0.1       |
| 14’                                | -1.7                 | +1.8       | -0.5                 | 0          | -1.1                 | 0          |
| 332                                | -1.9                 | -2.1       | -0.5                 | +0.5       | -1.0                 | +1.0       |
| 33                                 | -1.9                 | 0          | -0.5                 | 0          | -1.0                 | 0          |
| 331                                | -1.9                 | -4.0       | -0.5                 | 0          | -1.0                 | 0          |
| 351                                | +1.2                 | -4.0       | +0.3                 | 0          | +0.6                 | 0          |
| 352                                | +1.2                 | -2.8       | +0.3                 | +0.3       | +0.6                 | +0.6       |
| 14’’                               | +2.6                 | +2.7       | +0.3                 | 0          | +0.5                 | 0          |
| 16                                 | +2.7                 | +2.3       | +0.9                 | 0          | +1.8                 | 0          |
| 161                                | +2.7                 | +1.4       | +0.9                 | 0          | +1.8                 | 0          |
| 17                                 | +3.6                 | +1.4       | +0.9                 | 0          | +1.8                 | 0          |
| 37                                 | 0                    | 0          | +0.9                 | 0          | +1.8                 | 0          |
| 371’                               | +3.5                 | +0.3       | +0.9                 | 0          | +1.8                 | 0          |
| 36                                 | +2.4                 | 0.3        | +0.9                 | 0          | +1.8                 | 0          |
| 371’’                              | +3.5                 | +0.4       | +0.9                 | 0          | +1.8                 | 0          |
| 47                                 | +3.5                 | -0.5       | 0                    | 0          | 0                    | 0          |
| 471’                               | 0                    | 0          | +0.9                 | 0          | +1.8                 | 0          |
| 46                                 | 0                    | 0          | +0.9                 | 0          | +1.8                 | 0          |
| 471                                | 0                    | 0          | +0.9                 | 0          | +1.8                 | 0          |
| 57                                 | +5.2                 | -0.9       | +0.9                 | 0          | +1.8                 | 0          |
| 97                                 | +3.5                 | -0.8       | +0.9                 | 0          | +1.8                 | 0          |
| 432                                | -2.3                 | -0.4       | -0.2                 | 0          | -0.4                 | 0          |
| 432’                               | -1.4                 | -0.4       | -0.7                 | 0          | -1.4                 | 0          |
| 542                                | +0.9                 | -0.4       | +0.4                 | 0          | +0.8                 | 0          |
| 542’                               | +1.2                 | -0.4       | +0.3                 | 0          | +0.6                 | 0          |
| 532                                | -2.4                 | -0.6       | -0.6                 | 0          | -1.2                 | 0          |
| 532’                               | -1.4                 | -0.6       | -0.8                 | 0          | -1.6                 | 0          |
| 931                                | -2.4                 | -0.8       | -0.3                 | 0          | -0.6                 | 0          |
| 931’                               | -1.4                 | -0.8       | -0.8                 | 0          | -1.6                 | 0          |
| 91                                 | -2.5                 | -0.8       | -1.1                 | 0          | -2.2                 | 0          |
| 51                                 | -2.5                 | -0.9       | -1.1                 | 0          | -2.2                 | 0          |
| 41                                 | -2.5                 | -0.5       | -1.1                 | 0          | -2.2                 | 0          |
| 31                                 | -2.5                 | 0          | -1.1                 | 0          | -2.2                 | 0          |

5. Results
The method of silhouette modification is based on the displacement of the main structural points (Figure 15), the values of which are introduced into the industrial system of automated clothing design "Julivi".
Figure 15. The main design points of the backrest pattern in the mode of gradation patterns.

The linear variability of the main silhouettes of the men's jacket (Si1 - adjacent, Si2 - semi-adjacent, Si3 - straight) (Figure 14) provides silhouette modification both in the direct transformation of Si1→Si2→Si3 and the inverse transformation of Si3→Si2→Si1:

\[ Si2(x_2; y_2) \rightarrow [(x_1 \pm \Delta x_1); (y_1 \pm \Delta y_1)] \]

(7)

where \( x_i, y_i \) - the coordinates of the structural points of the structure Si1;
\( \Delta x_i, \Delta y_i \) - the value of displacements of the corresponding structural points, which provides the transition in the system Si1 → Si2; Cu2 → Cu3;
“+” at the direct transformation (Si1 → Si2 → Si3);
”-“ at the inverse transformation (Si3 → Si2→ Si1).

The combination of uneven and even shift is illustrated by the complex drawing of the design of the classical line jacket (figure 16).

Figure 16. Complex drawing of silhouettes of a classic jacket (Si1 → Si2 → Si3).
The development of a reference book of standard displacements in the mode allows you to transform both the structure and the pattern by specifying the coordinates of the displacement of the point relative to the starting point in both direct and inverse transformation, taking into account the method of dimensional transformation [22] and method determining the gradation coefficients considered in [23].

For practical application in the modeling module, a method of modifying functional units for the design of boundary lines has been developed [24]. Schemes of construction of unified details are given in figure 17.

![Figure 17](image)

**Figure 17.** Modification: a – lapel; b - rounding of the bort.

6. Conclusions
Based on the theoretical foundations of engineering design of scans on a given rigid surface of the mannequin, a method of affine transformation by the operation ”shift” in the growth of silhouette volume on the principle of interchangeability of models in the sketch design of classic jacket lines has been developed.

A key module of anthropometric modification of a 3D digital model of a mannequin surface by the method of mesh deformation for the formation of equivalent 2D scans in the generation of structural zones of the jacket has been offered.

The connection of geometric modification of the structure silhouette based on the use of the topological operation ”shift” in the informative points of the structure has been proved. The transition from the matrix structure $S_{i0}$ characterizes the uneven shift of the contours due to the rule of distribution of the allowance to the base. The linear variability of allowances on the silhouettes of $S_{i1}$, $S_{i2}$, $S_{i3}$ on the lines of the chest, waist and hips provides the use of shifts on the principle of gradation.

The linear silhouette modification provides both direct transformation of $S_{i1} \rightarrow S_{i2} \rightarrow S_{i3}$, and inverse transformation of $S_{i3} \rightarrow S_{i2} \rightarrow S_{i1}$ in 2D designs of jacket’s details with the use of unified contours of a fastener’s edge in the mode of patterns’ gradation.

The research results can be used for stylists, designers, marketers and university students studying clothes design.

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