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3D VIRTUAL PROTOTYPING OF A SKI JUMPSUIT BASED ON A RECONSTRUCTED BODY SCAN MODEL

BY

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Abstract. 3D virtual prototyping become a topic of increasing interest of both computer graphics and computer-aided design for apparel production. These technologies are especially important when a garment prototype should be developed for a special purpose, such as ski-jumper suit. Namely, shape and size of a jumpsuit need to be individually adapted to each ski-jumper according to the exact requirements set by FIS (Féderation Internationale de Ski). The FIS requirements change annually or even more often in order to assure ski-jumpers' safety during competitive ski jumps. The conventional body measurement technique and development of ski-jumpers pattern are time consuming. In order to develop an accurate and rapid design, as well as an adaptable and quickly changeable jumpsuit, different modern technologies were used. The obtained virtual prototypes of a ski-jumper and a jumpsuit enable both - fast re-modelling according to FIS rules and expeditious development and/or simulations of a jumpsuit. All these measures are taken to improve the aerodynamic design of a suit and jumper's result.

The body scanning technology represents a great potential for textile industries and above all for producers of garments. It enables fast and reliable capture of 3D body data and extraction of precise measurements needed for design, construction, visualisation and animation of garments on virtual

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mannequins. However, there are also some problems related to the scanned body models, caused by the scanning technique. In this article we are discussing the techniques for reconstruction of the body models and its results using the example from one of the competitive sports clothing - ski-jumper suit.

In our study we have used different computer graphics programmes in order to reconstruct and prepare the 3D body scan model for successfully importing it into OptiTex CAD programme. The aim of this research was to enable effective 3D virtual garment prototyping using the reconstructed body scan model.

Key words: Virtual prototyping, ski jumpsuit, 3D body scanner, 3D software packages, Optitex.

1. Introduction and Motivation for the Study

The form of a jumpsuit, type of material and its production prescribes the international organization Fédération Internationale de Ski (FIS) (www.fis-ski.com) with the aim to assure the ski jumper safety. The jumpsuit pattern should be adjusted to the individual jumper (www.fis-ski.com/data/document/edition1011.pdf). The process requests from the pattern designer great struggle, while composed numerous iterative processes when preparing the basic pattern and modelling, as well as sewing of the prototypes.

The application of computer aided design (CAD) intended for garments development and their virtual prototyping has become an obvious trend in many of industries recently. Nowadays, the virtual prototyping allows us an accurate and rapid development of garments, as well as adaptable and quickly changeable garments (Rudolf *et al.*, 2008; Rudolf *et al.*, 2009).

Virtual garment simulation is the result of a large combination of techniques that have also dramatically evolved during the last decade. Unlike the mechanical models used for existing mechanical engineering for simulating deformable structures, a lot of new challenges arise from highly versatile nature of cloth. The central pillar of garment simulation presents the efficient mechanical simulation model, which can accurately reproduce the specific mechanical properties of the cloth. The cloth is by nature highly deformable, therefore the mechanical representation should be accurate enough to deal with the nonlinearities and large deformations occurring at any place in the cloth, such as folds and wrinkles. Moreover, the garment cloth interacts strongly with the body that wears it (Volino *et al.*, 2005).

Three-dimensional body model is critical for the virtual try-on system and has a strong impact on complexity and effect of a garment simulation. Therefore, the study of 3D body modelling has a great potential in both research and application. It is well know that commonly used methods include non-uniform rational basis spline (NURBS), manual modelling and 3D body scanning. 3D body scanning has become prevalent since 3D scanning technology is introduced into garment industry. It provides a realistic 3D body model on the basis of raw body scan data.

The development of a specific sportswear for professional purposes, such as competitive ski jumper suit, should base on the virtual prototyping and real simulation of garment behaviour in virtual environment on real 3D body model, gained by scanning technology. This allows us an effective individual treatment of a sportsman and effective development of a competitive jumpsuit taking into account the changeable demands. Since because of the safety reasons the FIS requirements for jumpsuit construction change annually or even more often, the main aim of the research is to introduce an accurate and rapid process for development of the individual ski jumper suit.

2. Experimental Part

Within the research course, we performed different activities, e.i. 3D scanning of the professional ski jumper's body and determination of body measures, jumpsuit pattern design, reconstruction of the 3D body model and jumpsuit simulations were done by using measured mechanical properties of the laminate for jumpsuit, Fig. 1. Furthermore, the real jumpsuit was sewn according to the FIS demands with the intention to make a comparison between the real and virtual jumpsuit prototype fitting (Rudolf *et al.*, 2010; Stjepanovič *et al.*, 2010).

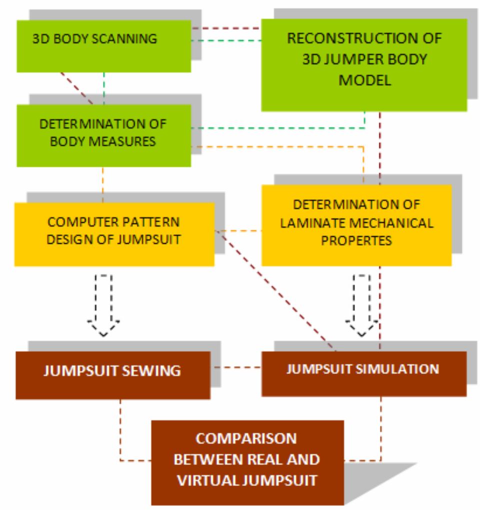


Fig. 1 – Diagram of the jumpsuit development process.

2.1. 3D Body Scanning

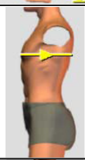
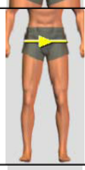
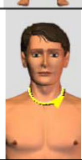
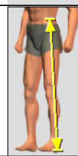
3D body scanning of the professional ski jumper was performed on 3D body scanner Vitus Smart at the Textile Technology Faculty, University of

Zagreb, Croatia. The scanner consists of 8 cameras that provide 500 000 to 600 000 points (point cloud). After that, the body measures were taken using the programme package ScanWorx V 2.7.2.

The determined body measures and measuring positions of one of the Slovenian ski jumpers are presented in Table 1.

Table 1

Body Measures Resulted from 3D Body Scanning Body

Body measure	Ski jumper measure (cm)	Measuring position	Body measure	Ski jumper measure (cm)	Measuring position
Body high	172,9		Length armpit-waist	19,6	
Chest circumference	89,1		Hip depth	22,2	
Waist circumference	64,7		Wrist circumference	15,3	
Hip circumference	93,1		High thigh circumference	52,1	
Neck circumference	39,8		Knee circumference	36,4 cm	
Length crotch-floor	75,7		Length waist-floor	110,2	
Hand length (7. neck vertebra – wrist)	82,8		Ankle circumference	28,4	

2.2. Jumpsuit Pattern Design

The jumpsuit pattern design was performed according to the FIS requirements (www.fis-ski.com/data/document/edition1011.pdf), Fig. 2, by using the ski jumper body measures. Optitex computer programme package was used to design the jumpsuit patterns (Stanc *et al.*, 2005, www.optitex.com/ en/products/main_modules).

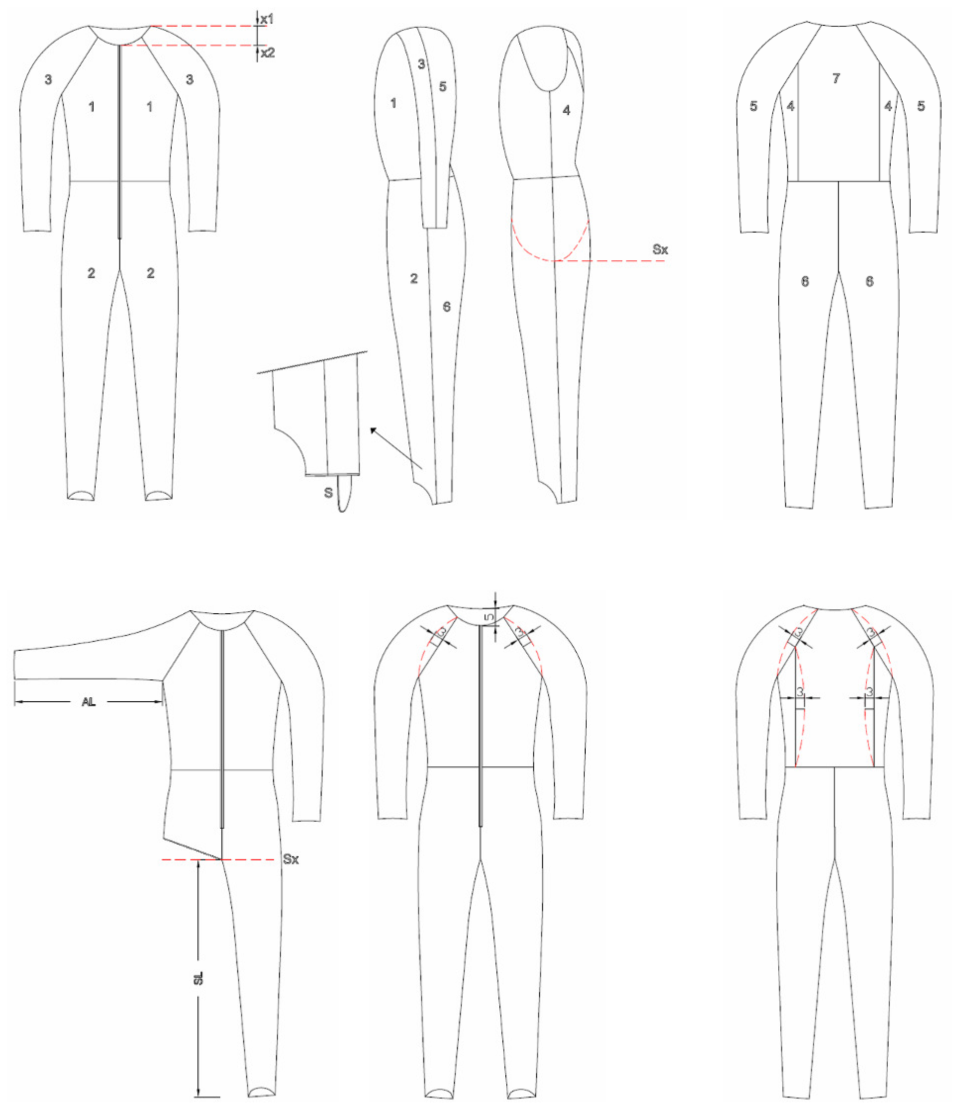


Fig. 2 − Jumpsuit patterns according to FIS regulations (www.fis-ski.com/data/document/edition1011.pdf).

2.3. Mechanical Properties of a Laminated Fabric

The prototype of the ski jumper suit was made from a five-layer laminated fabric that consists of the followings (www.fis-ski.com/data/document/edition1011.pdf):

− first layer: outer fabric;
− second layer: foam;
− third layer: elastic membrane;
− fourth layer: foam;
− fifth layer: lining fabric.

The components are laminated together by either a hot-melt process or flame lamination, where 4 acts are necessary to laminate the fabric. The outer fabric and lining fabric is a bi-elastic warp-knit fabric, called Charmeuse, which is produced on a 2-thread system warp knitting machine.

To obtain the realistic virtual prototype of the ski jumpsuit the measurements of the mechanical properties of the laminated fabric were done by using the FAST measuring system (De Boss, 1991). The measuring results of the mechanical properties of the laminated fabric were converted by using the Fabric Converter programme and for simulation of the laminate draping and jumpsuit fitting were carried out by OptiTex programm, Table 2.

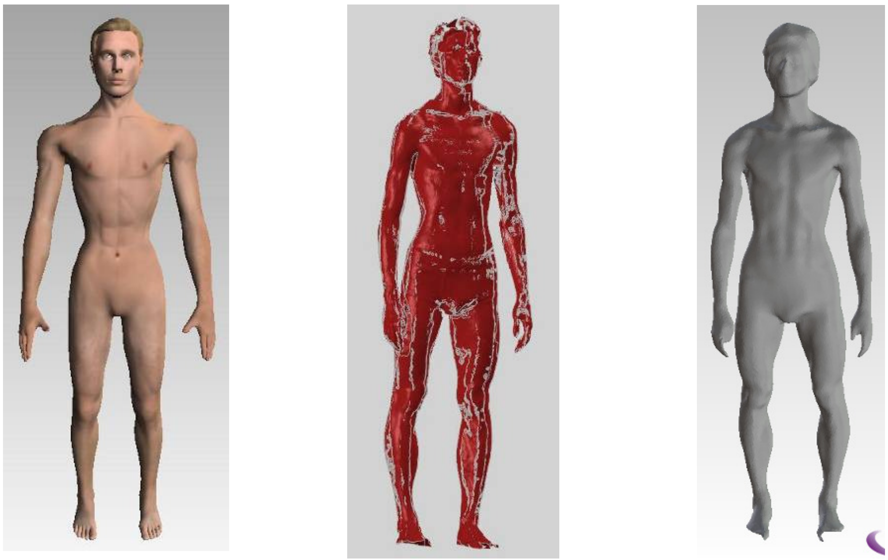
Table 2
Mechanical Properties of the Laminated Fabric Measured by FAST Measuring System and Converted Properties for Jumpsuit Simulation Using OptiTex Programme

Properties	Measured value			OptiTex parameters		
	Unit	Course d.	Wale d.	Unit	Course d.	Wale d.
Extension at load of 98.1 Nm^{-1}/E 100	[%]	9.6	10.9	[gcm^{-2}]	400.641	352.858
Bending rigidity/B	[μN·m]	44.8	54.5	[dyn*cm]	4965	
Shear rigidity/G	[Nm^{-1}]	199		[dyn*cm]	1990	
Surface thickness/ST	[mm]	0.035		[cm]	0.0035	
Mass per unit area/W	[gm^{-2}]	601		[gm^{-2}]	601	

2.4. 3D Body Scan Model Reconstruction

In our research we firstly used the parametric 3D body model of a ski jumper, determined with body measures obtained by the scanner, for virtual simulation of a jumpsuit. The parametric model was defined using the following measures: body high, chest circumference, waist circumference, neck circumference, length crotch-floor, high thigh circumference, knee circumference, shoulders width, shoulder slope, upper arm circumference and arm length. A great deviation between the parametric 3D body model, Fig. 3 *a*, and scanned 3D body model of the ski jumper is obvious. Therefore, we decided to use the scanned 3D body model of a ski-jumper for simulation of the ski jumpsuit prototype, Fig. 3 *c*.

The process of generation of the scanned 3D body model involved the body reconstruction. Namely, 3D scanner cannot produce sufficient scan data, which results in defected body model, Figure 3b, that influences the jumpsuit fitting. For this reason the reconstruction of the scanned 3D body model of the ski jumper was performed by using the programs Atos, Rhino 4, Netfabb and MeshLab.



a *b* *c*

Fig. 3 − Parametric 3D body model (*a*), scanned 3D body model showing defects (*b*) and reconstructed 3D body model (*c*).

2.5. Virtual Simulation and Production of a Jumpsuit

The sewing of a real ski jumpsuit by considering the FIS requirements, ex. seams, seam allowance, zip length and width, as well as requirements for sewing the neck line, sleeve length and trouser length was carried out on a Dürkopp sewing machine 271.

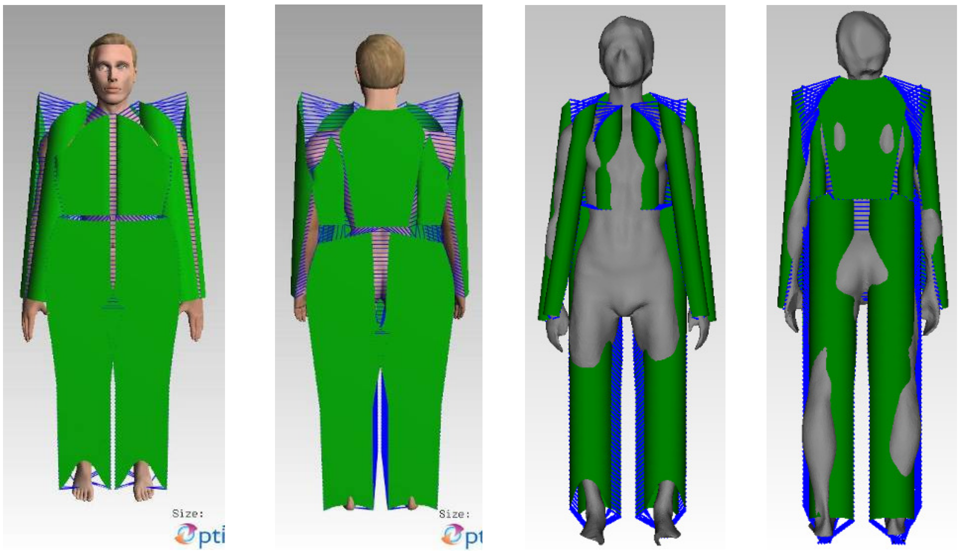
For the 3D virtual simulation of the competitive prototype of the ski jumper suit it was necessary to define the jumpsuit patterns by:

− type and position of the individual pattern regarding the virtual mannequin (*e.g*. front part, back part, right sleeve etc.),

− measured mechanical properties of the laminated fabric for all jumpsuit patterns and

− seam lines for stitching the patterns on the (*a*) parametric 3D body model and (*b*) scanned 3D model of ski jumper, Fig. 4.

Furthermore, the comparison of the ski jumper suit between the real prototype, simulated jumpsuit prototype on the parametric 3D body model and simulated jumpsuit prototype on scanned 3D body model of the ski jumper was performed.



a *b*

Fig. 4 − Positioning of the jumpsuit patterns on parametric (*a*) and scanned 3D body model (*b*), and appointed seams for stitching.

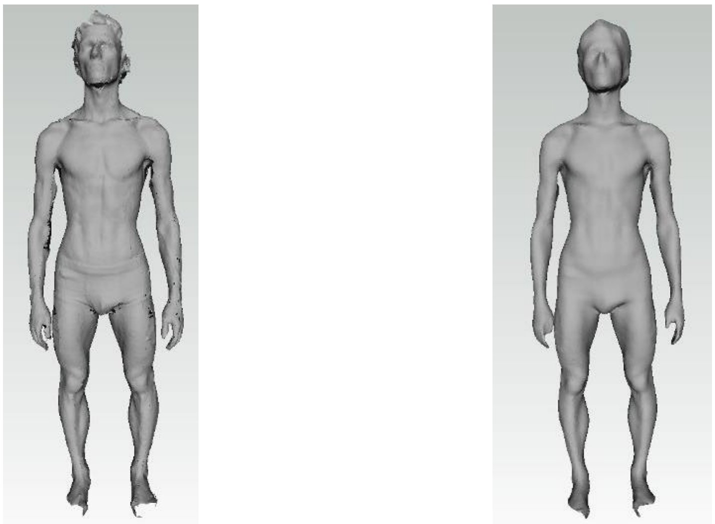
3. Results and Discussions

3.1. Results Related to the Reconstruction of a Scanned 3D Ski Jumper Body Model

Reconstruction of the ski jumper 3D body model was realized by different 3D computer programmes (Rhinoceros, 2002; http: meshlab.sourceforge. net/wiki/index.php/MeshLab_Documentation; ATOS User Manual v6; http://wiki.netfabb.com/Main_Page#Information). Programme ATOS was used first, Fig. 5. Number of polygons was reduced from about 660 000 to 150 000 triangles using the tool Thin Mesh. Then the mesh was repaired and holes were filled with the tools Repairing Mesh, Regularize Mesh, Eliminate Mesh Errors, Relax Mesh and Fill Holes. Several operations were repeated in order to reduce mesh errors. The mesh was then exported as a binary .stl file.

Fig. 5 – Reducing number of polygons and repairing the mesh in programme ATOS.

Then MeshLab programme was used. Mesh imported from ATOS was still not watertight and totally uniform, Fig. 6 *a*. Therefore, a tool Surface Reconstruction: Poisson was used. This tool makes from more partly overlapped meshes one uniform average mesh. There are less details included, but we got properly mesh for further work. The mesh was then exported as a .stl file again.



a *b*

Fig. 6 – Surface reconstruction.

Rhinoceros program was used after that. The whole object was scaled and properly rotated, Fig. 7. Programme NetFabb Basic was used for the final test and view of the model. This was the last step before importation of the scanned 3D body model into the OptiTex programme for clothes simulation.

The scanned 3D body model of the ski jumper imported in OptiTex programme is presented in Fig. 8.

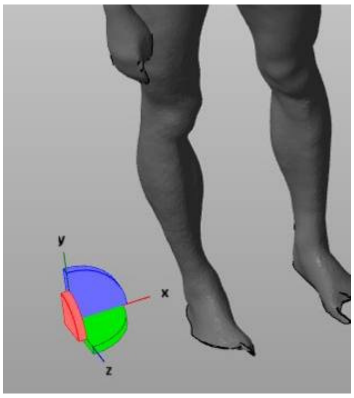
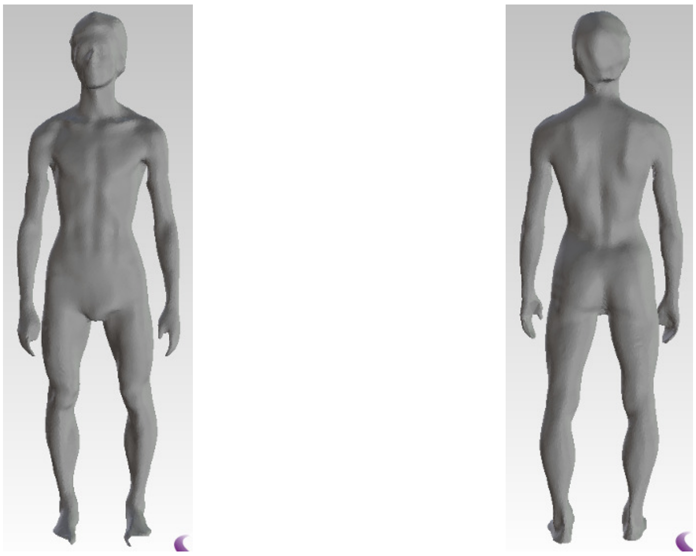


Fig. 7 − Scaled and rotated object.



a *b*

Fig. 8 − Reconstructed and imported scanned 3D body model of a ski jumper in OptiTex programme.

3.2. Comparison of Virtual Prototyping Results Using Parametric and Scanned Body Models

The computer simulation of the ski jumpsuit prototype was made using the parametric 3D body model and reconstructed scanned 3D body model, Figs. 9 and 10. In order to assure appropriate simulation of the jumpsuit different positioning and adjustment of the patterns regarding the parametric 3D body model and scanned 3D body model should be performed, Fig. 4. The reasons for this are different postures of the 3D body models. With the aim to make a proper comparison of virtual and real jumpsuit, we produced a real prototype using the materials and patterns explained in pt. 2 of the article. When estimating the fitting of the jumpsuit the estimation of the neck line, shoulder area and armpit front and back, as well as form of the sleeves, trousers and waist area were carried out.

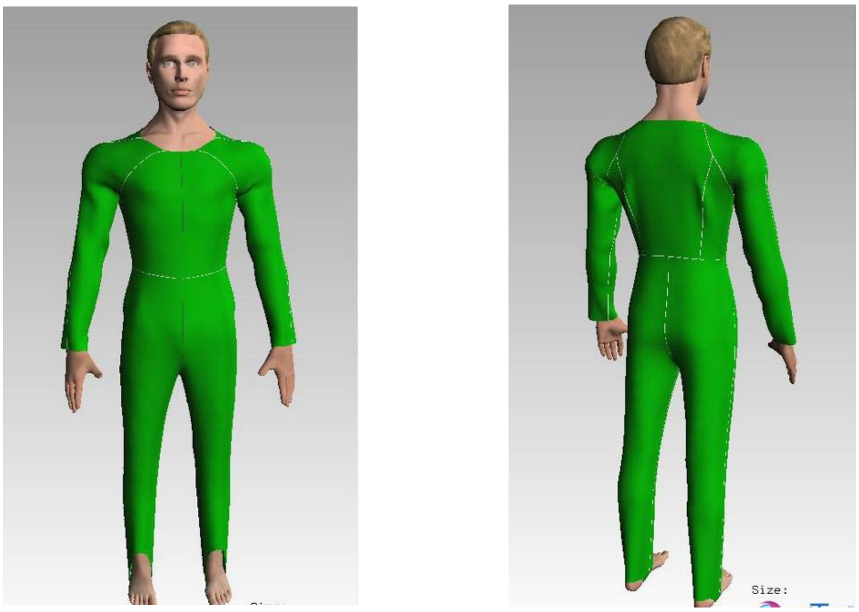


Fig. 9 − Simulation of the ski jumper suit on the 3D parametric body model.

The neck line on the virtual model is after simulation extended when compared with the real prototype, Figs. 9 and 10. Difference arises because of the draping of the laminate in the neck area on a parametric virtual mannequin. The real jumpsuit has the neck line made with non-elastic band. Considering the real material properties in this area, the simulation result on the scanned 3D body model is improved, Fig. 10.

The folds originate on the back part of the jumpsuit seams and sleeve seams, as well as in the armpit area. These folds present expansion considered in the seams areas (+ 1.5 cm) to achieve appropriate aerodynamic form of the jumpsuit during the jump of the ski jumper. When taking the closer view of the folds in the armpit area, we could see the additional transverse fold that reflects through the parametric mannequin anomaly in the high chest circumference, Fig. 9, while this fold doesn't appear when simulating the jumpsuit on a scanned 3D body model of the ski jumper, Fig. 10.

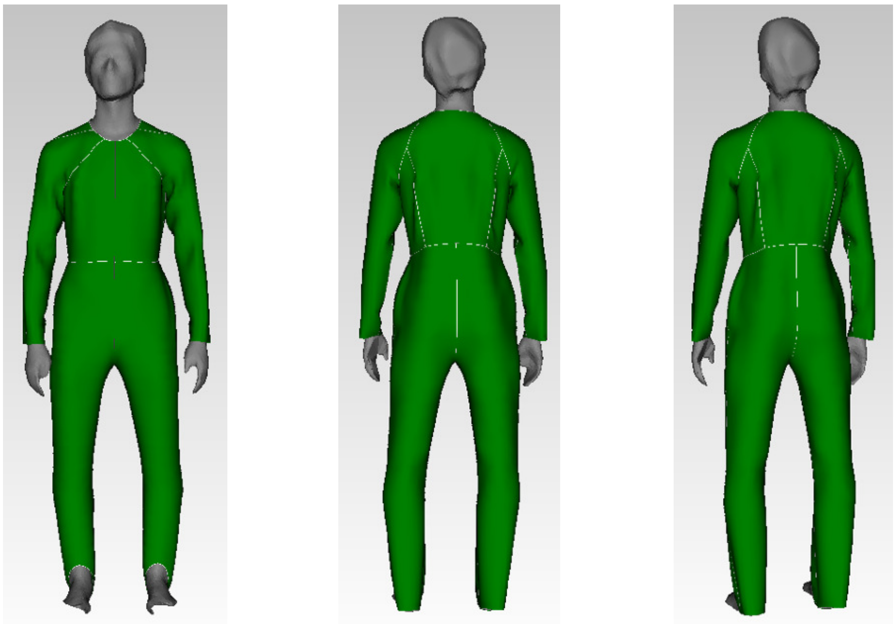


Fig. 10 – Simulation of the jumpsuit on the real 3D body model of the ski jumper.

When analysing the simulated jumpsuits in the waist area, an additional fold in the area of waist and buttock area appears, Fig. 10, while it isn't visible when simulating the jumpsuit on a parametric 3D body model, Fig. 9. The appearance of the bottom part of the jumpsuit is smooth and gives us the filling of tension and discomfort, Fig. 9. On the other hand the real jumpsuit and simulated jumpsuit on a scanned 3D body model of the ski jumper expresses non-stretched trousers and assures felling of a good comfort and requested width in this area.

The form and fitting of the sleeves are very similar on all of prototypes with the exception the shoulder and armpit area, because of the anomalies of the parametric mannequin. Additional folds on sleeves appear in elbow area. These are visible on real and simulated jumpsuit on scanned 3D body model, Fig. 10, while they are not visible on a parametric body model because of the stretched arms, Fig. 9.

4. Conclusions

In this article we presented the process of 3D virtual prototyping of a ski jumpsuit based on a reconstructed body scan model. Based on the analysis of a visual appearance of two virtual (parametric and scanned) and real model of a ski-jumper suit it can be concluded that the differences occur above all because of significant differences in the form of a parametric body model and consequently the fitting of a laminated textile material. When using a parametric body model, we can set only certain body measures, which proved not to be enough for a realistic appearance and similarity with the real body model. Therefore, we used a scanned 3D body model of a real ski-jumper for a better and more realistic simulation of a jumping suit. For this purpose we carried out the reconstruction of a surface of a 3D ski-jumper's body model. Then, we transformed the data into a suitable format in order to import it into Optitex programme, which enabled an efficient and realistic simulation of a suit prototype.

Cognitions, related to the deviations of the appearance and fit of a virtual and real prototype of a jump suit clearly show the need for using a real 3D body model, originating from the body scanning process, if we want to achieve improved pattern development and more realistic simulation of garments in general. This is particularly important in competitive sports, where already slight improvements in professional equipment and clothing mean a great advantage. The research has proved that virtual 3D prototyping can be successfully used for efficient and rapid planning and simulation of competitive clothing for winter sports professionals.

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PROTOTIPAREA 3D A UNUI COSTUM DE SCHI FOLOSIND UN MODEL DE CORP SCANAT

(Rezumat)

Prototiparea 3D a devenit un subiect cu interes pentru industria de confecţii, atât din punct de vedere al graficii, cât şi al proiectării asistate de calculator. Aceste tehnici sunt şi mai importante în cazul produselor speciale, precum un costum folosit pentru salturi cu schiuri. Concret, forma şi dimensiunile unui astfel de costum trebuie adaptate la fiecare purtător, conform cerinţelor stabilite de FIS (Féderation Internationale de Ski). Cerinţele FIS sunt modificate anual şi chiar mai des, astfel încât să garanteze siguranţa sportivilor pe durata competiţiilor. Tehnicile convenţionale de stabilire a dimensiunilor corpului şi de construire a tiparelor necesită timp îndelungat. Pentru a dezvolta o proiectare precisă şi rapidă pentru un costum adaptabil la cerinţe, trebuie utilizate tehnici moderne. Prototipurile virtuale obţinute pentru sportiv şi costum permit atât remodelarea rapidă conform regulilor FIS, cât şi dezvoltarea şi/sau simularea costumelor în cel mai scurt timp. Toate acestea contribuie la îmbunătăţirea aerodinamicii costumelor şi a rezultatelor obţinute de sportivi.

Tehnicile de scanare a corpului prezintă un potenţial deosebit pentru industria textilă, mai ales pentru producătorii de îmbrăcăminte. Ele permit preluarea rapidă şi precisă a datelor 3D despre corp şi stabilirea dimensiunilor necesare pentru proiectarea, vizualizarea şi animarea produselor de îmbrăcăminte pe manechine virtuale. Totuşi, tehnica de scanare folosită determină unele probleme legate de modelarea corpului. Lucrarea discută tehnici de reconstrucţie a modelelor pentru corpul uman şi rezultatele obţinute folosind ca exemplu un produs pentru un sport competitiv – un costum pentru sărituri cu schiurile.

Studiul prezentat foloseşte diferite programe grafice pentru a putea reconstrui şi pregăti modelul scanat 3D pentru a fi importat fără probleme de programul OptiTex. Scopul acestei cercetări este de a permite prototiparea virtuală 3D a produselor de îmbrăcăminte utilizând modele reconstruite în baza scanării corpului.