HUMAN-FRIENDLY DESIGN OF VIRTUAL SYSTEM “FEMALE BODY-DRESS”

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Abstract:

Recently, the development efforts focused on the computer simulation of garments, which depend on the material's physico-mechanical properties. It intends to achieve the best possible and realistic simulations of garments, which are available for pressure prediction. In this manner, 3D garment virtual technology improvements allow the visualization of pressure areas with values where the fabric might be too tight against the body. Although the purposes of simulation graphics were acceptable, the accuracy for apparel shaping is not enough to meet the needs of Virtual Prototyping and CAD utilization especially while the fabric properties system design was inadequate. Moreover, the existing pressure simulation is intended to simply predict the pressure index or how the textile deformation extend, which are deficient in real human's perception. In this research, the 3D shapes belonging to typical female bodies and dresses made of different fabrics were obtained by 3D body scanners (ScanWorX and TELMAT). Through reconstruction for the 3D torso shapes, the volumetric eases between body and dress were calculated by means of a software Rhinoceros. A new approach for the selection of textile properties based on the Kawabata Evaluation System (KES) was proposed to investigate its relations with dress shaping and pressure comfort. Finally, fabric properties tested by the KES-F system were compared with volumetric eases, objective pressure indexes and subjective comfort scores to reveal the relations how the fabric properties have impacts on dress outside shaping and inside pressure comfort of a female body. In this manner, the human-friendly CAD instead of mechanical approach existing before has been presented as a new approach to promote the construction of a realistic system for the 3D simulation optimization.

Keywords:

female dress, fabric properties, KES indicators, volumetric ease, human-friendly design, pressure comfort, scale, 3D virtual try-on

1. Introduction

Due to the contributions from the computer graphics community, the simulation accuracy and the speed of CAD have been objective much improved in recent years as it was proved by Magnenat-Thalmann et al. [1] and Volino et al. [2]. Therefore, some scientists, e.g. Lim proposed that in the clothing and textiles field, 3D simulation was considered to be of great potential for fit analysis and pattern block correction after that analysis [3] and the number of commercial garment CAD systems, which deployed 3D simulation modules. However, the formalized database about how the textile material properties influenced the final shapes and their sequence relations, which are necessary for the 3D virtual design of system “body-clothes”, has not formed yet. Thence, the existing 3D simulation of apparel shaping is far from a perfect representation of the real situation. In Lucy's opinion, on one hand, the simulated garment has a tendency to behave more like “clay” than real soft fabric would be; it wrapped to fit the body instead of the real situation in the physical world that the garment would be too small to close or fit around the body. On the other hand, “bodies” in the virtual environment do not share the same physics as in the real physical world; they are rigid shells that are not able to compress in the same way as flesh [4]. In this way, the virtual environment offers different indicators that

may replace some or all of the missing physical fit indicators. Sensory test was used in Lee's research [5] to identify the deviation of virtual garments from real garments, which was based on body shape. In Kim's research [6], the effectiveness of a mainstream 3D simulation system for pants fit evaluation was carried out by wear trial, which proved that the visual information of the overall pants silhouette was accurate, but not the information about fabrics.

Additionally, although garment pressure simulation and visualization were available to predict the human perception with apparel in the existing try-on system, its practicality and reference value for the 3D design have been suspected due to the lack of subjective comfort perception simulations. In the real world, the wearer-perceived apparel depends on the clothes construction and the material properties; thus, a series of indicators that are manifested in the “comfort-wear” system was under the influence of constructive solutions. More complexly, the actual garment pressure is closely related to the space allowance between the body and garment during body movement as it was proved by Zhang et al. [7]. While the existing two methods for the simulated pressure display were concerned about objective indexes only, they were unintuitive and impractical for customers or designers observing how the human body would feel in the apparel.

In the previous research, the relations that how the parameters design on structural pattern blocks influenced the comfort perception in dynamic conditions were investigated with female dresses [8,9,10]. Since the choice for materials in the dress parameter design process was based on the textile properties' indicators, its contribution to the shaping performance has to be coordinated with the necessary allowance establishment. Since Kawabata established the objective evaluation system for apparel quality control with the KES testers [11], some recent research focus on 3D try-on system improvement combined with the KES fabric indicators as Luible [12]. Meanwhile, with the development of scanning technology, the modern equipment provides the basis for more accurate information than in the past [13].

The goal of this subsequent study was to improve the existing databases by adding new ones, which helped to create the new approach for human-friendly CAD (HF CAD). First, the fabric properties tested by KES and the volumetric ease between female body and dresses were chosen to be added in the new database; in this way, the relations between them were analysed to build the new algorithm for outside shape acquirement. Secondly, the objective pressure and subjective comfort perception were tested in static and dynamic conditions to compare with the KES indicators of materials; thus, the new algorithm of the inside pressure was proposed. Thirdly, through the combination of physical pressure indexes and psychological human perception scores, objective and subjective scales in parallel were designed for the HF CAD related to system "body-dress", which allow the visualization for designers or customers. In the above three steps, the neoteric HF CAD of the virtual system "female body-dress" was built through new database of both outside shape and inside pressure comfort; moreover, the human-sensitive

information would be available instead of merely predicting the mechanical indexes.

The approaches about how the HF CAD would upgrade the existed apparel CAD are shown in Figure 1. Traditionally, a 3D simulation of "body-clothes" in static and dynamic postures was achievable through pattern block and pattern-grading parameters' design, which predict the outside shape and inside pressure with few aspects of textile fabrics indicators. It was constructed based on the mechanical approach as shown in the blue frames. In this study, the realistic virtual 3D system "body-clothes" with the functions of predicting the human perception was proposed. Superior to the existed CAD, it is adapting to the human features that even allow to adjust the comfort level in the design process.

2. Objectives and methods of research

2.1. Female dress

In this research, female dress was chosen as the main object, which was structured from the basic pattern block with short sleeves and stand-collar. Ease was designed as the tight-fitting style: to half bust is 1 cm; to half waist is 1 cm; to half hip is 1 cm and to arm girth is 7 cm.

2.2. Female body for experiment

Five female models with similar dimensional characteristics (height = 160 cm, bust girth = 84 cm, waist girth = 64 cm, hip girth = 90 cm) were chosen for the whole process of experiment, which includes the volumetric eases calculation, pressure indexes measurement and comfort perception judgement.

Figure 1. Possibilities of traditional CAD based on the mechanical approach (in blue) and human-friendly CAD (in brown).

2.3. Pattern blocks preparation

Through historical analysis of female dress structure, five patterns were prepared with the same eases for the standard female size as mentioned above; but in five different structures the indexes varied for designing the dart in waist level. In this way, the pattern blocks were prepared in the same size but with different parameters for darts including: place of dart, length of dart, dart value and shrink in back centre. Therefore, the final results for outside shaping and inside pressure comfort were applicable with different structures in details for the reason that they were obtained from the average values of the five patterns.

2.4. Fabric properties tested by KES testers

Textile materials for the dresses were chosen including two types of woven (I and II, Table 1) and one knitted fabric (III, Table 1). The main characteristics for physical and mechanical fabric properties' indicators were selected out to be tested by the Kawabata evaluation system (KES) on the basis of Kawabata's theory [14]. Each fabric was measured for five times following standard specimen sizes and methods to obtain the average indicator indexes. Thence, 11 parameters were obtained by Kawabata devices for tensile, shear, pure bending and compression ability as shown in Table 1.

2.5. Volumetric eases calculation

In the real three-dimensional "body-dress" system, a complex index of samples was measured and analysed with the help of 3D modelling software (Rhinceros) for obtaining the materials shaping performance on human body. The volumetric ease indexes were obtained through five steps. First, 2D patterns for dress samples were prepared with five different structures for dart parameters design but in one size as mentioned in Section 2.3. Secondly, for each pattern the samples were sewn with the above three kinds of fabrics. Thirdly, the 3D shapes of five female bodies and additionally with dresses were scanned in 3D body scanners "ScanWorX" and "TELMAT". Fourthly, the 3D digital shapes were analysed after separating the "bust-hip" torso into six cross-sections as shown in Figure 2, which were selected as the main curve varied on female body: 3 – bust girth; 4 – underbust girth; 5 – torso girth between underbust and waist levels; w – waist girth; 6 – torso girth in the middle between waist and hip; h – hip girth. Finally, through reconstructing them into five parts, the constructive volumes are achievable in the 3D modelling software (Rhinceros). Finally, the 3D shape of a system "body-dress" was synthesized for the integrated volumetric indexes as "constructive ease volume" (CEV) from bust to hip level on female torso through:

$$CEV = \text{Volume of dress} - \text{Volume of body} \quad (1)$$

Table 1. Physical and mechanical properties of the materials for experiment

Characteristic or properties of indexes		Warp/ weft Fabric I	Testing result for indexes		
			Fabric II	Fabric III	
Structure type			Woven	Woven	Knitted
Fibre content (%)		–	Cotton (100)	Cotton (100)	Polyester (85), cotton (15)
Mass per square metre (g/m ²)		–	88	92	165
Shear (Tester KES-FB-1)	Shear stiffness 8°, G , cN/cm deg.	Warp	0.722	1.072	0.626
		Weft	0.726	0.926	0.6
Tensile (Tester KES-FB-1)	Linearity of the stress/strain curve, LT	Warp	0.823	0.82	0.611
		Weft	0.674	0.714	0.567
	Tensile energy (maximum load: 500 gf/cm), WT , cN cm/cm ²	Warp	3.7	3.49	24.663
		Weft	20.3	25.85	43.525
	Tensile recovery following extension, RT , %	Warp	57.782	60.3	45.55
		Weft	21.088	22.976	43.858
	Necessary deformation for elongation in 0.5%, $F 0.5$, cH	Warp	293.667	288.32	2.32
		Weft	12.08	13.95	0.94
	Elongation at a set load (maximum load: 500 cN/cm), EMT , %	Warp	1.782	1.704	16.148
		Weft	12.062	14.464	30.743
Bending (Tester KES-FB-2)	Bending stiffness, B , cN cm ² /cm	Warp	0.404	0.108	0.008
		Weft	0.04	0.039	0.01
	Hysteresis of shear force at ±0.5° of shear angle, $2HG$, cN/cm	Warp	0.982	1.332	1.276
		Weft	1.262	1.482	1.436
	Hysteresis of shear force at ±5° of shear angle, $2HG5$, cH/cm	Warp	2.958	4.232	1.296
		Weft	3.242	4.166	1.418
Compression (Tester KES-FB-3)	Work done in compressing the fabric, WC , cN cm/cm ²	–	0.126	0.157	0.169
	Compressive resilience of the fabric, RT , %	–	57.266	48.862	64.274

Figure 2. Torso volumes obtained in Rhinoceros software for “body–dress” system scanned: 3 – bust girth; 4 – underbust girth; w – waist girth; h – hip girth, 5 – torso girth between underbust and waist levels; 6 – torso girth in the middle between waist and hip.

Database of the volumetric ease has the advantage of allowing to study and display the shaping information in 3D way; thus, it is superior to the existing method since it can analyse the sections separately. In this way, the shaping database of volumetric ease was built to be compared with the KES fabric indicators, which helped to propose a new algorithm for the outside shape in the system “female body–dress”.

2.6. Objective pressure indexes tested by FlexiForce sensor and subjective comfort scores judged by models

The comfort of dresses was evaluated by objective and subjective indicators: pressure indexes were measured instrumentally in the selected anthropometric points using the FlexiForce sensor, and measurements were obtained after five repetitions for each model in each point; simultaneously, comfort perception degree on body surface with dress was offered by experts at the same points in seven different postures as same as the previous research [10]: 1 – simply standing; 2 – waist side bending; 3 – waist front bending; 4 – arm front swing; 5 – arm back swing; 6 – sitting as moving out of the car; 7 – one leg lifting as moving upstairs.

3. Improvement for the outside shape prediction in HF CAD

In this part, the relations how the fabric properties impact on dress’s outside shape were analysed on the basis of 3D scanning and modelling technologies. Textile material indicators were compared with the volumetric eases located between the body and dress to learn the relations between them.

3.1. Volumetric ease between body and dress

The “constructive ease volumes” were divided into three groups (as shown in Figure 2) depending on the possible impact on

the silhouettes shaping and volumetric gaps beneath reliable minimum ease (Table 2):

- Volumetric ease that is influenced directly by morphological feature of the breast level (*CEV3,4*).
- Volumetric ease located between the upper and lower abutment surfaces, which does not have direct impact by body morphology (*CEV4,6*).
- Volumetric ease located directly above the hip area (*CEV6,h*).

Indexes in Table 2 indicate how each fabric has influence on *CEV* in different parts of the female body. For example, *CEV3,4* (bust underbust) are small for all types of fabrics because it is more close to the female body. While in the part between the upper and lower abutment surfaces, the fabrics have different performances on *CEV* indexes in the separated three parts; thus, the sum index of this part is more important. Finally, the total volumetric ease (*CEV3,h*) described the comprehensive fabric properties impact on 3D ease between the body and dress as for the dress shaping process.

3.2. New algorithm of dress shaping

However, some indicators of the KES system were related with others for the reason that they described the mechanical property from diverse aspects, so it is necessary to choose the important ones for investigating. Thus, the next way of choosing the textile materials’ properties related to the dress shaping and pressure distribution has been created:

- Correlative coefficient was analysed between each KES indicators to find out the independent variables.
- The independent variables of fabric indicators were compared in warp and weft; if it influence shaping or comfort pressure in both directions similarly, then it is judged as the valid variables.
- After the above two steps, the final valid variable was chosen to obtain the result.

In this way, correlative relations between material properties and *CEV* values were analysed to investigate how the former

Table 2. Volumetric eases in “body–dress” systems.

Compartmentalization of constructive ease volumes between horizontal sections in “body–dress” system	The average value of the constructive ease volumes calculated for five models in systems “body–dress”, which is made of different materials (cm ³)		
	Fabric I	Fabric II	Fabric III
Situating under the upper bearing surface			
CEV _{3,4}	71.6	22.2	14.0
Situating between the upper and lower abutment surfaces			
CEV _{4,5}	89.3	147.8	70.4
CEV _{5,w}	197.9	228.4	197.2
CEV _{w,6}	358.3	314.9	186.4
Sum	645.5	691.1	454.3
Situating above the bottom bearing surface			
CEV _{6,h}	1617.9	1417.5	1417.0
The total volumetric ease			
CEV _{3,h}	2335.0	2130.8	1885

influenced the latter. After checking the links existing between all indicators in Table 1, the adequacy of existing indexes in warp and weft directions formed a series of paramount indicators as follows (in descending order according to how the average correlative coefficient values impact on the dress volumes) ($n = 15$, $p = 90\%$, $F_{crit} = 0.412$):

$$WC (-0.5975) - 2HB(0.595) - B(0.5763) - RT (-0.5375) - LT (0.5087) - 2HG5(0.3988) \quad (2)$$

Thus, the prediction for the final silhouettes by CEV values is achievable with the fabric properties been selected, which express the deformation of dresses by means of indexes obtained through KES-F devices; the two indicators were selected from different groups based on the analysis and the established restrictions:

- In the tensile property group, the linearity of the curve stress/strain LT (average of warp and weft), indicates how the stress uniformity increased within the material under tension. In the case of dress shaping, this indicator can be related to the ability that the fabric resists adaptation against the shaping. The decreasing of the LT -value implied increase in the difficulty for changing outside shape.
- In the bending property group, the flexural rigidity B (average of warp and weft) represents the resist ability of bending the textile fabric. The increasing of B -value indicates the increasing of difficulty for bending the fabric.

Equations for calculating the CEV values located between different levels on female torso are shown in Table 3 (statistical significance of equations verified by the criteria *Fisher* and *Student*, as well as the multiple correlation coefficients, $n = 15$, $p = 95\%$, $F = 2.4$):

The Equations (3)–(6) revealed how the selected indexes increased the volumetric ease, which confirmed the validity of the assumption and verified that they are related to the dress shaping. The results indicate how the fabric properties impact on different parts of dress shaping. In the upper part “3,4” (Equation 3) and bottom bearing surface part “6,h” (Equation 5), the indicator B (bending stiffness) is the contributing factor; meanwhile for the part between upper and bottom abutment surfaces (Equation 4), the indicator LT of tensile ability became the causative factor; consequently, both indicators influenced the dress shaping (Equation 6). Thus, the legitimately prediction for outside shape of female dress in the “body–dress” system is realizable through testing physical and mechanical properties of fabric at low loads by the KES devices.

Consequently, the database of outside shape was established for the HF CAD, which creates the new method to predict the 3D shape with KES fabric indicators.

Table 3. Equations for CEV prediction

Constructive ease	Equations for constructive ease volume (CEV) prediction	
CEV _{3,4}	$CEV_{3,4} = 323.77 B$ ($F = 2.58$)	(3)
CEV _{4,6}	$CEV_{4,6} = 1381.2 LT - 358.34$ ($F = 19.6$)	(4)
CEV _{6,h}	$CEV_{6,h} = 1680 + 1291.4 B$ ($F = 4.33$)	(5)
CEV _{3,h}	$CEV_{3,h} = 1374 + 844.4 LT + 1480 B$ ($F = 14.85$)	(6)

4. Improvement for the inside pressure comfort prediction consistency of objective and subjective indicators in HF CAD

According to the law of the sensitivity how human body endured the pressure [15] and the basic points [16], 13 points (as shown in Table 4) required to be tested for pressure and comfort perception were selected: front and back corner of the armpit; front, back and side points belonging to bust level, waist level and upper arm level; shoulder point and hip point.

4.1. Pressure comfort indexes in both subjective and objective aspects

To clarify the comfort perception, the expert assessment scale was divided into three levels and was denoted with scores: for every model in each postures, “U” (uncomfortable) – score 2; “E” (endurable) – score 1; “C” (comfortable) – score 0. The results of the subjective comfort score with corresponding objective pressure measurement are shown in Table 3; both objective and subjective parameters were obtained as the average value of the results testing with five female models.

Both objective and subjective indexes in each point were calculated as the average value for five models in seven postures, which revealed the general situation that how these anthropometrical points endure pressure in daily movement. The parameters in the above table for the three fabrics indicate

how the comfort indexes changed in both objective and subjective aspects, which emphasize the importance of both mechanical data and human perception.

In this way, the new approach to describe pressure comfort was proposed with two scales that are available for objective and subjective simulation in parallel for the human-friendly 3D try-on system (Figures 3 and 4).

Figure 3. Subjective scale (prediction for human comfort perception). Unit: comfort level (obtained from comfort score).

Figure 4. Objective scale (prediction for pressure indexes). Unit: Pascal.

Table 4. Objective pressure measurements and subjective evaluation scores of comfort

Anthropometric points	Average pressure P, Pa, calculated in six positions for five models in the „body-dress” system, which made of different materials			Average comfort scores obtained from the five models, CS		
	Fabric I	Fabric II	Fabric III	Fabric I	Fabric II	Fabric III
P1 – Front corner of the armpit	669.4	612.4	427.6	0.9	0.6	0
P2 – Back corner of the armpit	898.8	780.2	616.8	0.6	0.3	0
P3 – Bust point	210.8	177.3	120	0.1	0	0
P4 – Side in bust level	1197.7	1033	788.6	0.6	0.4	0
P5 – Back in bust level under scapular	851.9	500.8	338	0.2	0.2	0
P6 – Front in waist level under bust point	495.3	450.4	339.1	0.6	0.4	0
P7 – Side in waist level	465.7	419.3	276.8	0.8	0.3	0
P8 – Back in waist level under scapular	452.7	406	232.2	0.8	0.2	0
P9 – Hip point	417.8	340.3	205.4	0	0	0
P10 – Shoulder point	548.6	498.4	393.6	0	0	0
P11 – Front in upper-arm level	367.2	348.1	287.6	1.1	0.8	0.2
P12 – Side in upper-arm level	596.5	565.1	458.5	1.1	0.8	0.04
P13 – Back in upper-arm level	148	132.3	113.2	0.04	0.04	0
Average	563.1	481.8	353.6	0.5	0.3	0.02

In summary, the results in Table 4 convey that the pressure indexes and comfort scores were strongly correlated after comparison with different materials. Decrease in pressure leads to an increase in the comfort degree, so these two indicators – objective and subjective – can be used in parallel. However, a stable relationship between them does not exist due to different intervals and accuracy of physical pressure measurement (range 113, ..., 1197.7 Pa) and subjective evaluation (range 0, ..., 2).

4.2. New algorithm for pressure comfort

The correlations between the materials properties were investigated for the significant parameters selection; in this method, the truly independent indicators in each property group were compared in warp and weft with objective and subjective indexes of comfort (in the same way as mentioned in Section 3.2). The performance that how the fabric properties affect the comfort indicators were sorted as follows (in descending order according to their influence on the objective and subjective comfort as the order of correlation coefficient average values):

$$WC (-0.53) - 2HB(0.53) - B(0.5125) - RT (-0.47) - LT (0.4425) - 2HG5(0.3475) \quad (7)$$

Worthy of attention was the absolute value in the above sequence rows, which contain the rank indicators for CEV and pressure. It indicated the existence of a common mechanism for both phenomena been studied – apparel shaping and pressure on the body surface.

In this process, the same two indicators as in Section 3.2 were selected from different groups based on the analysis and the established restrictions:

- In the pure bending group – the bending rigidity B .
- In the tensile group – linearity of the stress/strain curve, LT (with more independent significance compared with RT).

In Table 5, the fabric properties effect on comfort indexes were jointly examined with the dress quantity through the correlation analysis (Table 5).

The strongest influence on the pressure change (the correlation coefficient is 0.858) and comfort score (0.6267) existed in the

constructive ease volume $CEV_{4,6}$ between the upper and lower bearing surfaces; afterwards, the second is the full $CEV_{3,h}$. Such a result was not accidental: the volumetric ease between the body and dress is actually the allowance of clothes movement relative to the body, which creates the conditions for realization of the different material properties as well as the pressure. Therefore, the intensity of the selected physical and mechanical properties impact on the dress shaping and comfort was approximately the same.

Furthermore, the parameters in Table 4 lead to another extremely important conclusion: the material properties performance impact on a pressure is limited to the volumetric ease. With the increase in the influence of the volumetric ease that the material properties contribute, the pressure is decreasing. In general terms, the pressure generated under dress could be expressed as follows:

$$P_{ij} = f [CEV, \lim TM] \quad (8)$$

where: P_{ij} is the pressure (or subjective comfort score) in i anthropometrical point and j dynamic posture, Pa (score); CEV is the constructive ease volume (cm^3); $\lim TM$ is the single or complex property indicators of the textile material that affect the CEV value.

Through the multivariate regression analysis, the equations for harmonization of objective and subjective comfort evaluations under textile materials properties were obtained as shown in Table 6 ($n = 27$, $p = 95\%$, $F_{\text{crit}} = 1.91$).

Table 6. Equations for objective and subjective evaluation

Objective evaluation	$P = 24.55 + 577.4 LT + 775.56 B$ ($F = 2.23$)	(9)
Subjective evaluation	$CS = -0.07 + 0.12 LT + 0.31 B$ ($F = 12.43$)	(10)

Note: P , pressure; Pa; CS , subjective score; LT , linearity of the curve stress/strain (mean of warp and weft with a load of 500 cN); B , bending stiffness (mean of warp and weft) ($\text{cN cm}^2/\text{cm}$).

Simultaneous solution of Equations (3)–(6) and (9)–(10) provides the basis for a common mechanism, which helped in forecasting the dress volume shaping and the corresponding

Table 5. The correlation matrix

Output factors relating to the "body-dress" system	The correlation coefficient ($n = 39$, $p = 95\%$) input for the following factors relating to the materials' properties performance							
	In the flat state				In the wearing state			
	B warp	B weft	LT warp	LT weft	$CEV_{3,h}$	$CEV_{3,4}$	$CEV_{4,6}$	$CEV_{6,h}$
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Pressure (Y_1) (Pa)	0.37	0.37	0.36	0.31	0.3956	0.345	0.858	0.78
Subjective score (Y_2)	0.69	0.62	0.61	0.49	0.7112	0.4111	0.6267	0.9687
Number of samples (the testing points*3 groups)	39	39	39	39	39	9	9	3
Critical correlation coefficient [17]	0.2360				0.5822		0.9877	
The arithmetic mean value and the rank of significant correlation coefficients	0.53 (3)	0.485 (4)	0.485 (4)	0.4 (5)	0.5534 (2)	–	0.7424 (1)	–

pressure exerted. In this way, the database of the inside pressure comfort was established.

5. Theoretical database and realization outlook of HF CAD for the system “female body–dress”

5.1. Framework of the HF CAD

As mentioned before, the existing 3D try-on system had provided the pressure map with the avatar. Figure 5 displays the result of pressure simulation from Marvelous Designer 3D try-on system, which is obtained with the dress of fabric I and fourth posture (as mentioned in Section 2.6), and the avatar in standard female sizes. However, the result of simulation is unsatisfactory after comparison with the real testing result obtained (Figure 6): the pressure values on the upper torso were much smaller than the real one, especially for the side and back areas on bust level. This unreal situation has been generated by the complex of serious factors including: the avatar was lack of authenticity; the mistakes appearing during the simulation from 2D pattern to 3D shape; the incomplete fabric properties in system design; the mistakes of fabric simulation; etc.

Thus, the improvement for the existing try-on system simulation is in need. For this reason, the database that was built in this research had provided the solutions for 3D apparel CAD upgrade. Traditionally, the databases that helped to achieve the 3D simulation results were divided into four parts: textile material properties' indexes; 2D outside shape indexes; body size indexes and pattern block indexes (Figure 7). For improving the existing try-on system, new databases of the HF CAD were proposed to be added instead of the old ones:

- The “KES fabric properties' indexes” took the place of the old “Textile material properties' indexes”; the former was superior to the latter as it introduced the method, which provides the important fabric indicators in a standardized system. Therefore, the database of textile materials was upgraded in an undifferentiated way that solves the problem of fabric testing error or indicators' inadequacy.
- The old “2D outside shape indexes” was replaced by the “3D volumetric ease indexes”. In this way, the simulation process of shaping would transform from the simple 2D section's view to the 3D view; it allows to take the full consideration of the relations between body and clothing in a three-dimensional way.
- The database of “pressure indexes and comfort perception scores” was added to express the inside pressure comfort in both objective and subjective aspects with KES fabric indicators.
- The two scales for both objective and subjective indexes were suggested to be added. They make possible for the visualization of human perception, instead of the simple pressure indexes simulation as in the old ones.

Through the above four database improvement, a new algorithm of outside shape and inside pressure comfort was achieved, which constructed the new HF CAD to display the objective pressure and subjective comfort with two scales in parallel.

5.2. Simulation of pressure comfort in the HF CAD for the system “female body–dress”

Finally, the simulation results have been upgraded through the new algorithm of outside shape and inside pressure comfort, which were obtained in this research. Examples of the pressure comfort map for three fabrics were shown in the following table

Figure 5. Simulation of pressure in Marvelous designer.

Figure 6. Pressure display with real testing result.

Figure 7. Framework of created HF CAD.

with objective and subjective scales (Table 7). The differences between the objective pressure map and subjective comfort map were composed mainly for the two reasons:

- The human perceived pressure with dissimilar sensitivity in different areas, e.g. on the objective pressure map the indexes changed step by step for the back area on bust level, that is the colour transfer from green to blue (Table 7). Nevertheless, on the subjective comfort map they were all in purple. Therefore, the HF CAD that afford pressure map with sensational information was intuitive to avoid wrong judgements from the single objective pressure parameters.
- The human perceived fabrics in different ways, e.g. in the side area of the upper arm level, the objective pressure was in the same level for all the three fabrics (where coloured in yellow in Table 7); while for the subjective comfort they varied from each other. In this case, a designer or a customer would determine the type of fabrics simply by checking the simulation results in the HF CAD, or adjust the pattern block to achieve an ideal comfort level.

Meanwhile, the influence from structural design on human perception would be available with the subjective comfort maps. For example, some perceptual differences have been found between the different patterns (with variable dart parameters, as mentioned in Section 2.3) as shown in Figure 8.

These perceptual changes were subtle and only appeared with certain dynamic postures, while on the objective pressure maps they would be the same everywhere. Therefore, the subjective comfort maps would be helpful to improve the process of pattern blocks design, which was unachievable with the single objective pressure map.

6. CONCLUSIONS

The common principles of HF CAD were created based on the fabric properties, 3D shape of dresses and pressure comfort in the system “body–dress” and allowed to visualize the simulation result with the human perception. New databases were suggested to be added for the HF CAD: (1) fabric properties indexes tested by KES; (2) 3D volumetric ease indexes; (3) pressure indexes and comfort scores. In this way, the common mechanism of dress outside shaping and inside pressure comfort distribution in the system “female torso–dress” contributes to the HF CAD establishment, which is based on the same textile materials’ properties:

- With textile properties’ indicators tested by KES system, a new algorithm was established for the human-friendly and realistic 3D virtual system design, which is available for outside shape and inside pressure comfort consistency of objective and subjective simulation results.
- Relation between volumetric ease and pressure comfort (in both objective and subjective aspects) was analysed for the 3D HF CAD simulation implement.
- Investigation of the topography that how the pressure distribution around the female torso in different parts with objective and subjective evaluation methods was made to establish new database for the “body–dress” system.

Therefore, the system “female body–dress” for HF CAD consists of the three factors: KES fabric indicators; 3D volumetric ease for outside shaping indexes and inside comfort pressure indexes. Consequently, the interaction relations between each other make it an intrinsically linked system with intuitive simulation display for human sensation.

Table 7. Simulation of pressure comfort in the HF CAD with objective and subjective scales

	Fabric I	Fabric II	Fabric III
With the objective pressure scale
With the subjective comfort scale

Figure 8. Comparison of subjective comfort maps made of fabric I (in the same size) but with different pattern blocks (cm), where Pd (place of dart): a = 8, b = 9; Ldf (length of front dart): a = 29.5, b = 31.5; Ldb (length of back dart): a = 24, b = 26; Dv (dart value): a = 4, b = 3; Sb (shrink in back centre): a = 0, b = 1.

Additionally, the influence how material properties impact on dress shaping around female torso was analysed, as well as its influence on the pressure comfort. According to the conclusions, the selected indexes of bending B and tensile LT indicators were taking the critical importance for dress shaping and comfort process in the “female body–dress” system. However, the reason for this phenomenon is not clear now and deserves more research in the future. On the other hand, the limitations of fabric species in this research restrict the practicality and systematic integrity. Thus, a further extension of the fabric sorts is necessary and the discrete for woven and knitted objects is required.

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