An Algorithm for Obtaining 3D Forms of Draperies From Visual Images of Recycled Textile

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ABSTRACT

Adding economic value to textile waste, when developing fashion products from them, requires knowledge of their characteristics. In the present work, an algorithm for reproducing a three-dimensional shape from two-dimensional images of draperies is proposed. An analytical predictive model has been created for automated prediction of the step of the contours of draperies. This model depends on the execution time of the algorithm for creating three-dimensional shapes of draperies from used textiles. The optimal values of the step and the corresponding time for execution of the algorithm are determined. It has been proven that at step st=48 and execution time t=7s, sufficient accuracy of the three-dimensional simulation of used textile draperies is achieved. Software tools suitable for the study of draperies of used textile materials are proposed. The results of this study can be used to make interior textile accessories such as curtains, upholstery, tablecloths, napkins, blankets. Also for fashion models and garments.

1. INTRODUCTION

The traditional linear model of production and consumption of textiles and textiles, which uses raw materials, creates products from them, consumes them and throws away the remains. This model relies on large quantities of available low-cost materials and energy sources [1]. Some materials need higher technology for their recycling, such as textiles, clothing and boxes for their packaging. A solution could be to limit the use of these materials, for example by promoting the use of natural cotton only for the fashion industry and glass or metal packaging. In order to achieve sustainable production of textiles and clothing, it is necessary that the technologies for recycling materials be sufficiently developed to meet all the requirements of industries - both in number and quality [2].

Sustainable production is focused on products and materials that are reused, in a continuous cycle, instead of being discarded. Products that cannot be reused are recycled through chemical or mechanical processes or through biological processes such as composting [3].

Figure 1 shows a diagram for sustainable production of textiles and clothing. Once disposed of by consumers, textile waste is identified by an appropriate electronic system and sorted. The ordered materials are returned for reuse in the creation of new textile fabrics and clothing. These stages are repeated. The effect of the use of textile materials on the climate and the environment is critical because they create a wide range of sources of air, water and soil pollution. During their decomposition, textiles create harmful substances such as methane, ozone, toxic synthetic compounds that are deposited in groundwater and soil. To reduce the waste, material organizations are called upon to move from a linear production model to the sustainable use of textile materials.

Figure 2 shows the stages of obtaining and sharing data from different types of sensors in modern intelligent systems for analysis of textile waste. The initial stage includes obtaining data on the studied textile waste products through ultrasonic, optical, inductive, capacitive sensors. The technological and geometrical characteristics of these waste products are determined. The large volume

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of data of feature vectors can be reduced by appropriate methods such as principal component analysis, factor analysis, weighting factors. The obtained data are convenient to use in the classification of textile waste, to predict their technological characteristics through appropriate regression models, as well as to create algorithms for data processing. As a result of these studies, the characteristics of the textile materials used can be determined and used effectively.

No research has been found in the available literature on the properties of used textile materials. For example, recycled clothing offered is sorted according to the interest of the buyer [4, 5] and not according to the properties of the materials and their reuse.

One of the main characteristics of textile fabrics is their drapery. It is associated with the flexibility and firmness of the fabric. These qualities affect how it falls, folds and thus shapes the final look of a stylish fashion accessory or garment. Material waste from textile production is considered an important asset.

The main motivation of the paper is to obtain 3D shapes from 2D images of fabric draperies resulting from recycled textile. Methods and tools for obtaining 3D shapes of drapes have been proposed.

2. RELATED WORKS

Numerical analysis and simulation of the characteristics of textile fabrics are used in the textile and fashion industry. Through computer simulation, the cost of creating new products can be reduced. For a simulation to be effective, the parameters of the textile fabric must be known. Such characteristics are, for example, the physical and mechanical properties of the fabric.
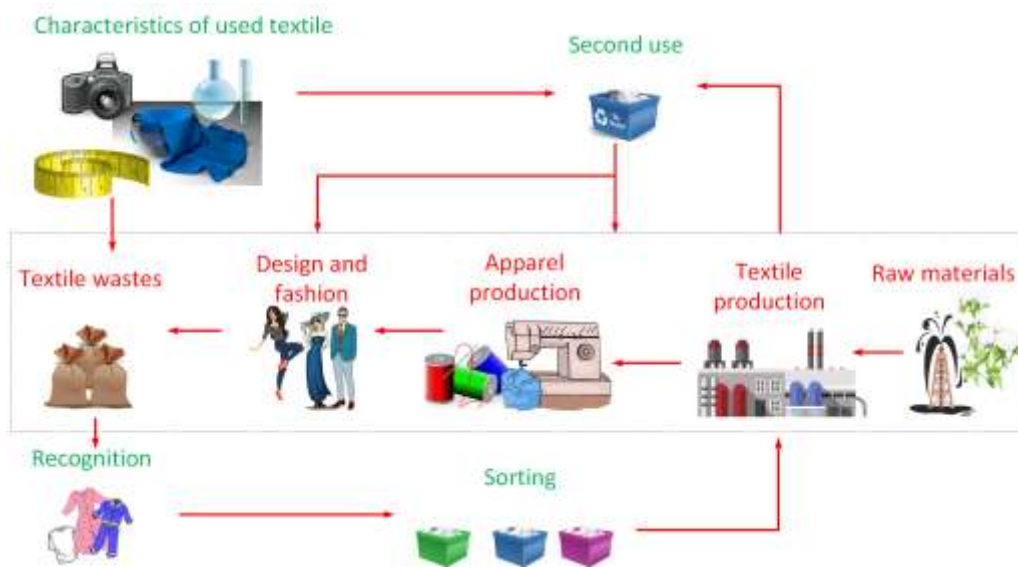

Figure 1. Transition from linear to sustainable production of textiles and clothing
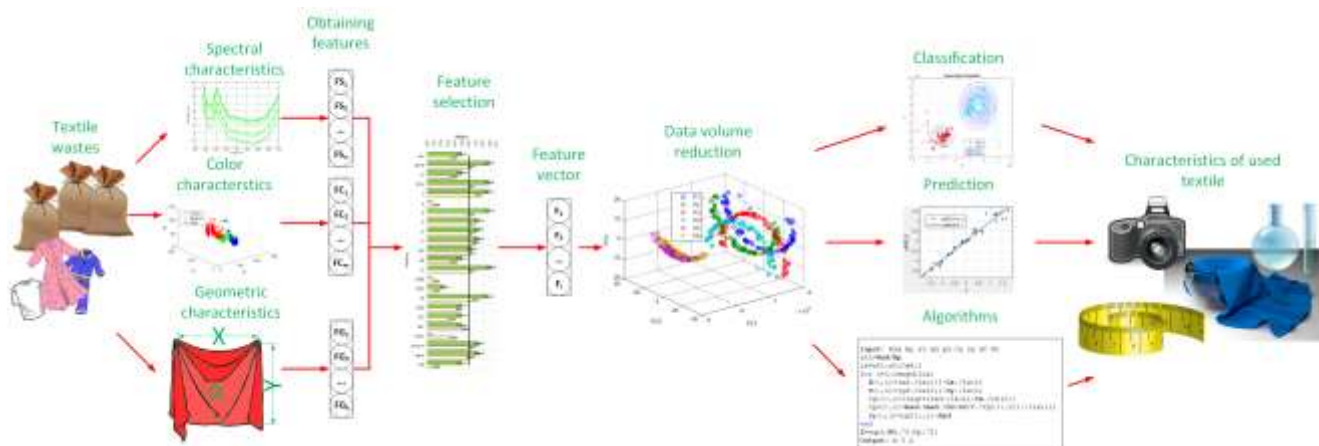

Figure 2. Scheme for obtaining, processing and analysis of the basic characteristics of textile waste

Modern CAD software systems offer functions for simulating draperies. In order to achieve a sufficiently realistic simulation of the real textile fabric, it is necessary to introduce many parameters. Errors in the simulation of textile fabrics increase, especially if they are from used textiles. Due to the deterioration of the fabric after use, the

use of pre-set in the software data on the textile material will not lead to proper simulation of its characteristics.

Rudolf et al. [6], followed by Han et al. [7], have made a comparative analysis between 3D draperies and those obtained by a standard image processing methodology. Due to the lack of correspondence between real and three-dimensional draperies, it is necessary to do more research to achieve results that are applicable in practice. In order to achieve accurate 3D models of draperies, it is important to take into account the mechanical properties of the material such as distortion and mechanical strength. Petrak et al. [8] point out that the cross-sectional thickness of the polygonal model is a significant indicator for the drapery.

One way to check the correct setting of the parameters in the simulation is by testing with a laboratory method, such as a Cusick Drape Tester. If the real and simulated drapery match, the setting of the parameters can be considered sufficiently accurate. This type of analysis would be suitable for textile fabrics from used clothing, because its parameters cannot be known in advance and entered into a simulation software system. Suitable for determining the degree of draping of the fabric is the developed methods, using 3D scanning and stereo video cameras [9, 10]. The disadvantage of these methods is that they are time-consuming and require the use of complex equipment for operation and maintenance, at a high cost. Reproduction of a 3D model on one visual image is possible with the methods of hanging drapes, Cusick's drape, modified Cusick's drape [11]. The modified method uses a rectangle instead of a round sample. For hanging drape, studies have been conducted [12] on the possibility of reproducing 3D drapery from its digital images. The disadvantage of the proposed method is that the accuracy of the restoration of the three-dimensional contour depends on the way of lighting the captured scene.

The Cusick's drape method is suitable for creating an algorithm that can be used to reproduce 3D drapery. The main research on the automation of this method is to determine the parameters of the drapery on its 2D image.

No research has been found in the available literature related to the reproduction of a three-dimensional shape from two-dimensional images obtained by this method. In this method, the shooting conditions are known. Also, the basic dimensions of the object areas in the image are known, such as the size of the supporting disk, the size of the sample.

When creating algorithms for image analysis and processing, it is necessary to answer the following questions [13]: Are the results sufficiently accurate? Is it easy to understand and reproduce? Is it applicable in practice? How much memory does it take up and how many variables it uses in the computer system? What is the time for its implementation?

3. MATERIAL AND METHODS

In the present work, second-hand textile fabrics are used. They are mainly knitted fabrics. Some of them contain elastic components. The fabrics are combinations of cotton, polyester, elastane, polyamide. No analyzes have been made of the surface structure, mechanical, physical, chemical properties of textile fabrics.

Standard test methods for draperies, for example one of which is the British Standard Institute BS5058/ 1974, called the Cusick's Method. Also, the measurement of the characteristics of draperies using image processing techniques is enshrined in the standard BS EN ISO 9073-9: 2008. According to these standards, samples with dimensions 30x30 cm are used in this work. The mass of textile fabrics (GSM, g/m^2) is determined. Also, the drape coefficient (DC, %). The fabric thickness is determined by using Carbon Fiber Composites Digital Thickness Caliper Micrometer Gauge (Shenzhen Ruize Technology Co., Ltd., Shenzhen, PR China), with range of 12,7 mm, resolution 0,01 mm and accuracy 0,1 mm.

Table 1 shows data on the textile fabric samples used. They are represented by their minimum and maximum values, as well as by mean and standard deviation.

Table 1. Data on the textile fabrics used

Parameter	Mean±SD
Cotton, %	72,74±40,76
Polyester, %	24,21±38,23
Elastan %	1,47±2,12
DC, %	35,42±6,11
B, mm	0,82±0,3
GSM, g/m^2	208,84±56,45

The experimental setup used to obtain color digital images of draperies is shown in Figure 3. It consists of: Video camera. Trust Exis (Trust International B.V.) placed above the measured sample; Diode light 6400K, for lighting the drapery from above SMD3528-120/1 (V-TAC Europe, Ltd., Sofia, Bulgaria); Diode light lamp 6400K, for lighting the drapery below VT-2017 (V-TAC Europe, Ltd., Sofia, Bulgaria); Sample placement cylinder. It has a diameter of 110 mm and a height of 180 mm; Measured sample, round samples with a diameter of 200 mm were prepared.

The setup is placed in a dark box to reduce the effects of ambient light.

The images of draperies were taken from a height of 24 cm and have a resolution of 640x480 pix.

Figure 4 shows the parameters of the drapery, which must be determined to create its three-dimensional model.

The designations are: R_t – radius of the sample; R_{sd} – radius of the cylinder on which the sample is placed; R_p – radius

of each point of the drapery; D_p – difference between R_p and R_{sd}; D_s – length of the inclined part of the drapery, calculated for each point of the drapery; H_d – height of each point of the drapery.

Determination of the drapery parameters is based on data from the "*regionprops*" function in the Matlab software system and mathematical dependencies between them.

According to data from this function, R_p and R_{sd} are determined.

$$R_p = \frac{L_p}{2} ; R_{sd} = \frac{L_{sd}}{2} \tag{1}$$

where L_p is the length of the major axis of the drapery contour; L_{sd} is the length of the major cross-sectional axis of the cylinder on which the drapery is placed.

In determining the full radius of the textile sample R_t, a scale s_c. For a cylinder cross-sectional diameter of 110 mm and a sample diameter of 200 mm, the following calculations have been made:

$$s_c = \frac{110}{L_{sd}} ; R_t = \frac{200s_c}{2} \tag{2}$$

The determination of the parameters described above is according to the following formulas:

$$D_p = R_p - R_{sd} \tag{3}$$
$$D_s = R_t - D_p \tag{4}$$
$$H_d = \sqrt{D_s{}^2 - D_p{}^2} \tag{5}$$

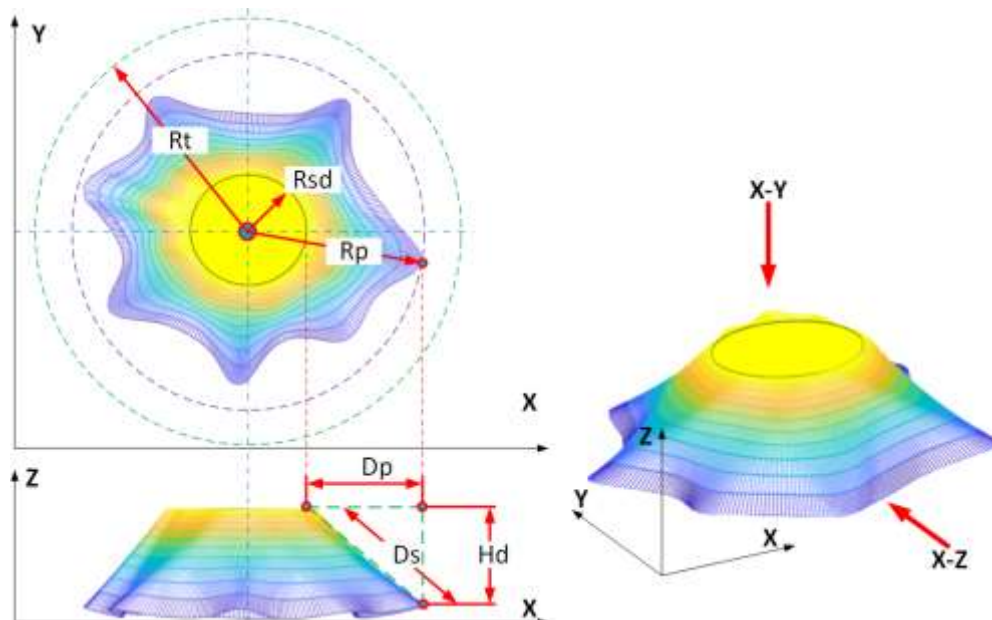**Figure 3.** Experimental setup – general view

Figure 4. Drapery parameters

The coefficient of the drapery (DC) has been determined, which is included in the calculation of its height.

$$DC = \frac{A_d - A_{sd}}{A_p - A_{sd}} \qquad (6)$$

where A_{sd} is the cross-sectional area of the cylinder on which the drapery is placed; A_p – area of the circle around the drapery; A_d – area of the drapery.

The A_{sd} and A_d parameters are determined directly by the regionprops function. The area of the circle around the drapery is determined by:

$$A_p = \pi R_p{}^2 \qquad (7)$$

In determining the step for drawing the contours of the drapery, data from a survey of specialists in the field of clothing design were used. A 5-point scale has been compiled.

The scale has the form: 1-I do not agree at all; 2-I do not agree; 3-no opinion; 4-I agree; 5-I completely agree. Estimates from experts have been used to determine the optimal step for drawing the contours of the draperies.

In determining the size of the step for drawing the contours of the drapery, a polynomial of the second row model was used, describing the relationship between the selected characteristics of the algorithm for drawing the drapery:

$$z = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 \qquad (8)$$

where z is a dependent variable; x and y are independent variables; b - coefficients of the model.

Coefficient of determination (R^2), standard error of model coefficients (SE), p-value, Fisher's criterion (F) are determined. Non-informative coefficients (those with $p>\alpha$) were rejected by the model. The significance of the coefficients is determined by Student's criterion, and their adequacy – by Fisher's criterion.

A linear programming algorithm was used to determine the optimal step of the draped contours. This algorithm is implemented using the linprog function in the Matlab software system (The Mathworks Inc., Natick, MA, USA).

An "*Interior-point-legacy*" algorithm was used. This algorithm is used to solve linear programming problems for which the simplex method is not suitable. The algorithm arrives at an appropriate solution by traversing the inside of the data area.

All data were processed at a level of significance $\alpha=0.05$.

4. RESULTS AND DISCUSSION

The stages of operation of the developed algorithm are shown in Figure 5. Stage 1 – Includes obtaining a color digital image of the drapery. The image contains three matrices, with the values of the RGB color model. Stage 2 – The image is converted to HSV. The S-component is separated from this color model. From the histogram of this component are obtained the ranges in which the three main object areas in the image are located – background, cross section of the cylinder on which the sample is placed and the drapery itself. Stage 3 – Separate the contour of the cylinder cross section. Through the "*regionprops*" function, the length of its major axis, area, coordinates of its center are determined. Stage 4 – Separate the contour of the drapery. Through the "*regionprops*" function, the length of its major axis, area, coordinates of its center are determined. The contours are smoothed. Stage 5 – Calculation of the parameters of the three-dimensional shape of the drapery. They are determined by the mathematical dependencies described above.

Figure 6 shows a pseudocode for calculating the coordinates of a drapery. The italic text shows the commands used directly by Matlab. The constant "st1" is determined by the ratio of the radii of the drapery and the cross section of the cylinder on which it is placed. How many contours of the drapery will depend on the constant "st". The vector "ix" determines the number of contours. The vectors "xd" and "yd" contain the coordinates of the outer contour of the drapery, defined by the "*regionprops*" function. The constants "Cx" and "Cy" are the coordinates of the center of the drapery. These data were used to calculate the coordinates of the drapery along the X and Y axes. The matrix "rp1" contains the radii of each point of the contours of the drapery. To calculate the matrix "Dp", the data from "rp2", the radius of the cylinder section and DC are used as a correction factor. Finally, the coordinates along the Z axis are calculated.
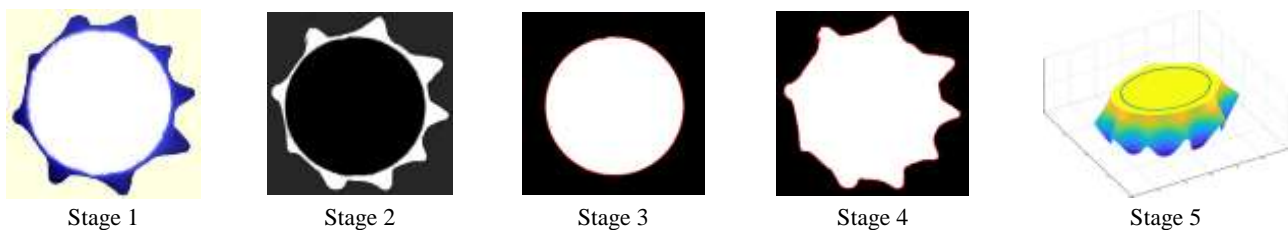

| Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 |

Figure 5. Stages of an algorithm for obtaining 3D shapes of draperies

| **Input:** Rsd Rp st xd yd Cx Cy DC Rt
st1=**Rsd/Rp** | ix=st1:st1/**st**:1
for i=1:length(ix) |

```
X(:,i)=(xd./ix(i))-Cx./ix(i)
Y(:,i)=(yd./ix(i))-Cy./ix(i)
rp1(:,i)=(sqrt((xd./ix(i)-Cx./ix(i)).^2+(yd./ix(i)-Cy./ix(i)).^2))
rp2(:,i)=Rsd-(Rsd./DC-DC/2.*rp1(:,i))./(ix(i))
 Dp(:,i)=rp2(:,i)-Rsd
end
Z=sqrt(Rt.^2-Dp.^2)
Output: X Y Z
```

Figure 6. Pseudocode for calculating drapery coordinates

Figure 7 shows the obtained contours of the drapery. These contours can be used in detailed analysis of the drapery. The final version of the contours of the drapery is obtained by successively smoothing them in the direction from the center to the outside of the drapery. A "*moving average*" filter was used in the Matlab software system. The change of the contours is obtained by changing the parameter "*span*" of the filter from large to small value. The application of this filter has some peculiarities. The value of the "*span*" parameter must be odd. It is automatically adjusted for data points that cannot take the specified number of adjacent points on both sides of a point in the drapery curve. The first and last points of the drapery contour are not filtered because no interval of surrounding points can be defined for them.
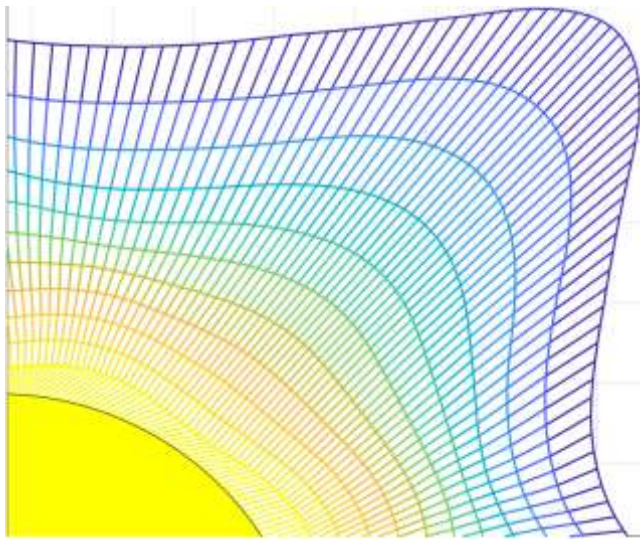

Figure 7. Drapery contours

The implementation of this algorithm in the Matlab software environment is presented in Appendix A. The algorithm can be implemented in the Octave software system (GNU Octave). In this case, it is necessary to use additional functions to filter the contours of the drapery and the cross section of the cylinder on which it is placed.

A model has been compiled, according to which the optimal step of drawing the contours of draperies has been determined. The drapery step (st) and time (t, s) for the execution of the algorithm were used as independent variables. The dependent variable is the decision of specialists in the field of clothing design. The five-point scale presented above was used to evaluate the obtained draperies. After removing the insignificant coefficients, the following model was obtained with p-value>α:

$$D = -3.498 + 0.09s_t + 1.49t - 0.0009s_t{}^2 - 0.09t^2 \quad (9)$$

The evaluation of this model shows that: the coefficient of determination $R^2=0.79$; according to Fischer's criterion $F(4,35)=31.9$, which is much higher than the critical for the same degrees of freedom, $F_{cr}=2.64$; $p<0.00$; standard error $SE=0.6$. The results of the evaluation of the model show that it is adequate and describes with sufficient accuracy the experimental data.
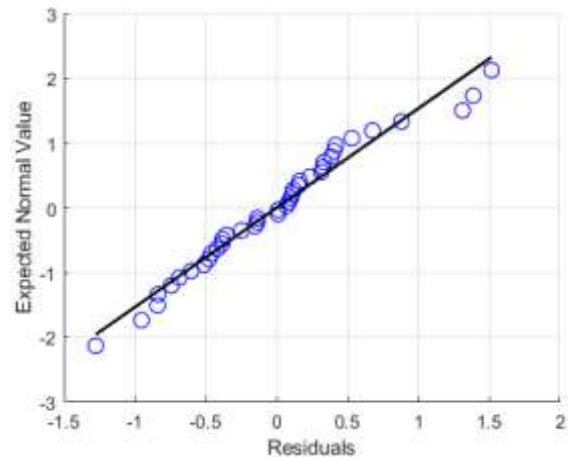
Figure 8 shows the obtained model and its residuals. As can be seen from the distribution of the residuals, in the normal probability graph, they are close to the normal distribution and it can be considered that the prerequisites of the regression analysis are met. The optimal step value and the corresponding execution time of the algorithm are determined by the "*linprog*" function in the Matlab software system. An "*Interior-point-legacy*" algorithm was used. The obtained optimal value of the step is $s_t=48$, at execution time t=7s. Using these settings can be expected a solution of the specialists in the field of clothing design, close to 5, on the appropriate scale.

Figure 9 shows examples of three-dimensional shapes of draperies derived from their images. Samples that were not involved in compiling the regression model and determining the optimal step and time to perform the algorithm were used. It can be seen that the obtained three-dimensional models are visually similar to those of digital images. The three-dimensional shapes are obtained at a step of the contours of the draperies $s_t=48$. Execution time is in the range t=5-8s. The assessment of the specialists in the field of design is 4 and 5, according to the respective scale.

Figure 10 shows an example of export of 3D coordinates of drape in CAD software system. AutoCAD 2023 (Autodesk, Inc., California, USA) is used. From Matlab workspace, the coordinates are copied in MS Excel (Microsoft Corp., New Mexico, USA). Using concatenation, and by changing the decimal symbol to point ".", the coordinates are presented in appropriate form to be used in AutoCAD 3D. By Activating the "3DPOLY" command and pasting the coordinates, the 3D form of the drape is visualized.
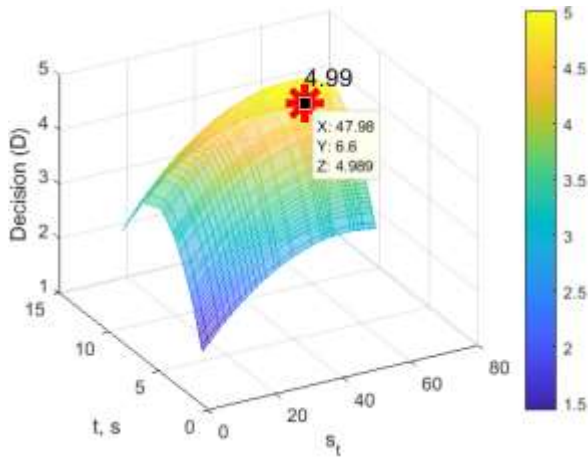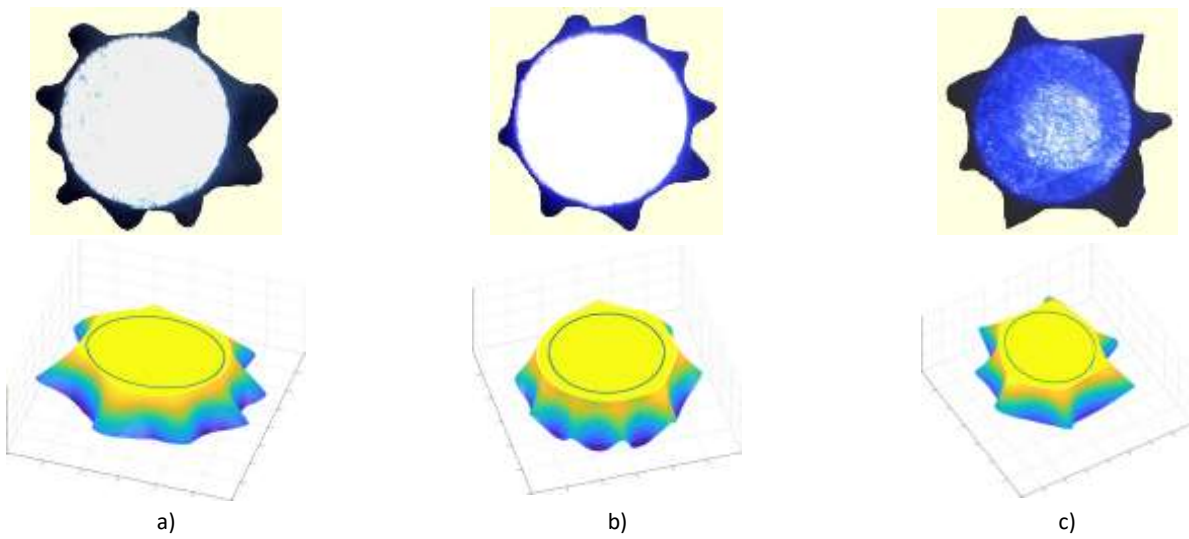
a) model D=f(s_t, t) – general view   **b)** normal probability plot of residuals

Figure 8. Determining the optimal step for drawing the contours of draperies

a)   b)   c)

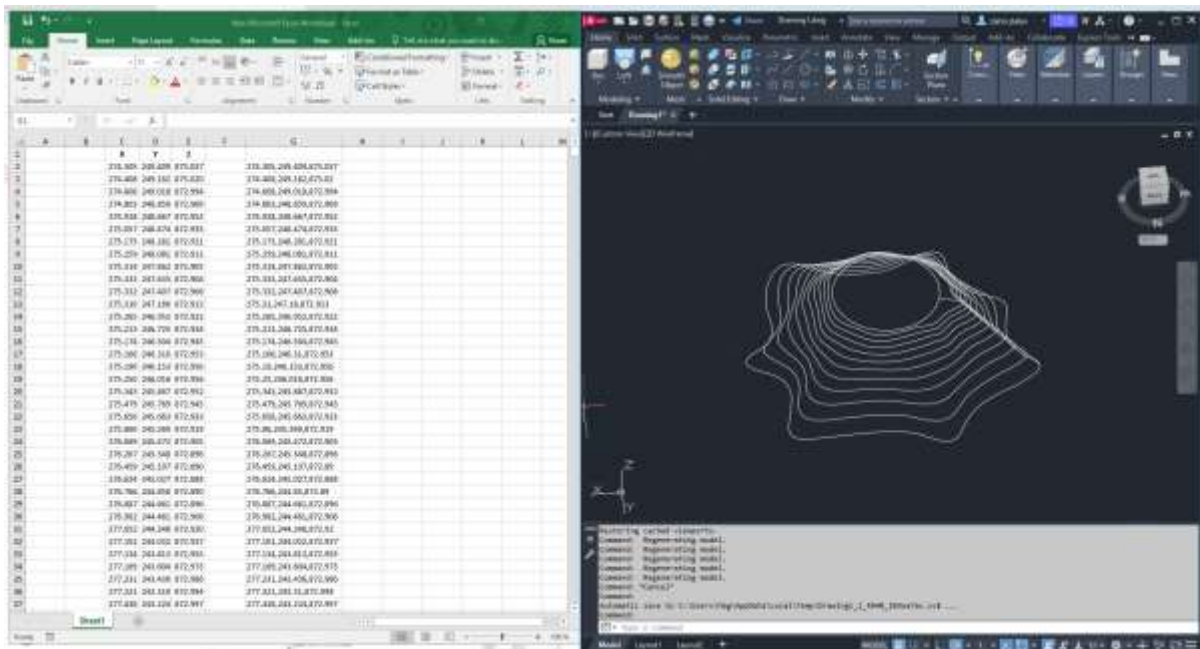**Figure 9.** 3D shapes of draperies

Figure 10. Export of 3D drape coordinates in CAD software system

The limitations of the proposed algorithm are related to the correct definition of the step "s_t", which determines the number of contours in the drapery. It is also necessary to correctly select the range of modification of the parameter "*span*" of the filter function, which creates the final appearance of the contours of the drapery. According to the criteria cited in the available literature [13], the results obtained from the algorithm have sufficient accuracy, when evaluated by specialists in the field of textile production and clothing design. The optimal execution time is t=7s, which corresponds to the work of the proposed algorithm, according to the results of its validation.

According to Petrak et al. [8], the mesh density of the polygonal model is an important parameter for the results of the drapery simulation. Appropriate density is obtained in the present work by determining the optimal step of the contours of the drapery.

The research of Rudolf et al. [6], as well as Han et al. [7] are supplemented in the present paper. An algorithm is proposed to improve the correspondence between real and simulated draperies. When using this algorithm, it is not necessary to fully know the mechanical properties of textile fabric such as deformation, mechanical strength.

5. CONCLUSION

In the present work, an algorithm for reproducing a three-dimensional shape from two-dimensional images of draperies is proposed. This is possible because this method knows the shooting conditions as well as the basic dimensions of the subject areas in the image.

An analytical predictive model has been created for automated prediction of the step of the contours of draperies. This model can be used to determine this step, depending on the execution time of the algorithm for creating three-dimensional shapes of draperies from used textiles. The optimal values of the step and the corresponding time for execution of the algorithm are determined. It has been proven that at step s_t=48 and execution time t=7s, sufficient accuracy of the three-dimensional simulation of used textile draperies is achieved.

The results presented in the available literature are supplemented. Software tools suitable for the study of draperies of used textile materials are proposed. The comparative analysis shows that due to the change in the characteristics of the textile fabrics after use, it reduces the accuracy of recognition and grouping of the draperies obtained from them.

Guidelines for further research include reducing the constraints of the proposed algorithm and including more factors involved in creating the three-dimensional contour of the drapery.

The results of this study can be used to make interior textile accessories such as curtains, upholstery, tablecloths, napkins, blankets. Also, the results of this study can be applied to add economic value to textile waste, in the development of fashion products from them.

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Appendix A. Realization of the proposed algorithm in Matlab environment

```
tic; clc, clear all, close all
i1=imread('t3.jpg') %load drape image
figure; imshow(i1)
s1=rgb2hsv(i1) %conversion to HSV
s2=s1(:,:,2); s1=s1(:,:,2) %S-component
figure; imshow(s1)
figure %contour of internal circle
b2=roicolor(s2,0.0,0.05);
bo2 = bwareaopen(b2, 3500);
se = strel('disk',1);
bj2 = imclose(bo2,se);
bf2 = imfill(bj2,'holes')
[B,L] = bwboundaries(bf2);
imshow(bf2)
s = regionprops(bf2,'all');
cent1 = cat(1,s.Centroid);
hold on
for k = 1:length(B)
boundary2 = B{k};
plot(boundary2(:,2), boundary2(:,1), 'r', 'LineWidth', 2)
end
figure %drape contour
b1=roicolor(s1,0.55,1.0);
bo1 = bwareaopen(b1, 1500);
se = strel('disk',1);
bj1 = imclose(bo1,se);
bf1 = imfill(bj1,'holes')
[B,L] = bwboundaries(bf1);
imshow(bf1)
s1 = regionprops(bf1,'all');
hold on
for k = 1:length(B)
boundary1 = B{k};
plot(boundary1(:,2), boundary1(:,1), 'r', 'LineWidth', 2)
end
xd=boundary1(:,2); yd=boundary1(:,1) %drape contour
%internal circle
rsd=(s.MajorAxisLength) %radius of internal circle
scale=110/rsd %Determination of scale
cx1=s1.Centroid(1); cy1=s1.Centroid(2) %drape center

rp=(s1.MajorAxisLength) %drape radius
st=45
st1=rsd/rp
dr=rp-rsd
ix=st1:st1/st:1
tex=200/scale %textile diameter
afs=s1.Area; asd=s.Area; ao=3.14159*(rp/2)^2
dc=((afs-asd)/(ao-asd))
sm=0.01:0.09/length(ix):0.1 %smooth values
for i=1:length(ix)
xd1(:,i)=(xd./ix(i))-cx1./ix(i)
yd1(:,i)=(yd./ix(i))-cy1./ix(i)
rp1(:,i)=(sqrt((xd./ix(i)-cx1./ix(i)).^2+(yd./ix(i)-cy1./ix(i)).^2))
rp1(:,i)=rsd-(rsd./dc-dc/2.*rp1(:,i))./(ix(i))
xd1(:,i)=smooth(xd1(:,i),sm(i))
yd1(:,i)=smooth(yd1(:,i),sm(i))
rp1(:,i)=smooth(rp1(:,i),sm(i))
end
a=length(xd1(:,1)
dp=rp1-rsd
ds=(tex-xd).*dp
hd=sqrt((10.*tex).^2-(dp.^2))
zd1=hd
figure; hold on
fi=0:360/a:360;
t=3.14159/2
x=cx1+rsd/2.5*cos(fi*t)
y=cy1+rsd/2.5*sin(fi*t)
x=x(1:a);x=x'
y=y(1:a);y=y'
x=(x./ix(1))-cx1./ix(1)
y=(y./ix(1))-cy1./ix(1)
z=repmat(max(max(zd1)),a,1)
xd1=[xd1,x]; yd1=[yd1,y]; zd1=[zd1,z]
xd1(:,end-1)=smooth(xd1(:,end-1),0.1)
yd1(:,end-1)=smooth(yd1(:,end-1),0.1)
zd1(:,end-1)=z
mesh(xd1,yd1,zd1) %3D drapery visualization
plot3(x,y,z,'linewidth',2)
grid on; axis equal; toc
```