Digital twin and men's underwear design

Z Cheng\textsuperscript{1,2,3} and V E Kuzmichev\textsuperscript{1,2,3}
\textsuperscript{1} Fashion of School, Wuhan Textile University, Fangzhi Road, Wuhan, Hubei, China
\textsuperscript{2} Textile Institute, Ivanovo State Polytechnic University, 21, Sheremetev Av., Ivanovo, Russian Federation
\textsuperscript{3} Wuhan Textile and Clothing Digital Engineering Technology Research Center
zcheng@wtu.edu.cn, wkd37@list.ru

Abstract. Based on 3D body scanning technology, KES properties of real knitted materials, new body measurements for digital twin generating, we developed the virtual method of men’s underwear try-on. The results show that by means of virtual software 3D CLO we can simulate well the body characteristic, the underwear structure, the knitted material elongation, and the compression pressure distribution. New underwear design can have a good presentation in customization and mass production.

Key words: men’s underwear design; 3D simulation; digital twin; pressure; knitted material

1. Introduction
The current 3D simulation technology provides great convenience for apparel design and product development [1, 2]. Advances in 3D simulation technology can be used for clothing suitability assess. But there is only a small number of researches on tight-fitting clothing and few studies between male virtual body and knitted underwear. Most of the 3D simulation is about the design of clothing 2D pattern or the choice of material, few studies are concerned on “body-clothing” system. Many studies focus on some loose-fitting clothing that does not directly contact with human skin. Only a few studies on tight-fitting clothing, or between male virtual body and knitted underwear.

Most of 3D simulations are only about the common clothing pattern or the material simulation [3]. Few studies are concerned on system “body-clothing” and tight-fitting/compression clothing [4, 5]. The negative ease allowance is often designing required because the tight-fitting underwear fitness truly reflects the human body morphology [6]. Nowadays, men’s compression underwear also needs to be customized due to different needs, comfortable satisfaction, and shape characteristics [7, 8]. For this purpose, we examine the system “body-underwear” from several points of view such as structure, wearing effect, material deformation, and pressure distribution. We also compared various underwear sizes with corresponding body to verify our new classification of body size.

2. Experimental methods and steps
This study includes 3D body scanning measurements, 2D&3D underwear structure design, virtual materials analysis, pattern, pressure evaluation etc.
We used VITUS Smart 3D body scanner to measure 115 Chinese (18...28 age young males) and test 14 kinds of knitted materials by KES. Some basic research has been done before to establish databases of reasonable pressure values, ease range etc. [9]. We cut 14 kinds of knitted materials “shell” and make underwear to measure pressure values (38 points per piece) on one hand. We use the software CLO 4.1 to simulate these 14 kinds of knitted materials to check its pressure values accuracy and reliability, then build virtual underwear on another hand. After, we compare the difference of real and virtual pressure values to obtain the error value. Next, we used new method of underwear design (for basic types), build virtual underwear in 12 sizes S, S, S+, S++, M...L++, and change its eases from -20 to 0 %, the S, M, L is size to describe the hip girth, “+” and “−” are different type of waist girth and other details.

![Figure 1. Flow chart](image)

3. Reconstruction of human models
The 160 men scanned and reclassified according to their body features. Figure 2(a) shows three male profiles. We can see that the shape of the profile is very different, even at the same size M.

So, we used software of MakeHuman (see Figure 2b) to establish S, M, L sizes virtual male bodies (see Figure 2c), the male genitalia are set to the same at here. It can be clearly seen from the profiles that different waist sizes have different shape on the part of abdomen and the back of the body, when the hip circumference is the same. Therefore, a more detailed classification with the S, M, L number is necessary.

Then, we try on a variety of virtual bodies to test the pattern of underwear designed for more detailed body shape. Figure 2(c) are virtual models meets the average size of our classification, covers the genital area for lower torso of the body. Finally, the “obj” human model file is imported into the CLO software for subsequent simulation work.

![(a)](image)
Figure 2. 3D Human lower torso models: (a) – 3D scanning body; (b) – size modification; (c) – virtual body

4. Materials pressure error between real and virtual

4.1. Software parameter correction for material

Form the simulations of 14 kinds virtual materials, we adjust the parameters and put the KES results into CLO 4.1. Such as the options material’s “detail”, the best way is take the material parameters $G$ (shear stiffness), thickness and density into these 3 options of “stretch”, “shear”, “thickness” and “density”.

After this, we simulate the knitted material properties and measure pressure values (see Figure 3b).

Figure 3. Material simulation for virtual pressure test

4.2. Virtual pressure test

We have test nearly 5000 virtual pressure value data (PV) in knitted materials two yarn directions on 7 parts of virtual body. The simulated virtual pressure (PV) is 0.14–2.13 kPa (the real pressure on human body PB is 0.05–2.31 kPa) with knitted materials elongated from -20.0 to -5.0% in warp and pressure is 0.00–2.82 kPa (PB is 0.13–2.02 kPa) in weft. As shown in Figure 4(a), there are definite correlations between PB and PV of 14 knitted materials, which means that there are certain connections between them and the simulated pressure are feasible, but the error needs to be corrected.

As shown in Figure 4(b), we find that the knitted materials elongated value from -15.0 to -10.0% has the largest difference from -0.26 to 0.24 kPa, and lines intersect at -12.5%; in total, as for average is ± 0.19 kPa error.

Then, we build virtual underwear and measure virtual pressure PV′, from ease -20.0 to -5.0%, the result as shown in Figure 4(b).
Figure 4. Paired pressure values on body (PB) and virtual (PV): (a) – 14 knitted materials, (b) – elongated (ease) during -20.0…0.0%

4.3. Pattern adjustment and test

After, we checked the underwear pattern test the virtual pressure sensibility and underwear deformation at various parts. Figure 5(a) shows the virtual underwear try on in front view. We clearly see that there is an excessive pressure (red color) at the crotch part and front belt. We need to further modify this original pattern. Figure 5(a) left shows the modified front crotch part and belt length of the pattern (increased to the red), after this, we measured the pressure is lower than before and the deformation at crotch part is changed to 32.8…41.2%, see Figure 5(b) right. Figure 5(c, d) shows the back view. 2D pattern and 3D simulation are also shown. The crotch part of back pattern has also been modified.

Figure 5. Basic type underwear simulations: (a) – front part modify; (b) – front part pressure and material defamation; (c) – back part modify; (d) – back part pressure and material defamation

4.4. Underwear comfort evaluation and grade

Figure 6 shows the several examples of pairing test of multiple sizes, pressure distributions and the rating evaluations. As for this, five grades are applicable to evaluate the compression underwear from low pressure to high. The range includes five grades: 1 (very low pressure/loose), 2 (low pressure/a little loose), 3 (comfort pressure/close-fit), 4 (high pressure/very close-fit), 5 (very high pressure/extra
close-fit) to evaluate the final score which was equal to the average grades measured in six parts per underwear. During the 2-4 is fit, 4-5 also fit, just feeling tight.

![Figure 6. Virtual evaluation of pressure distribution when underwear has the ease = -19.5%: (a) different sizes underwear on S body; (b) same sizes S underwear on different bodies](image)

### 5. Conclusion

By adjusting the virtual body dimensions to fit our new classification, we build a variety of virtual human models with different sizes and male characteristic. We use 3D simulation technology to test our new patterns on virtual bodies. After our correction, the CLO software can simulate well. The simulation experiment demonstrates the rationality of our design method and classifications. The body wears matching underwear size performed the best fitting and reasonable pressure distribution. Next, we will apply these results to the underwear factory for the verification of real products.

### Acknowledgments

This work is supported by China Wuhan I’d Co., Ltd. and Russian Ministry of Science and Education under the project № 2.2425.2017/4.6 “Development of software for virtual design of system ‘body-clothes’ in static and dynamic and for virtual try-on FashionNet”.

### References

[1] Loker S and Ashdown S 2005 Size-specific analysis of body scan data to improve apparel fit Journal of Textile and Apparel Technology and Management vol 4 pp 1–15

[2] Hwalin S 2016 Fitting simulation evaluation on personalized avatars Journal of Textile Engineering & Fashion Technology vol 4 pp 125–130

[3] Ancutienė K and Sinkevičiūtė D 2011 The influence of textile materials mechanical properties upon virtual garment fit Materials science vol 17 pp 160–167

[4] Fontana M and Rizzi C 2005 3D virtual apparel design for industrial applications Computer-Aided Design vol 37 pp 609–622

[5] Yeung K W and Li Y 2004 A 3D biomechanical human model for numerical simulation of garment-body dynamic mechanical interactions during wear Journal of The Textile Institute vol 95 pp 59–79

[6] Kuzmichev V E and Zhe C 2016 Improving men’s underwear design by 3d body scanning technology Proc. Int. Conf. on 7th 3D Body Scanning Technologies (Lugano, Switzerland) p 328

[7] Kuzmichev V E, Zhe C and Adolph D C 2015 Development of male underwear compression designing Int. Conf. on AUTEX 2015 World Textile (Bucharest, Romania) (Gheorghe Asachi Technical University of Iasi), p 100

[8] Yeung K W and Li Y 2004 A 3D biomechanical human model for numerical simulation of garment-body dynamic mechanical interactions during wear The Journal of The Textile Institute vol 95 pp 59–79

[9] Zhe C, Kuzmichev V E and Adolphe D C 2017 Development of knitted materials selection for compression underwear Austex Research Journal vol 17 pp 177–187