УДК 687.016
DOI 10.47367/0021-3497_2024_5_83

СОВЕРШЕНСТВОВАНИЕ ИСПЫТАНИЯ ТКАНЕЙ ДЛЯ ОДЕЖДЫ В ВИРТУАЛЬНОЙ СРЕДЕ*

DEVELOPMENT OF TEXTILE FABRIC TESTING IN A VIRTUAL ENVIRONMENT

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Выполнен обзор современных методов определения драпируемости тканей и представлен новый подход к их тестированию в 3D-среде. В исследовании использовалось программное обеспечение Style3D в качестве технологического инструмента для проектирования стенда и образцов ткани с различным дизайном в соответствии со структурой одежды и ее особенностями. Инновацией исследования является создание нового метода, основанного на моделировании текстильного материала, отображаемого в разных плоскостях. Проведено сравнение измерительных платформ в виде 3D-примитивов (цилиндров, конусов и сфер) с разработанным стендом с особенностями морфологии человеческого тела. Пробы были изготовлены из двух частей, которые были очень близки к деталям одежды, позволяли имитировать швы и отображать направления раскроя. Методология и алгоритмы дают возможность лучше прогнозировать и создавать контурно-реалистичные формы системы "аватар + одежда" в виртуальной среде, а также устранять разрыв между цифровыми двойниками и их материальными прототипами. Практическое применение этого исследования связано с совершенствованием существующих методов компьютерного моделирования и разработкой новых методов компьютерного моделирования, включая 4D для динамических систем "аватар + одежда".

This study presents a new approach on how to develop the method of testing textile fabric in 3D environment. The study used Style3D software as a technological instrument to design a stand and fabric samples with different planar design according to the garment structure and its features. The innovation of the study is the creation of new method based on the simulation of textile material rendered in different planes. The required measurement platforms were set up as different test stands ranging from 3D primitives (cylinders, cone and spheres) to more complex stand with features of human body morphology. The samples were designed from two parts that were very close to the garment pieces and joined by seams. Finally, the con-

* Работа выполнена при финансовой поддержке Российского научного фонда, грант № 24-29-00268 «Разработка технологии генерирования и испытаний цифровых двойников исторических костюмов: новый формат для исследования нематериального культурного наследия России».

struction and shape of generic virtual samples which are capable of presenting textile fabric properties were established. On the base of this research, a new method for predicting the behaviour of textile fabrics in virtual apparel was created. The methodology and algorithms make it possible to better predict and create contour-realistic forms of the "avatar + clothing" system in a virtual environment, as well as to eliminate the gap between digital twins and their material prototypes. The practical application of this research is related to the improvement of existing computer modelling techniques and the development of new computer modelling techniques, including 4D for "avatar + clothing" dynamic systems.

Ключевые слова: текстильные ткани, драпируемость, аватар, одежда, проба, стенд, виртуальная реальность.

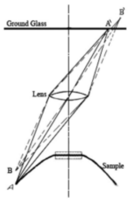
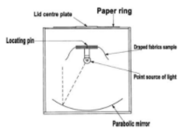
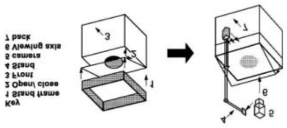
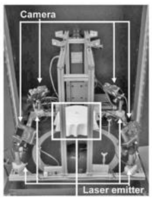
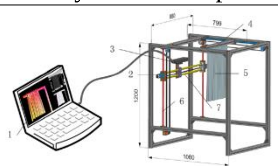
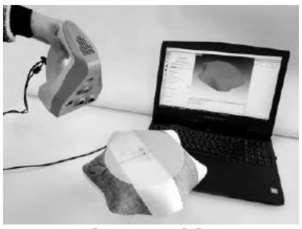
Keywords: textile fabrics, draping, body avatar, clothing, sample, tester, VR.

1. Introduction

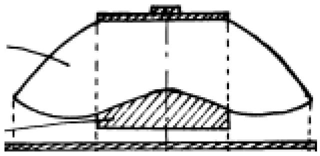
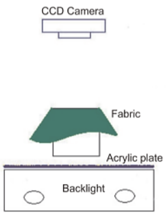
Virtual fashion models are becoming increasingly popular for various reasons related to the economic, creative and marketing aspects of the fashion industry [1]. Computer programs for generating virtual twins of clothes allow to obtaing realistic images, to present them in a static and dynamic manner, to simulate external factors and to assess the position of clothes around the avatar from the point of view of their elasticity. Accuracy and realism of the virtual system "avatar + garment" depends on the algorithm of description and parameterization of its elements - shape and materials used to generate it –shape and textile materials [2, 3]. The quality of clothing simulation will depend on the accuracy of reproducing the behavior of the textile in a three-dimensional virtual space, and the capabilities of modern 3D simulation systems for clothing, which can be considered as a technological tool for testing [4]. The virtual simulation effect is affected by four aspects, drape effect, fold simulation effect, texture representation and material representation effect. Among them, fabric drape is the main attribute to show the 3D effect of clothing. Fabric drape is the performance of fabrics that naturally drape due to their own gravity. The drape parameter of fabric is the most important performance index of textile material, which reflects the construction characteristics and drape level of clothing. The applicability of fabric drape directly depends on the quality of the virtual digital model of fabric [5], which can intuitively show the difference between the virtual garment and the real garment, so drape is crucial for virtual simulation. Fabric drape has always been an important direction of research by experts and scholars, especially with the progress of digital technology, measuring fabric drape in virtual environment has gradually become a research hotspot.

There are mainly two methods of fabric drape evaluation: subjective and objective [6]. Subjective evaluation relies on the expert's feeling, and there is no hard standard; objective evaluation usually obtains the objective data through instrumental testing, which can avoid the influence of subjective factors on the results of fabric drape. The study of fabrics draping has been going on since 1930, starting with Pierce's development of an objective test to measure the bending length of fabrics [7]. Cusick and Chu made a great contribution to the measurement of the draping. They developed the "Drape Coefficient" (*DC*), a value which can be defined as the percentage of the area of the annular ring of fabric covered by a vertical projection of the draped fabric [8]. Cusick improved the drapemeter again in 1962 and 1965 [9, 10] and proposed the weighing method in 1968 [11]. Three standards related to draping measurements, BS 5058:1973, BS EN ISO 9073-9:1998 and BS EN ISO 9073-9:2008, are based on Cusick's work. Table 1 summarizes all contemporary methods of draping test in static and dynamic. The drape image is obtained by drape meter. Analyzing the drape image then computes the drape coefficient using different methods.

Table 1

Test method	DC Calculation	*DC*		Author
		Real	virtual	
 FRL optical drapemeter	Area of the draped sample on the annular ring/Area of the annular ring (between the two circles)	-	-	Chu CC, et al. [8]
 Cusick drapemeter	Measuring the area of a projected shadow using an area meter	-	-	G.E. Cusick [9,10]
 Cusick drapemeter	cut-and-weigh method	-	-	G.E. Cusick [11]
 Image analysing drapemeter	image-analysis	0.90	-	Farajikhah S et al. [12]
 Sylvie 3-D drapetester	Drape projected area/sample area	0.80		Al-Gaadi B, et al. [15]
 Unidirectional drapemeter	Sample length-drape width/ Sample length- folded width	0.47	0.76	Mei Z, et al. [16]
 ArtecSpider Portable 3D scanner	Degree of fit between individual fold morphology and overall morphology for drape simulation	0.59	0.57	Ryklin D, et al. [18]
 Single and double layer fabric comparison test	Projected area and number of folds of the sample	0.48	-	Miguel R, et al. [19]

Ending of table 1

 F.R.L. Drapemeter	The ratio of the area between the two edges of the original and drape sample shadows /The area of its flat unsupported portion.	0.40	-	Frydrych I, et al. [20]
 Direct acquisition of a fabric image using backlight.	Drape projected area/sample area	0.72	-	Wang N, et al. [21]
 Virtual drapemeter by 3D Max	Drape projected area/sample area	0.52	0.30	Buyukaslan E, et al. [22]
 PhabrOmeter Model 3 Fabric Evaluation System	Cut-and-weigh method	0.81	-	Pan N, et al. [23]
 [TC]2 3DBody Scanner	Geomagic^{TM}software	0.33	-	Kenkare N, et al. [24]

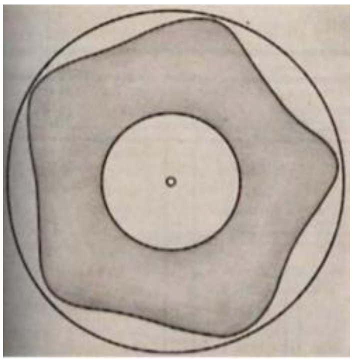


Fig. 1

Traditional tests [8…11] use an optical system to obtain the drape image (Fig. 1) and calculate *DC* based on an area meter or cut-and-weigh method, which has been improved to provide more accurate measurements, but still suffers from limitations such as poor data quality or cumbersome measurement steps. These problems are better solved by the image analysis test [12], which has the advantage of being fast and easy to measure several times, as used in BS EN ISO 9073-9:2008. Fig. 1 shows basic image of draped sample.

In the photovoltaic drape meter test method [13, 14], the light source is located directly above the test sample as the covered sample blocks the light emitted from the light source. A voltmeter connected to the drape meter determines the amount of unblocked/sensed light through the photovoltaic cell. The main advantage of this device is that it allows direct measurement of DC. However, it was found that the sensitivity and lifetime of the photovoltaic cells used are limited and the Drapemeter has to be calibrated after each test.

Al-Gaadi B, et al. [15] created a new parameter "Drape Unevenness Factor" to describe the geometric asymmetry and unevenness of the drape of fabric samples. The samples were measured using a Sylvie 3D drape meter to determine the relationship between drape properties and the direction of yarn twisting and to investigate the effect of loops. The method adds a dynamic impact on the sample during the measurement process, which also reduces the deviation of *DC*, thus making the measurement more accurate. However, the high velocity does not replicate normal human motion during the dynamic simulation.

Mei Z, et al. [16] developed of a unidirectional test drape method. A low-cost Kinect sensor device was applied to capture 3D drape contours, and *DC* were obtained through 3D reconstruction and image processing and analysis techniques. The method not only simulates gravity parallel to the fabric plane but also uses 3D measurements. A comprehensive and realistic reflection of the drape properties of the fabric can be obtained. However, the fabrics tested by this method are not comprehensive enough, and only ester materials and woven fabrics are used as research objects.

Jeong J. [17] proposed the "Drape Distance Ratio" (*DDR*) as an alternative measure of drape. the DDC is based on distance, while *DC* is based on area. There is no significant difference between this method and Cusick's drape meter measurements.

Ryklin D, et al. [18] proposed two new mathematical models that can accurately describe the drape appearance morphology of different linen fabrics. Tests on different plain linen fabrics and data analyses confirmed that the new methods have high accuracy and can evaluate the drape morphology of fabrics more effectively than the umbrella measurement method. The method does not take into account the diversity of fabrics and measuring only linen fabrics is not sufficient to illustrate the accuracy of the method.

Miguel R, et al. [19] performed draping simulation using MD8 software. Analyzing the drape profile area and folds of single and double-layer samples, it was concluded that double-layer fabrics drape better and have more folds than single-layer fabrics, proving that the grammage of the fabric has a significant effect on *DC*. However, the method only compared one fabric and did not use harder or softer fabrics for testing.

Frydrych I, et al. [20] defined as the ratio of the area between two edges of the original and draped sample's shadow, to the area of its flat unsupported part. This ratio is more comprehensive than traditional DC because it is directly related to fabric drape.

The fabric drape meter developed by Wang P. N. et al. [21] can effectively enhance the grey scale contrast between fabric and background when directly acquiring fabric drape images in a darkroom using backlighting. The method can directly acquire fabric drape images under backlight in a darkroom and can calculate *DC* of fabrics with different fibres, thicknesses, colour shades, patterns, high transparency and partial transparency.

Buyukaslan E, et al. [22] created virtual drapemeter in 3D Max to simulate virtual fabric drape using Optitex software. *DC* of the virtual fabric was calculated by image analysis. The actual and virtual *DC* of fabrics were compared. However, the simulation software is less capable of reflecting the characteristics of *DC*.

Pan N, et al. [23] by using a PhabrOmeter as well as a fabric line density λ, a more efficient alternative to fabric drape testing can be achieved. A validation *DC* using a Cusick drape meter showed that the results of the two approaches were consistent, but this approach will not be sensitive if fabric directionality or curling is of interest to be studied.

Kenkare N, et al. [24] developed and validated a new technique for measuring fabric drape using a 3D body scanner while measuring the actual drape properties of real fabrics by means of a Cusick drape meter. The simulation is successful if the simulated *DC* is ±15% of the real *DC*. However, the testing process of this method is cumbersome.

However, current research has focused on actual and virtual draping of textiles which have designed as flat samples traditionally. But the exploration of the draping behavior of textiles on the surface of the human body in the interaction between avatars and garments is still unclear.

Based on the above problems, there is a need for a new test stand for fabric drape study in the research of virtual fabric measurement. The aim of this study is to develop a capable new test method for virtual samples which might copied real fabrics behavior in garment. The test method should allow to study the drape of virtual textile materials when the sample simulated on the human body in order to further improve the prediction and creation of contour-realistic shapes of "avatar + garment" systems in virtual environments, and to narrow the gap between digital twins and their material prototypes. At the same time, the practical application of this research is related to the improvement of existing computer modelling techniques and the development of new computer modelling techniques, including 4D for "avatar + garment" dynamic systems.

2. Experiment

2.1. Common Methods Suspension Simulation

The results obtained from flat testing based on virtual environments are *DC* values which are not sufficiently good to describe the draping behavior of fabrics on the human body, so there is a need to develop a new methodology for virtual textile testing. The textile material was tested prior to the virtual simulation of the material samples [25, 26] (Kawabata Evaluation System KES, Fabric Analyzer by Browzwear (FAB) and corresponded to the virtual fabric based on physical parameters. Virtual simulations are performed using CLO3D and Style3D software [27]. Their advantage is that virtual testing saves material, reduces costs and minimizeslabor compared to traditional testing methods, and has therefore become an increasingly popular method in the modern textile and fashion industry.

Currently, the simulation of material drape is demonstrated on the simplest geometries: sphere, cylinder, cone, and the geometrical test stands are all 40 cm in diameter. Fig. 2 shows the virtual test stand for fabrics.

a) b) c)

Fig . 2

The effect of using geometric stands was analysed according to the structural characteristics of the samples. *DC* was calculated using equation (1), which derived from the area of the fabric before the simulation (S0) over the projected area after the simulation (S1), and the coefficient of variation (V) was calculated using equation (2). The test results are shown in Table 2.

$$DC = \frac{S_0}{s_1}, \quad (1)$$

$$V = \frac{max - min}{average}. \quad (2)$$

Table 2

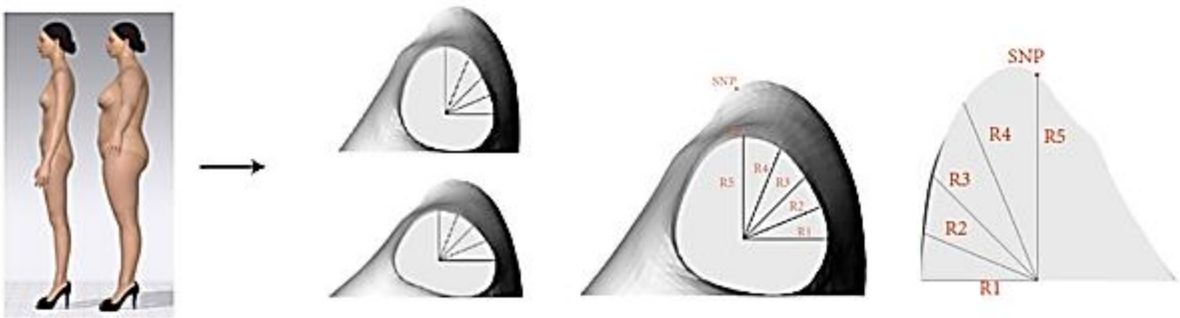
Sample structure	*DC*		
Yarn direction and type of seams	spherical	cone	cylinder
Warp, Warp and Plain Seam	0.44	0.48	0.43
Warp, Weft and Welt Seam	0.43	0.47	0.42
Warp, Bias and Flat-fell Seam	0.41	0.49	0.41
Average (*AVG*)	0.43	0.48	0.42
Variation（*V*）	0.07	0.04	0.05

Table 2 shows *DC* and mean values of the three stands, and the coefficient of variation *V* of the spherical stand is 0.07, which is greater than that of the cylindrical and conical. This shows that the samples have better drape on spherical stands. Similarly calculating the coefficient of *V* for the sample structures, the warp, bias and flat-fell seam structures have a coefficient of *V* of 0.18, which is greater than the other two results. However, by observing *DC* reflected by the samples of different structures on the three geometrical stands, it can be seen that the geometrical stands do not reflect the effect of the sample structure on the drape.

2.2. Establishment of new test stand

In the first phase of the experiment, the geometric modeling of the virtual stand was set up. In order to show the differences in *DC* between the different construction samples, the surface of the garment in contact with the human shoulder was chosen as the main shape of the new test stand. The reasons for this were as follows: a) shoulder seams have a specific effect on the clothing fit; b) the front and back of the samples could be cut in different orientations (along the warp, weft, and angle); c) to investigate the effect of the bottom width on *DC*.

In this study, 3D model of the shoulder was established by cropping operation based on the size data of US-ASTM-Missy-Curvy. The reconstruction process of the shoulder model was as follows: the avatar of female body was established by selecting sizes 0-20 from CLO3D software, and the human body model was imported into Rhion-7 software in OBJ. format. The model was processed for mesh redivision in Rhion-7 software, and the complex human body mesh was converted into a Nurbs surface. The required height spacing for the shoulder model is *SNP*-armhole bottom and the width spacing is *SP-SNP*. Then the cropping manipulation is performed after determining *SP* and *SNP* points of the human body. The required model was cut to shape using the cut plane tool as shown in Figure 3a.



a) b)

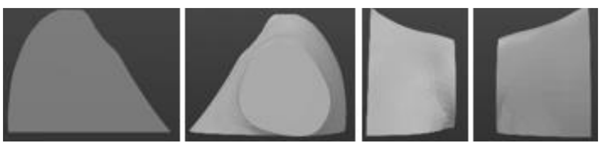
Fig. 3

To further confirm the dimensions of the final test stand, 10 shoulder models obtained were measured. By measuring the radius distance between the sections where *SP* and *SNP* are located, the measurements are shown in Fig. 3b. In *SP* interface, the angle of each radius between *R1-R5* was set to 22.5° (Table 3).

Table 3

Radius of cross-section from SP (mm)					Radius of cross-section from SNP (mm)					Shoulder line (mm)	
R1	R2	R3	R4	R5	R1	R2	R3	R4	R5	Surface distance	Linear distance
68.3	66.4	68	75	78.7	105.6	111.9	130.7	162.2	165.8	128.54	124.32

SNP plane was measured in the same way. The radius parameters of all the models obtained from the measurements were obtained by calculating the average value of each data to get the data of the new stand, as shown in Table 3. *SNP-SP* is the shoulder line, which has a straight-line distance of 124.32 mm and a surface-distance of 128.54 mm. The shoulder test stand required for this study was built in Rhion-7 software and imported into Style3D software in OBJ format, as Fig.4 shown.

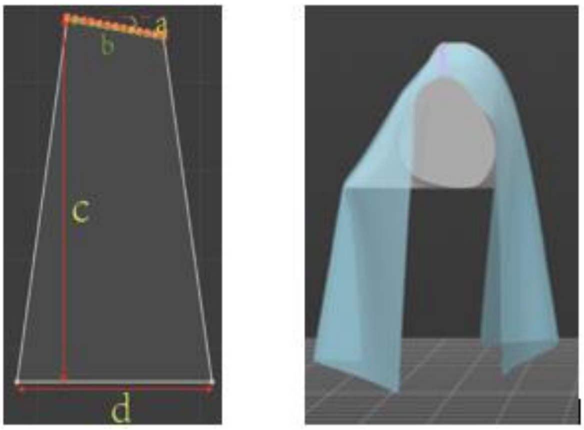


a) b) c) d)

Fig. 4

2.3. Experimental samples

To better reflect the effect of sample structure on drape, a new test sample was created instead of using a circular sample. Here the sample suitable for shoulder test stand was developed, and the shoulder part of the prototype pattern was selected [14], as shown in Fig. 5.



a) b)

Fig. 5

The shoulder pattern affects the silhouette of the garment and contains more sample structures, including the shoulder angle, the bottom hem size, etc.

The sample has next sizes:

1) "*a*" a is the shoulder seam angle. According to Rip Liu in the book "Principles and Applications of Garment Pattern Design" [28], the sum of the front and back pattern angles is found to be minimum 20° and maximum 40° [28]. Therefore, the range of shoulder angle is 20°, 25°….40°;

2) "*b*" is the shoulder length. According to the US-ASTM-Missy-Curvy size chart, the average shoulder length of all sizes was calculated to be 12cm, so the sample shoulder length was set to be 12cm;

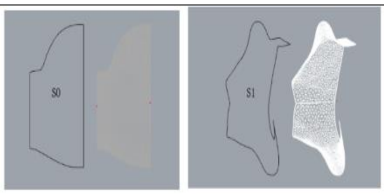
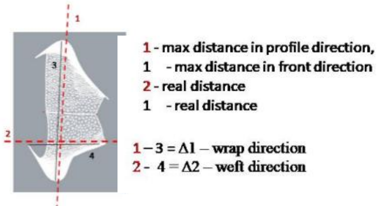
3) "*c*" is the sample length which is equal to the length from SNP -Waist. According to the US-ASTM-Missy-Curvy size chart, the average value is calculated to be 41 cm;

4) "*d*" is the bottom size. According to US-ASTM-Missy-Curvy size chart, the average bust girth of the human bodies were collected, and using the 0.25Bust Girth value, the range of the bottom is 24,3....49 cm.

2.4. Method and designed criteria

After measuring the initial area of the sample, the shoulder seams were simulated by fixing them along the shoulder line. The fabric was kept in the simulation with natural drape. After exporting the sample in obj.format, data such as sample projection area and distance were measured in Rhion-7 software.

Table 4

NO.	Testschemes	Equation	Result			
			Mix	Max	AVG	V
1		$k_1 = \frac{S_0}{S_1}$	0.54	0.78	0.62	0.38
2		$k_2 = \frac{S_3}{S_2}$	0.16	0.23	0.19	0.36
3		$k_3 = \frac{\Delta_2}{\Delta_1}$	0.24	0.86	0.66	0.93

Next measurement schemes were explored:

1) *S0* is the area of the stand, S1 is the projected area after the sample simulation;

2) *S2* is the area before the sample simulation, S3 is the projected area after the sample simulation;

3) △1 is the maximum distance of the front and back pieces of the fabric before simulation minus the maximum distance of the front and back pieces of the simulation after the simulation, and △2 is the mean value of the width of the bottom side of the fabric before the simulation minus the mean value of the width of the bottom side of the fabric after the simulation.

Observing the comparison of *V* in Table 4, scheme 3 has the highest value 0.93. This indicates that scheme 3 clearly reflects the effect of different structural fabrics on drape. Therefore, the design standard of the sample was developed based on the data of scheme 3 as shown in Table 5.

Table 5

Sample size, см	Sample angle				
	20°	25°	30°	35°	40°
24	0.65	0.57	0.44	0.33	0.24
29	0.68	0.64	0.61	0.51	0.46
34	0.87	0.78	0.66	0.50	0.44
39	0.82	0.79	0.74	0.66	0.54
44	0.90	0.85	0.77	0.64	0.60
49	0.86	0.84	0.79	0.75	0.73

The coefficients of variation of angle factor and size factor were calculated according to Table 5 with equation (2) to find the best sample. The V factor 0.98 is highest when the size is constant and the angle is 40°. Similarly, coefficient of variation 0.93 is highest when size is 24 cm.

Therefore, the structure of the optimum sample is angle 40° and size 24 cm.

2.5 Comparison common and new test

The comparisons were made using spherical test and new test. Three equations for calculating the DC are selected.

Equation 1 [8] is the most common calculation:

$$DC = \frac{\text{The area of a draped fabric's shadow}}{\text{Area in an un-deformed flat state}}. \quad (3)$$

Equation 2 [29] showed good correlation and high reproducibility with the cut-and-weigh (conventional) method:

$$DC = \frac{\text{Drape fabric's shadow area - Stand area}}{\text{The area of the region outside the Stand - Stand area}}. \quad (4)$$

Equation 3 [30] is considered to be more comprehensive than the conventional DC because it is directly related to the fabric drape measured using either the shear-weighing method or the digital method. It increases as fabric drape increases, in contrast to conventional DC:

$$\mathrm{DC} = \frac{\text{Sample area - Drape fabric's shadow area}}{\text{Sample area- Stand area}} \quad (5)$$

The samples tested by new method have the angle: 40° and bottom size 24 cm. The samples were constructed with yarn direction: Warp, Bias; seam type: Flat-fell Seam. Five woven fabrics with different properties selected from Style3D library as shown in Table 6.

Table 6

Fabrics	Showcase	Weight (g/m2)	Thickness (mm)	Bends Warp (g*mm2/s2/rad)	Bends Weft (g*mm2/s2/rad)	Bends Bais (g*mm2/s2/rad)
Swimsuit fabric		130	0.47	100	50	60

Ending of table 6

Cotton Linen Plain		123	0.21	250	100	200
Polyester Paracord Crepe		102	0.29	350	250	300
Silk Crepe Satin		52	0.13	650	100	200

3. Result and Discussion

The drape test was performed in Style3D as shown in Fig. 6, a,b. The sample image was acquired in Rhino-7 in OBJ. format as shown in Fig. 6, c, d.

(a) (b) (c) (d)

Fig. 6

The results of the comparison between the new method and the common method with application of three equation for *DC* calculating are shown in Fig.7.

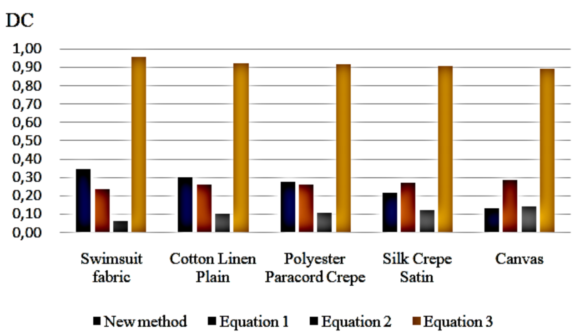


Fig. 7

The new method is opposite to Equations (1) and (2) in terms of *DC*: the better the drape the higher *DC*. In Equation 1, the drape is inversely proportional to the drape coefficient, and the better the drape the lower *DC*. Equation 2 showed good correlation and high repeatability compared to Equation 1. Equation 3 is considered more comprehensive than Equation 1 as it is directly related to the fabric drape measured. Equation 3 was in agreement with the new method in terms of drape coefficients, with drape being directly proportional to *DC*. However, the difference in *DC* for Equation 3 was minimal.

Table 7 shows the comparative results of *DC* measured by the four schemes.

Table 7

Fabric	DC			
	New method	Common		
		Equation 1	Equation 2	Equation 3
1	0.34	0.23	0.06	0.95
2	0.30	0.26	0.10	0.92
3	0.27	0.26	0.11	0.92
4	0.22	0.27	0.12	0.91
5	0.13	0.28	0.14	0.89
AVG	0.25	0.26	0.11	0.92
V	0.85	0.19	0.77	0.07

New method has the highest V = 0.85, thus, proving that the new method is better than the remaining common method applications. This is followed by Equation 2 with $V = 0.77$. This method calculates *DC* from the draping projection, which is able to reflect the variation of *DC* between samples.

4. Conclusion

Based on these findings, as shown in Tab.2, the geometric test stand is not suitable for drape measurements on samples with different structures. Therefore, a test stand related to the human shoulder was built for the development of new methods for testing textile fabrics in a virtual environment. New test samples related to the human body and prototype patterns were designed based on the test stand. A new testing scheme was proposed to calculate *DC* by measuring the change in the warp and weft direction of the samples before and after the simulation. Sample design criteria were derived from the measurements, where a sample with an angle of 49° and a size of 24 cm was optimal. Five types of fabrics ranging from soft to hard were selected and tested using the new method in comparison with the three calculation formulas in the common method. The test results showed that *DC* measured by the new method was inversely proportional to that of the commonly used method, but with the largest coefficient of variation, indicating that the new method is more sensitive than the commonly used method in measuring the variation of fabric drape.

In this study, we successfully developed a new method to test the drape of textile fabrics in a virtual environment. With the new test stand we constructed; the drape of different structural samples showed significant variations in the tests of the new method. This method allows for better prediction and creation of realistic profiles of "avatar+garment" systems in virtual environments and bridges the gap between digital twins and their material prototypes. Practical applications of this research include the improvement of existing computer modelling techniques and the development of new computer modelling techniques, including 4D techniques for "avatar + garment" dynamic systems.

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Рекомендована кафедрой конструирования швейных изделий ИВГПУ. Поступила 03.08.24.