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An investigation on the validity of 3D clothing simulation for garment fit evaluation

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Abstract

Virtual cloth simulation received much attention in the past decade, and the fashion industry has been attracted to use this newly available tool in actual product development process to strengthen the collaboration along the supply chain and shorten the product time to market. This paper serves as an exploratory study to analyse the accuracy of 3D cloth simulation system so as to examine its validity and effectiveness in garment fit evaluation. A four-phase methodology is proposed in this paper: 20 types of woven fabrics are first tested in standard laboratory, and the obtained fabric property data are input to simulate the results of a flare skirt design. Real sample skirts are produced for comparison. An objective evaluation method is proposed to assess the accuracy of 3D simulation by comparing the quality of 3D virtual simulation results. Generally speaking, 3D clothing simulation is accurate because 18 out of the 20 tested fabrics have statistically similar results of 3D simulation and the real sample. The simulated results of the two fabrics are different from the real sample, particularly in the hip areas. Further study is thus required. With the range of validity identified, guidelines can be provided to the fashion industry for the use of 3D simulation system in design and fit evaluation.

1 Introduction

In the past few decades, large efforts have been devoted to 3D computer aided design and simulation, which can speed up the product development process and cut down the cost of development by vividly visualizing a design before actual manufacturing is committed. Many industries such as architecture and automobile have been benefited from the 3D CAD technology; comparatively, the fashion industry lags behind its development and applications. The research on 3D human modelling and virtual garment was started in 1980s, mainly for the applications in movies or animations. Since then, different systems for 3D virtual garment simulation have been developed from different perspectives and with various objectives. Both geometric-based and physical-based approaches have been proposed in modelling and simulation in order to increase the accuracy and speed. It is interesting to note that although a number of commercial clothing CAD software packages are now providing 3D virtual simulation modules, such as Runway 3D by OptiTex, V-stitcher by Browzwear of Gerber Technology or Modrias 3D Fit by Lectra, the fashion industry somehow hesitates to adopt these 3D features in the actual pattern design process. One major concern is the accuracy of the 3D virtual simulation results. To evaluate design, 3D simulation systems should not only predict the garment shapes correctly on a 3D fit model, but also accurately simulate a variety of fabric behaviours. For a given clothing design, the draping effects would be very different if the same fabric is cut on different grain alignments or different fabrics are used. This is because clothing fabrics have substantial influence on the resulted garment shapes. Some commercial 3D simulation systems claim that the draping effects of different fabrics can be predicted by inputting the fabric material properties, which is obtainable from standard laboratory tests. It is imperative to investigate the validity of the simulation results, namely within which range the simulation results can be regarded as reliable, while beyond which caution must be taken in referencing the simulation results in fashion product development. There is so far no systematic study been taken on the effectiveness of virtual clothing simulation system as design and fit evaluation tool. This paper proposes a four-phase method to examine the accuracy of 3D virtual clothing simulation systems.

The organization of this paper is as follows: the related literatures are first reviewed in section 2. The four-phase methodology is explained in section 3. Then, experimental results are presented and discussed. Finally, the findings and further works are outlined in the conclusion section.

2 Literature Review

Clothing fit is an influential factor for customers' purchase decision making. However, garment fit is an abstract concept, and the definition and perception of fit vary between cultures and people. Fitting trial is thus a necessary step in the product development process. Traditionally, live models are favoured because they represent real human body shape and interact with designers in the fitting process to give detail comments. However, this method is expensive. Comparatively, dress forms have more consistent measurements and are convenient to use. However, both live models and dress forms are not efficient enough for today's fast moving business, in particular the fitting sessions are now taking place in multiple locations. Photographs and videotapes [1,2] have been used for fitting analysis, however they provide limited information on fit evaluation. To compete in the global arena, a reliable and convenient virtual tool for garment fit analysis is necessary [3].

With the advancement of 3D technologies, such as 3D body scanning, 3D modelling and 3D clothing simulation, some studies have been carried out recently to investigate the reliability and usability of 3D technology in garment fit evaluation. Ashdown et al. tested the effectiveness of using 3D scans of clothed participants in the fit analysis process and pointed out that 3D scan was of potential to substitute live fit models, though some dimensions of a live fit analysis cannot be addressed from a 3D scan [4,5]. Bye and McKinney further investigated the reliability of 3D scan model as a fit analysis tool by comparing it with a live model [6]. They found that though fit can be virtually tested with 3D scans, there are some concerns about its accuracy in some specific locations.

On the other hand, the research on 3D clothing simulation is booming. 3D cloth simulations are either geometrical based or physical based. Because of the contributions from the computer graphics community, the simulation accuracy and speed have been much improved in recent years [7,8]. In the field of clothing and textiles, 3D simulation is considered to be of great potential for fit analysis [9], and a number of commercial clothing CAD systems have deployed 3D simulation modules. Typically, a 3D virtual fit model is firstly created and then the clothing patterns are virtually sewn around the 3D model as if the garment were worn by the customer. The fit model can be customised based on customers' body dimensions. It can be an excellent tool for clothing product development, because costly sample making and fitting process can be reduced or completely eliminated, suggested by the software suppliers. However, there is no systematic investigation on the validity of 3D clothing simulation for fit analysis, especially in view of the fabric property diversity. Sensory test was used in [10] to identify the deviation of virtual garments from real garments based on body shape, yet a non-mainstream 3D simulation was adopted. In [11], the effectiveness of a mainstream 3D simulation system for pants fit evaluation was carried out by wear trial. It was found that the visual information of overall pants silhouette was accurate, but not the information about fabrics. Further investigation is required to identify the range of validity for fabric simulation.

3 Methodology

A four-phase methodology is proposed to study the accuracy of the clothing simulation, namely fabric property test, 3D simulation, real sample production, and virtual sample and real sample comparison, as shown in fig. 1.

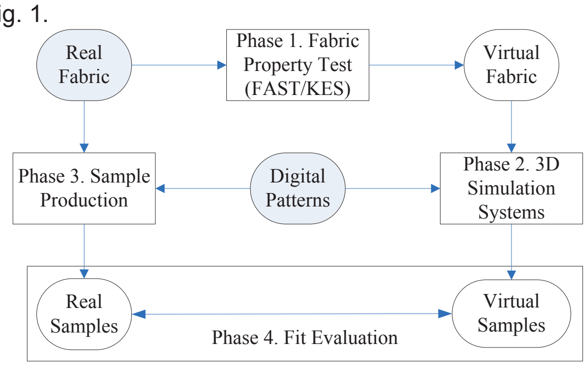

Fig. 1 Methodology Outline

A dress form of size 12 is used in the experiment for fitting trial. A simple design of flare skirt with opening at centre back is used in the experiment, and a set of patterns are created for the flare skirt (see fig. 2). The same set of skirt patterns is used in simulation and sample production. For 3D clothing simulation, OptiTex software system is chosen because it is one of the most widely accepted clothing CAD systems, and its 3D simulation is well known for versatility and quality. Besides, it allows user to input fabric properties to define the fabric materials in the simulation.

The first phase of the proposed method is fabric property test. In total, 20 types of woven fabrics are tested in the experiment. These fabrics are selected because they represent the most popular fabrics used in apparel product development, and these fabrics can be categorized into different groups according to the fabric properties. Fabric objective measurement methods by Fabric Assurance by Simple Testing Systems (FAST) and Kawabata Evaluation Systems (KES) are used to measure fabric physical properties. Both FAST and KES test results can be inputted to the OptiTex software to define fabrics in the simulation experiment. In this paper, only FAST results are reported, because FAST systems are relatively more reliable, less expensive and simpler to operate compared with KES.

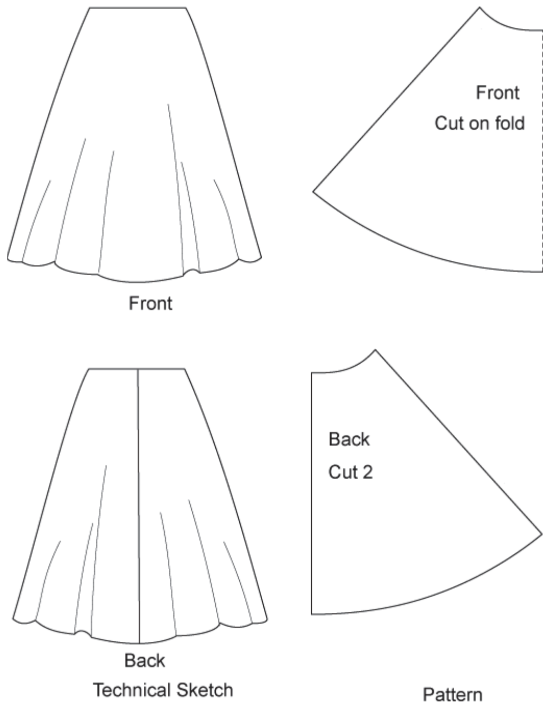

Fig. 2 Flare Skirt Design and Clothing Patterns

Fabric	Extensibility		Bending		Shear Rigidity	Thick ness	Weight
	E001	E002	B1	B2			
1	10.20	12.27	4.46	2.64	12.1	0.155	146.8
2	2.77	8.83	2.66	2.37	14.2	0.060	69.3
3	5.10	14.50	11.92	2.21	9.9	0.450	115.5
4	3.87	2.90	0.66	1.83	11.0	0.131	29.0
5	2.70	6.17	3.08	0.68	11.4	0.085	38.8
6	7.23	13.87	0.77	0.64	8.0	0.221	31.4
7	12.37	5.27	1.08	1.76	9.4	0.229	39.3
8	6.97	7.93	1.30	0.68	8.9	0.201	30.8
9	5.50	7.97	1.85	1.77	9.0	0.137	32.8
10	1.60	0.60	8.40	11.98	41.0	0.058	74.4
11	4.90	12.17	1.49	1.35	10.8	0.057	48.3
12	5.70	8.67	11.53	4.64	17.1	0.063	207.4
13	1.30	1.00	7.60	12.47	34.3	0.222	120.9
14	1.37	15.63	79.47	17.65	615.0	0.194	230.9
15	4.33	4.03	6.86	3.03	19.7	0.191	116.8
16	5.73	0.30	15.38	119.52	369.4	0.211	305.8
17	1.47	4.90	29.15	16.87	31.0	0.181	151.1
18	4.77	4.57	32.22	7.87	28.9	0.156	237.8
19	1.10	4.50	36.19	29.56	59.5	0.215	261.7
20	1.63	2.67	26.43	14.43	321.2	0.193	153.4

Tab. 1 FAST Fabric Properties

Fig. 3 Customised Model and Standard Dress Form

The second phase of the experiment is 3D simulation. OptiTex software allows importing 3D scan data as fit model. However, detail fit evaluation is only available when the default 3D model is used. The default model can indeed easily be customised by defining all the body measurements. A model is created based on the measurement specification of the standard dress form (see fig. 3), and the same dress form is used for fitting evaluation of the real samples. In order to ensure the exact shape of the virtual model and the dress form, the customised model can be exported to a standard 3D file, like WRL file. The exported model is compared with the scanned dress form model using reverse engineering software say RapidForm.

Fabric data obtained by FAST system in the phase 1 experiment are input to the OptiTex Software to define the 20 fabrics. Five properties including Extensibility, Bending Rigidity, Shear Rigidity, Surface Thickness and Weights by FAST tests are used for fabric definition in the simulation software. The pattern pieces of a flare skirt (see fig. 2) are virtually sewn up around the model, as shown in fig. 4. Among the 20 types of fabric, 5 types (Fabric NO. 1, 8, 12, 16, 18) are randomly selected to cut on straight grain, while the rest are cut on bias. Both grain lines are popular for flare skirt designs. The simulation software provides detail information for fit evaluations, e.g., the gap value describing the distance between virtual garment and the model surface, the fabric stretch and tension maps (see fig. 5). In other to compare the simulated shape or drape with real sample garment, the front view, side view and back view images are captured from the simulation results.

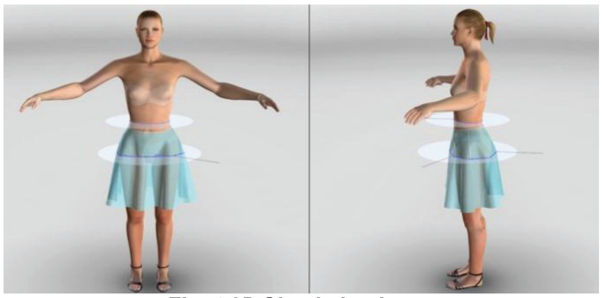

Fig. 4 3D Simulation Image

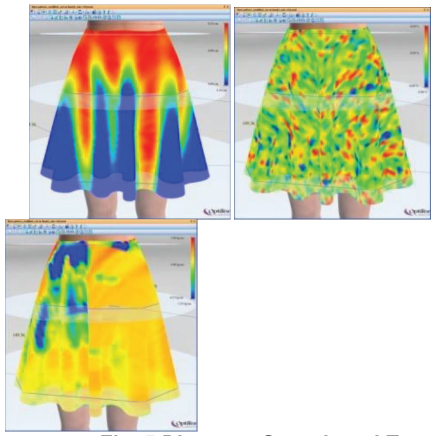

Fig. 5 Distance, Stretch and Tension Maps

In the third phase, 20 real samples are produced using the 20 types of fabrics, and the samples are put on the dress form for fit evaluation (see fig. 6). Although 3D body scanning can be applied for fit evaluation [4], it is not chosen in this study because 3D scanning technology is only good at evaluating tight-fit or just-fit garments. For loose-fit garments, some part of the garment surface cannot be scanned due to the folders and flares, and the resulted data would contain lots of noise. Instead, photographs are taken for the front, side and back views of each sample garment. The shape and drape are analysed by extracting measurements from the photographs.

Fig. 6 Real Sample Photo

Important measurements for fit and shape evaluations are extracted from image, which include both width and length measurements. In total, four data are extracted from the photos of each 3D simulation and real sample, namely Waist Width (WW), Hip Width (HW), Hem Width (HEW), and Skirt Length (SL). Figs. 7 and 8 show the definition of these measurements on simulated result images and real sample photos. Since images have different resolutions, the absolute pixel measurements are converted into ratio by eq. 1:

$$RM = \frac{AM}{P} \quad (1)$$

where AM represents absolute pixel measurements obtained directly from simulation images and real sample photos. In the calculation of horizontal measurements such as WW, HW and HEW, P equals to the absolute pixel measurements of the model waist width, while it represents the waist to hip distance in the calculation of vertical measurement of SL. Therefore, 3D simulation images and photos could be compared in the same scale according to eq. 2:

$$V = \frac{RM_{Simulation} - RM_{Real}}{RM_{Real}} \times 100\% \quad (2)$$

In eq. 2, $RM_{Simulation}$ and RM_{Real} represent the measurement ratios obtained form 3D simulation images and real samples' pictures, respectively. *V* shows the percentage of difference between the 3D simulation and the real samples, thus the accuracy of fabric drape simulation can be evaluated accordingly.

When calculated the measurement ratios by eq. 1, the mean value of both front view data and side view data are calculated for fit and shape similarity comparison.

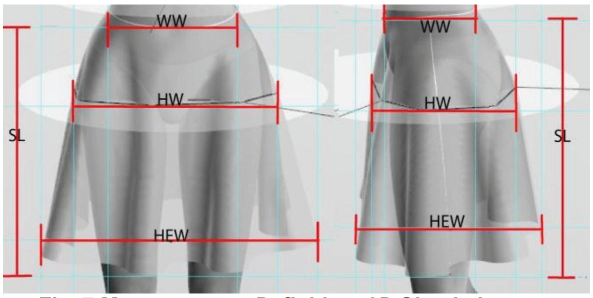

Fig. 7 Measurements Definition: 3D Simulation

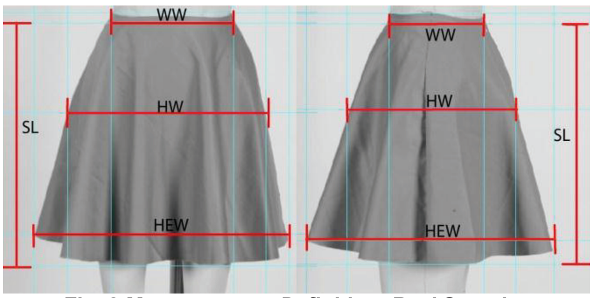

Fig. 8 Measurements Definition: Real Samples

4 Results and Discussion

The 20 types of fabric (Tab. 1) are simulated by OptiTex software and used to produce real samples. The defined measurement ratios are extracted from the 20 3D-simulation images and real sample photos. Tab. 2 compares the percentages V obtained from eq. (2)

Fabric	V(WW)	V(HW)	V(HEW)	V(SL)
1	-4.95	-1.66	-10.81	-2.26
2	0.19	-4.15	9.63	2.36
3	-5.33	-3.71	1.40	-1.05
4	1.51	-3.84	6.30	1.97
5	0.93	6.21	13.95	-1.83
6	-1.30	-4.06	6.97	-0.14
7	-1.90	-4.56	-0.14	-0.38
8	0.41	2.67	5.66	-7.43
9	0.72	-1.44	4.71	-3.38
10	-0.31	-5.84	-0.27	3.63
11	1.46	5.24	0.58	-3.63
12	3.10	-9.41	5.62	0.38
13	0.77	-6.39	-8.23	6.80
14	1.81	-2.68	-8.98	2.61
15	-2.02	-6.37	1.86	5.07
16	-1.02	-5.29	-9.76	2.07
17	-0.26	-4.07	-7.12	3.87
18	-1.56	-4.44	-8.10	-1.09
19	2.38	-3.92	-8.77	2.20
20	4.31	-3.14	-13.59	4.33
Min	-5.33	-9.41	-13.59	-7.43
Max	4.31	6.21	13.95	6.80
Ave	-0.05	-3.04	-0.96	0.70
StdDev	2.40	3.81	7.90	3.44

Tab. 2 Data Variations

As shown in tab.2, generally the four measurement ratios are relatively small when comparing the 3D simulation and real samples.

However, in the HW data, only 3 out of 20 fabrics have positive values of V(HW) (see fig. 9). The difference between 3D simulation and real samples shows that simulated results are often smaller than the real samples at the hip width. This may indicate a bias in the 3D simulation system. Further study is needed to invest two problems: (1) why there is bias at hip level, (2) why for three fabrics, namely fabric NO. 5, 8, 11, simulation results are different. Such investigation can identify the range of validity in 3D simulation, so cautions can be taken by the industry when 3D simulation is used as a virtual tool for fit evaluation.

For the rest of the three measurement ratios, only slight differences are detected. As shown in fig. 10, although the values of V(HEW) vary for different clothing fabrics, they are randomly distributed. It means the simulation results are not consistently smaller or larger than the real samples, the difference are come from natural randomness. Comparing with other locations, 3D simulations perform the best at waist, where the differences between the simulations and real samples are less than 6%. Similarly, there is no obvious bias in skirt length simulation.

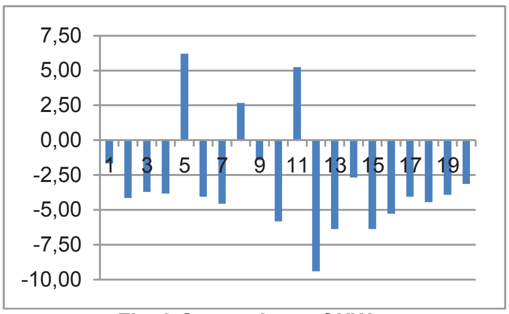

Fig. 9 Comparison of HW

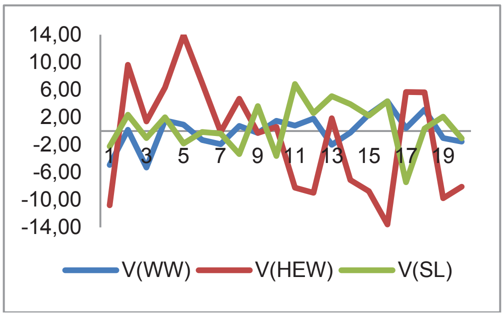

***Fig. 10** Comparison of WW, HEM, and SL*

In this paper, box plot figures are utilized to graphically depict groups of numerical data through their five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). Q1, Q2 and Q3 are set as 25%, 50% and 75%, respectively. Without making any assumptions of the underlying statistical distribution, box plots displayed differences between the 20 fabrics. By examining the spacing between the different parts of the box, the applicable range of 3D simulation as a virtual tool for garment fit evaluation is indicated.

A box plot for variation percentage (eq. 2) of 3D simulations and real samples are generated using SPSS software. Results are identical with previous ones: no outliers were found in the box plots of WW, HEW, and SL, while fabric NO. 5 and 11 were highlighted in the box plot of HW as outliers. The rest analyses of 3D simulations and real samples are excluded results of fabrics No. 5 and 11. More investigations should be carried out to study the validity range.

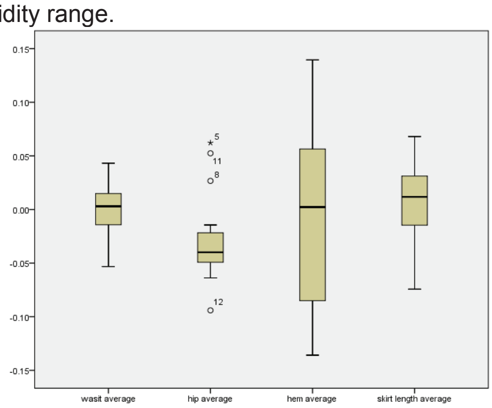

***Fig.11** Box Plot*

After screen out outlier fabrics that the 3D simulation cannot generate reliable simulation, t-tests are carried out to investigate is there any statistically significant differences between 3D simulation results and real samples. The results of fabrics 5 and 8 are taken out from the t-tests. The paired t-test results are shown in tab. 3. Since paired t-test result of HW is -6.91 with significance value 0, less than 0.05 meaning 3D simulation results has significant difference at hip level width, even though 2 fabrics have already been taken out. The rest measurements at waist width (WW), hem width (HEW) and skirt length (SL) shows no significant difference between the 3D simulation and the real sample. Therefore improvements are necessary in the hip level simulation.

Simulation VS Real	WW	HW	HEW	SL
Mean	-0.003	-0.050	-0.051	
Std. D	0.027	0.030	0.168	0.091
Std. Err Mean	0.006	0.007	0.039	0.022
Lower	-0.016	-0.065	-0.134	-0.024
Upper	0.011	-0.034	0.032	0.067
t	-0.400	-6.906	-1.290	1.014
d	17	17	17	17
Sig.	0.694	0.000	0.214	0.325

***Tab. 3** Paired Sample Test*

To sum up, this study shows the waist level is the most reliable location when assessing skirt fit through 3D simulation image. Though there are some problem in hem level simulation, these might be eased by improving 3D positioning and other related setting steps. On the other hand, the hip level shows the least satisfaction overall and should be examined and corrected carefully

5 Conclusion

This study has limitations because the results are based on a relatively small sample size. However, in this study we have developed objective fit evaluation method and analysed the 3D simulation results for a number of clothing fabrics to investigate the accuracy of the 3D simulation system. Fundamentally, the potential of using 3D simulation as a virtual tool for fit analysis has been identified, whereas several limitations of current mainstream commercial 3D simulation systems have also been indicated.

First of all, in some positions such as hip level, systematic error exists. Since hip level is a crucial location for garment fit evaluation, improvement is necessary. Secondly, for some particular clothing fabrics, 3D simulation results are significantly different from real samples. Further study is aiming at exploring the reason why some types of fabric couldn't be imitated correctly and thereby to indicate the direction of system rectification. 3D simulation system currently couldn't be used arbitrarily as a virtual tool and traditional sample making and fitting process cannot be completely eliminated. However, with the range of validity identified, guidelines can be provided to the fashion industry for the use of 3D simulation system in design and fit evaluation. Thereby 3D simulation can benefit the industry by reducing cost and shortening development process.

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