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DIGITAL TWINS OF TEXTILE MATERIALS FOR VISUALIZATION OF HISTORICAL COSTUMES

ЦИФРОВЫЕ ДВОЙНИКИ ТЕКСТИЛЬНЫХ МАТЕРИАЛОВ ДЛЯ ВИЗУАЛИЗАЦИИ ИСТОРИЧЕСКИХ КОСТЮМОВ*

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Digital twins of textile materials are widely used for creating virtual clothing. Digitization allows reproduction, studying, exhibition and preservation of historical costumes in virtual environment and the accuracy of costume visualization depends on the quality of digital textiles. The article presents a method for generating digital twins of textile materials for visualization of historical costumes during the process of their reconstructions. The method reproduces the surface performance and mechanical behavior of textile materials by using two different approaches. The first nondestructive approach is based on generating digital textiles after microscopic exploration and procedural texturing of saved historical prototypes. The second approach is based on real fabric and the results obtained after its 2D scanning, non-procedural texturing and testing including destruction. The method was applied to generate six digital twins of textile materials dating to the IVth century BC and to the XIXth century. The surface appearance and mechanical behaviour of the digital twins were evaluated to prove its adequacy in terms of physical, mechanical and optical properties.

Цифровые двойники текстильных материалов широко используют для создания виртуальной одежды. Цифровизация позволяет воспроизводить, изучать, экспонировать и сохранять исторические костюмы в виртуальной среде, а адекватность виртуальных двойников костюмов зависит от качества цифровых текстильных материалов. В статье описано применение метода создания цифровых двойников текстильных материалов для визуализации исторических костюмов во время их реконструкции. Этот метод

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воспроизводит внешний вид поверхности и механическое поведение текстильных материалов с использованием двух различных подходов. Первый неразрушающий подход основан на генерировании цифровых двойников после их микроскопического исследования и процедурного текстурирования сохранившихся исторических материалов. Второй подход основан на использовании современных текстильных материалов и их 2D-сканировании, непроцедурном текстурировании и тестировании, включая разрушающие методы. Разработанный метод был применен для генерирования шести цифровых двойников текстильных материалов, датируемых IV веком до н.э. и XIX веком н.э. Внешний вид поверхности и механическое поведение цифровых двойников были сопоставлены с прототипами, чтобы доказать их адекватность с позиций показателей физических, механических и оптических свойств.

Keywords: virtual twin, cloth simulation, archaeological textiles, virtual try on, digital reconstruction.

Ключевые слова: цифровой двойник, симуляции текстильных материалов, археологический текстиль, виртуальная примерка, цифровая реконструкция.

Digital twins of textile materials (DTTM) are widely used in engineering, commerce and computer graphics [1]. Computer simulation allows visualization of clothing before its producing. Thus, the style and the construction of clothing can be tested and improved within the first stages of design [2]. Highly detailed virtual clothing can be seen in the movies, the advertisement and the video games and its performance relies to a large extent on the adequacy of digital textiles [3].

The goal of textile material digitization is to reproduce, firstly, the surface appearance (SA), and, secondly, its mechanical behavior (MB) similar to real clothes.

SA covers the optical properties of textiles which are visible by unaided eye, such as color, glossiness, and transparency [2]. The information how textile material looks can be obtained by means of 2D scanning, digital photography (including standard and depth-perception cameras), special devices (colorimeters, glossmeters and roughness testers) and software (texture maps generators, 2D raster and vector editors.).

MB describes the physical and mechanical properties which are forming the appearance of textile material, such as weave type, yarn thickness, twist direction, twist angle and number of yarns per unit of length. The list of properties includes tensile, bending, shearing, compression and surface friction parameters [4]. Fabric objective measurement (FOM) systems, such as Kawabata Evaluation System (KES-F), Fabric Assurance by Simple Testing (FAST), Browzwear Fabric Analyzer (FAB), CLO Fabric Kit and OPTITEX Fabric Testing Unit are used to test the parameters [5]. The test results can be applied to model the material behavior under the external forces.

Obtaining of DTTM is the important part of historical costumes digitization and reconstruction by means of CAD and digital technologies which now represent a rapidly developing research area [6,7]. But before reconstruction, historical textile materials (being precious artifacts) cannot be tested because testing machines would harm the specimens. Several methods are developed in order to reproduce historical textiles in digital form [8,10]. However, the methods do not present a clear algorithm for the reproduction the both SA and MB. Thus, new methods for generating DTTM are required.

The aim of this study is to develop a new method for generating DTTM for virtual presentation of historical costumes. This study was based on special equipment (such as electronic microscope, Epson Perfection scanner, Kawabata Evaluation System KES-F) and software (Mari, 3D-Coat, Mudbox, Substance Designer, Clo3D, Substance Alchemist). To evaluate DTTM obtained, two experimental methods were used - the sensory analysis (in case of SA) and the graphic comparison of the overlapped clothes contours (in case of MB).

Figure 1 shows the algorithm of the developed method.

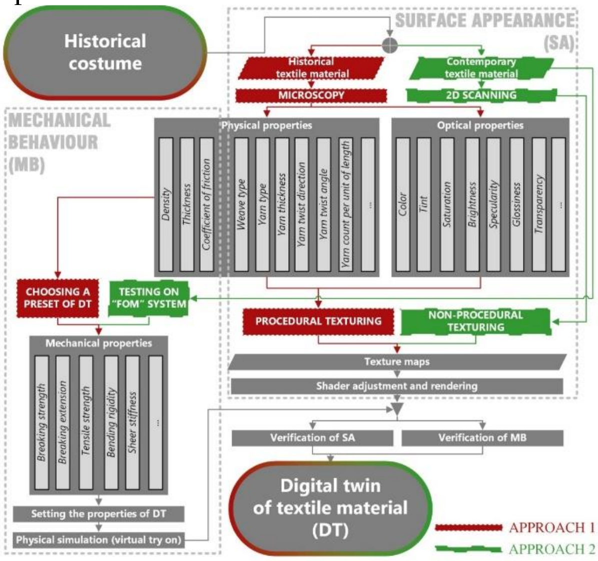


Fig. 1

As Fig.1 shows, the method incorporates two approaches. The both approaches allow reproduction of SA and MB of digital textile material. The difference between them lies in methodology and depends on availability of the specimen of textile fabric for testing.

The *first nondestructive approach* deals with the saved historical textile materials and is based on the microscopy, the procedural texturing and other database. The microscopy is applied to measure most of the physical properties, such as yarn type, thickness, twist direction, and twist angle, and the optical ones, such as color, tint, brightness, etc. The retrieved data is used to generate texture maps in special procedural texturing software module (Substance alchemist graph). After that, the physical properties are used to choose a preset of the mechanical properties from the cloth simulation software library. This is done by choosing a DT with a similar content, density, thickness and weave and yarn types. This approach allows the MB of the material to be reproduced without testing its specimens. Thus, the first approach is applicable for archaeological and museum costumes.

The *second approach* operates with contemporary textile materials which can be considered as historical prototypes. To implement this approach, three technologies - 2D scanning, non-procedural texturing and FOM testing including destructive tests - were combined. 2D scans were converted into a set of texture maps in special software (Mari, 3D-Coat, Substance alchemist, Mudbox). After that, the specimens of the material were tested on a FOM system. The parameters of physical and mechanical properties were used to reproduce its MB. Since the second approach involves testing procedures, it can only be applied to contemporary textiles, from which the reconstructed garments should be made.

a b

Fig. 2

To test the both approaches, two historical costumes were chosen. The first object (Fig. 2-a – salt man 4 (Photo by Abolfazl Aali [11])) is a part of archaeological artifact so-called

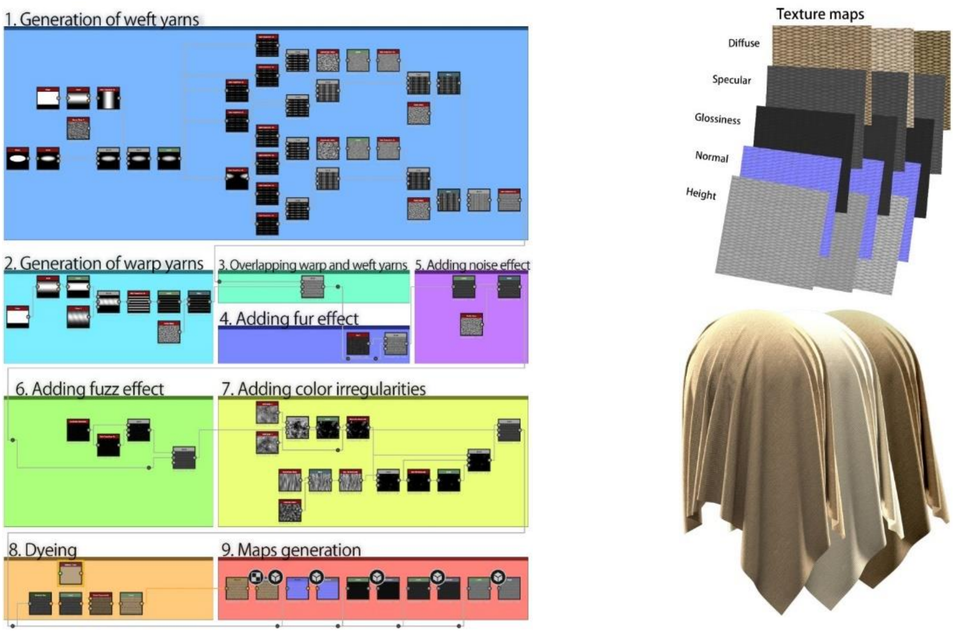
Salt man 4 (circa 405-380 BCE), which was found in a collapsed mine in Northern Iran [11]. Because of the unique conservation conditions, the tunic, the trousers and the belt of the salt man which were made of woven fabrics have preserved relatively well [12]. The second object (Fig. 2- b – woman's costume from a Russian lubok) is the reconstructed woman's costume which is depicted in a Russian lubok print called "A dwarf and a dwarfess" dating to the mid XIXth century [13]. For its reconstruction, the contemporary textile materials were used. As Fig. 2 shows, each costume includes three textile materials.

To digitize the textile materials of Salt man 4, we applied the first approach to generate DTTM through following steps.

1. The physical and optical properties were measured by using electronic microscopy (Measurements were done by K. Grömer, Naturhistorisches Museum Vienna).

2. In order to generate texture maps, a new software module for Substance Designer was developed (Fig. 3-a). The module reproduces the historical process of weaving and dyeing by generating 2D images of weft and warp yarns, twisting or overlapping them, adding special effects and colorizing the maps. Each operation was controlled by special functions (nodes) that are connected within a single process represented as a graph. The nodes use the physical and optical parameters of historical textiles to calculate the corresponding parameters of texture maps.

3. The physical properties of real existing materials were used to chose the presets from the Clo3D library. We chose the presets of the contemporary digital textile fabrics that have the weave type, content and thread thickness similar to the saved historical ones. Table 1 shows the physical and mechanical properties of DTTM. Fig. 3-b shows the DTTM of the salt man's textiles.



a) b)

Fig. 3

Table 1

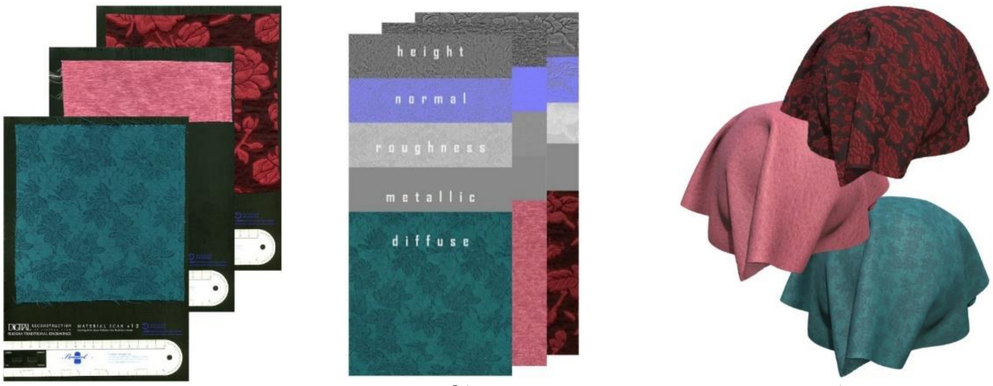
DTTM	Properties										
	Content	Density, cN/m^2	Stretch stiffness, cN/s^2		Bending stiffness, cN/mm^2/s^2/grad		Bending-bias stiffness, cN/mm^2/s^2/grad	Buckling ratio, (0-1)		Buckling stiffness, (0-1)	
			weft	warp	weft	warp		weft	warp	weft	warp
1 - Tunic	Wool	345	368706	489034	1300	1300	1300	0	0	0.20	1.0
2 - Trousers	Wool	345	368706	489034	1300	1300	1300	0	0	0.20	1.0
3 - Belt	Wool	427	512383	269877	2683	5616	3181	0	0	0.20	0.20

To digitize the textile materials of woman's costume, we applied the second approach.

1. The real existing contemporary fabrics were scanned by Epson Perfection to get the images with 1670, 6400 dpi (Fig. 4, a).

2. The scans were uploaded to Substance Alchemist software. Texture maps for each fabric were automatically generated (Fig. 4, b). We applied several commands, such as "Height scale", "Height details scale" and "Roughness value" to ensure the conformity between the texture maps to the existing fabrics.

3. The specimens of the materials were tested by Kawabata Evaluation System KES-F such as tensile, shearing, bending, compression and surface parameters (Table 2). The parameters were converted into Clo3D units and used to control MB of the DTTM. Fig. 4 (c) shows the DTTM from which the woman's costume was made.



a) b) c)

Fig. 4

Table 2

DTTM	Properties												
	Content	Weight, cN/m^2	Tensile energy, cN.cm/cm^2		Tensile resilience, %		Shear rigidity, cN/cm.deg		Bending rigidity, cN.cm^2/cm			Coefficient of friction	
			warp	weft	warp	weft	warp	weft	warp	weft	…	warp	weft
1 -Corset	Polyester	118.7	3.21	4.80	60.94	55.21	0.37	0.66	0.118	0.486		0.180	0.210
2-Upper dress	70% Cotton 30% Polyester	168.4	16.90	1.05	25.44	61.90	0.46	0.83	0.050	0.145		0.189	0.157
3-Skirt	Polyester	161.5	1.70	42.85	82.35	37.81	0.82	0.79	0.019	0.173		0.216	0.220

To evaluate SA, we compared them with the prototypes by sensory analysis. As can be seen in Fig. 3, b and Fig. 4, c, SA of the DTTM is similar to the real fabrics (Fig. 2). Regardless of the approach used to reproduce SA (approaches 1 and 2), DTTM match the prototypes in terms of color, tint, saturation, brightness and glossiness. The geometrical parameters of the weave and the yarns in DTs are the same as in real materials.

To evaluate MB of the DTTM, we used the DTTM to reconstruct the both costumes in virtual reality [12,13]. The dimensions of Salt man 4 garments were measured with a tape to reproduce the new patterns in 2D CAD software. The known patterns of the women costume was digitized and vectorized in the same 2D CAD software. The accuracy of both patterns is ±1 mm. The same parameters for cloth simulation in Clo3D software were used for both costumes: the gravitational acceleration of 9.8 m/s^2, the time step of 0,03 s, the particle distance of 3 mm and the additional thickness – collision of 0.1 mm. Fig. 5, a, c shows the digital reconstructions of the costumes. We measured the deviations between the overlapped contours of the virtual twins (Fig. 5, a, c) and the real garments (Fig. 2). The contours were extracted from the 2D images, vectorized and overlapped in 2D CAD software. Fig. 5, b, d shows the virtual twins.

a)

b)

Fig. 5

The virtual twin of women costume was overlapped with the photo of its real prototype. We estimated that the average deviation between two contours was 10.1 mm (the range is 0.2...23.5 mm). Such high level of virtual twin accuracy is the result of influencing by the physical and mechanical properties of real textile materials.

So, both reconstructions proved the rightness of second approach in terms of MB. We detected three major reasons that lie behind these deviations.

1) The randomness inherent for fabric draping. Digital textiles do not drape in the same way twice, just as real ones due to cloth physics computations. Many variables are used to calculate the position of each particle (vertex) on the surface of the garment several times per frame. The resulted position is calculated as the average value [1].

2) The imperfect mechanics of the virtual simulation. As Jevšnik et al. [3] mention that the mass-spring system used in particle-based models which control the behavior of virtual textiles cannot accurately represent the way in which yarns in the actual textile materials deform and interact with each other.

3) The insufficiency of physical and mechanical properties used to generate DTTM. The methods of fabric testing used in contemporary apparel industry [4] were initially developed to analyze textile materials and compare them. This is in line with works by Kuijpers et al. [2] and Sanad and Cassidy [5], which show that the existing list of characteristic values does not allow the draping process to be reproduced accurately.

CONCLUSIONS

1. A new method for digitizing textile materials of historical costumes was developed. The method uses two different approaches to generate digital twins of textile fabrics. The first approach is based on digital analogs of historical textiles, doesn’t require specimens of textiles to be tested and, thus, can be applied to archaeological and historical textile matertials. The second approach is based on 2D scanning, non-procedural texturing and testing on real fabric and intended for transforming similar contemporary fabrics into thier digital twins to reconstruct the historical garments.

2. The method was applied to generate two DTTM dating to the IVth century BC and three DTTM dating to the XIXth century in terms of surface appearance and mechanical behaviour of the prototypes.

ЛИТЕРАТУРА

1. *Keckeisen M.* Physical Cloth Simulation and Applications for the Visualization, Virtual Try-On, and Interactive Design of Garments. – Tübingen: Eberhard-Karls-Universität Tübingen, 2005.

2. *Kuijpers S., LuibleBär C., Gong H.* The measurement of fabric properties for virtual simulation: a critical review // IEEE SA industry connections, pp. 1-43. Available from https://standards.ieee.org/content/dam/ieee-standards/standards/web/governance/iccom/3D BP Measurement_of_fabric_properties.pdf (Accessed 15.07.2021).

3. *Jevšnik S., Kalaoglu F., Terliksiz S., & Purgaj J.* (2014). Review of Computer Models for Fabric Simulation // Tekstilec. – 2014. 57(4). P. 300…314.

4. *Hu J.* Fabric testing. – Cambridge: Woodhead Publishing, 2008.

5. *Sanad R.A., Cassidy T.* Fabric Objective Measurement and Drape // Textile Progress. – 2016. 47 (4). P. 317…406.

6. *Kuzmichev V., Moskvin A., Moskvina M., Pryor J.* Research on 3D reconstruction of late Victorian riding skirts // International Journal of Clothing Science and Technology. – 2018. - Vol. 30 Issue: 6. - pp. 790-807. DOI: https://doi.org/10.1108/IJCST-12-2017-0192.

7. *Wijnhoven M.A., Moskvin A.* Digital replication and reconstruction of mail armour // Journal of Cultural Heritage. – 2020. - №45. P. 221…233, DOI: 10.1016/j.culher.2020.04.010

8. *Cybulska M.* To see the unseen. Computer graphics in visualization and reconstruction of archaeological and historical textiles. - In: N. Mukai, ed., Computer graphics. - Rijeka: InTech, 2012. P. 213…228.

9. *Moskvin A., Kuzmichev V., Moskvina M.* Digital replicas of historical skirts // The Journal of The Textile Institute. – 2019. – Vol. 110 Issue 12. P. 1810…1826.

10. *Zhang S.C., Kuzmichev V.* A Method of selection the textile materials for virtual reconstruction // IOP Conference series materials science and engineering 811:012008. – 2020. DOI: 10.1088/1757-899X/811/1/012008

11. *Aali A., Stöllner T., Abar A. and Rühli F.* The salt men of Iran. The salt mine of Douzlakh, Chehrābād // Archäologisches Korrespondenzblatt. – 2012. 42(1). P. 61…81.

12. *Moskvin A., Moskvina M., Kuzmichev V.* Digitale Rekonstruktion von Salzmann 4 / Tod im Salz – Eine archäologische Ermittlung in Persien: Begleitbuch, Katalog und Graphic Novel (T. Stöllner, A. Aali, and N. Bagherpour Kashani (eds.)). Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum. – 2020. №246. P. 161…164.

13. *Москвин А.Ю., Кузьмичев В.Е.* Виртуальная и материальная реконструкция костюмов, представленных на русских лубочных картинках // Мат. XXIV Междунар. научн. конф.: Мода и дизайн: исторический опыт - новые технологии. – СПб.: СПбГУПТД. – 2021. С. 75...78.

REFERENCES

1. Keckeisen M. Physical Cloth Simulation and Applications for the Visualization, Virtual Try-On, and Interactive Design of Garments. – Tübingen: Eberhard-Karls-Universität Tübingen, 2005.

2. Kuijpers S., LuibleBär C., Gong H. The measurement of fabric properties for virtual simulation: a critical review // IEEE SA industry connections, pp. 1-43. Available from https://standards.ieee.org/content/dam/ieee-standards/standards/web/governance/ iccom/3D BP Measurement_of_fabric_properties.pdf (Accessed 15.07.2021).

3. Jevšnik S., Kalaoglu F., Terliksiz S., & Purgaj J. (2014). Review of Computer Models for Fabric Simulation // Tekstilec. – 2014. 57(4). P. 300…314.

4. Hu J. Fabric testing. – Cambridge: Woodhead Publishing, 2008.

5. Sanad R.A., Cassidy T. Fabric Objective Measurement and Drape // Textile Progress. – 2016. 47 (4). P. 317…406.

6. Kuzmichev V., Moskvin A., Moskvina M., Pryor J. Research on 3D reconstruction of late Victorian riding skirts // International Journal of Clothing Science and Technology. – 2018. - Vol. 30 Issue: 6. - pp. 790-807. DOI: https://doi.org/10.1108/IJCST-12-2017-0192.

7. Wijnhoven M.A., Moskvin A. Digital replication and reconstruction of mail armour // Journal of Cultural Heritage. – 2020. - №45. P. 221…233, DOI: 10.1016/j.culher.2020.04.010

8. Cybulska M. To see the unseen. Computer graphics in visualization and reconstruction of archaeological and historical textiles. - In: N. Mukai, ed., Computer graphics. - Rijeka: InTech, 2012. P. 213…228.

9. Moskvin A., Kuzmichev V., Moskvina M. Digital replicas of historical skirts // The Journal of The Textile Institute. – 2019. – Vol. 110 Issue 12. P. 1810…1826.

10. Zhang S.C., Kuzmichev V. A Method of selection the textile materials for virtual reconstruction // IOP Conference series materials science and engineering 811:012008. – 2020. DOI: 10.1088/1757-899X/811/1/012008

11. Aali A., Stöllner T., Abar A. and Rühli F. The salt men of Iran. The salt mine of Douzlakh, Chehrābād // Archäologisches Korrespondenzblatt. – 2012. 42(1). P. 61…81.

12. Moskvin A., Moskvina M., Kuzmichev V. Digitale Rekonstruktion von Salzmann 4 / Tod im Salz – Eine archäologische Ermittlung in Persien: Begleitbuch, Katalog und Graphic Novel (T. Stöllner, A. Aali, and N. Bagherpour Kashani (eds.)). Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum. – 2020. №246. P. 161…164.

13. Moskvin A.Yu., Kuzmichev V.E. Virtual and material reconstruction of costumes presented in Russian popular prints // Mat. XXIV Intern. scientific Conf.: Fashion and design: historical experience - new technologies. - St. Petersburg: SPbGUPTD. – 2021. P. 75...78

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