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万斯达

Wan Sida

Development of fit evaluation and prediction system of digital twins for women's classic jacket sleeves

Dissertation
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05.19.04 Technology of garments

Scientific adviser - Prof., Dr.Sc.,V.E.Kuzmichev

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CONTENT

FULL INTRODUCTION

Actuality. The digitalization process of clothing construction has become a reality in the fashion industry, allowing us to fill the content of many traditional processes with new digital information. Virtual "stitching" of clothes patterns takes place with two lines, which can be divided into several groups: open or closed, straight or curve, stacked on the plane or not stacked on the plane. Connecting the two closed curved lines occurs at sewing the sleeve assembled into the armhole. It is the most difficult from the aspect of designing and achieving the desired fit appearance. The "armhole-sleeve" not only is the quality indicator of design and but also the source of misfit appearance of several classic clothing (jacket, coat, outwear etc.).

The virtual process of sleeve-armhole assembly involves many factors. Under the influence of these factors, the necessary volume and position of the sleeve can be provided.

The flat pattern of sleeve cap and armhole are initially projected and overlapped. The configuration can be described by measurable parameters and Cartesian coordinates of feature points. After transfer from Cartesian coordinates to 3D space, the assembly lines of sleeve cap and armhole change their configuration and acquire approximately same shape under the complex-directed force field. For the mathematical modelling of armhole, many parametric factors are required: the sleeve cap and armhole shape; the ease-allowance of bust girth, the armhole plane direction; the stiffness and thickness of the materials; curvature of the original lines; anisotropy of material properties, because along the armhole seam are following possible combinations: weft + weft (in the widest point of the sleeve), basis + basis (under the armhole), basis + weft (in the highest point of the shoulder seam). Obviously, the complete model involves muti-factors. The 3D CAD software includes factors related to thickness and stiffness of materials, parameters of flat pattern, peculiarities of body morphology, methods of shaping, etc.

Depth of topic development. Currently The research on the "armhole - sleeve" was carried out by researchers from IVGPU (M.R. Smirnova, Chen Zhe, Lo Yun, N.M. Kochanova), Russian State University named after A.N. Kosygin (E.G. Andreeva, I.Y.

Petrosova), JinXiong Wu (China), JuHyeong Bae, Yurim Cho (Korea), Michiko Miyoshi, Wol Hi (Japan).

However, the successful development of this direction requires further formalization of professional knowledge in the areas of pattern construction and virtual objective qualimetry. Unfortunately, complete databases, knowledge, and rules are not yet formed due to the lack of a unified approach to the pattern and three-dimensional design processes. The existing CAD systems do not have enough functions to check sleeves and armholes and do not allow identifying the causes of defects appearance. Therefore, from the standpoint of further development and improvement of digital design, it is crucial to develop new design technologies in the virtual environment.

The work was performed in 2013-2022 at the Department of garment design, IVGPU, in the framework of the main scientific direction **"Analysis and synthesis of real and virtual systems 'body-clothing'"**, under the grants of the Heyuan Polytechnic Institute Research Fund No. 2017kj06 (China), and the Russian Foundation for Basic Research (RFBR) and Ivanovo region **"Development of the fundamentals of virtual design of digital twin systems 'human figure-apparel'"** using neuropsychological technologies and reversible engineering" No. 20-47-370006. The research has been done in accordance with the scientific specialty 05.19.04 - Technology of sewing garments (engineering sciences).

Aim of this research is to develop databases, knowledge, and rules to transfer the design process of the "armhole-sleeve" with given appearance parameter from the real to the virtual environment.

To achieve this aim, it is necessary to complete the **following tasks**:

1. A graphical analysis study of the pattern of women's jackets with different quality parameters was carried out, in order to build a database of the design parameters' influence on the appearance of virtual sleeves.

2. Develop geometric models of the "armhole-sleeve", in order to build the feature points database of the coordinates for armhole and sleeve assembly.

3. Develop a method and criteria for objectively evaluating the virtual sleeve appearance fit in women's jackets.

4. Investigate the reason for virtual sleeve defects under the designed pattern parameters.

5. Develop the algorithm to design the "armhole-sleeve" of women's jackets in the virtual environment and predict fit defects in the sleeve appearance.

6. Develop modules in Python environment for sleeve assembly fit evaluation and automatic selection of parameter combinations to prevent sleeve defects appearance.

7. Develop the comprehensive fit criteria and correlations for the whole sleeve.

8. Study the fit evaluation and defect recognition from grayscale.

9. Study the pressure and constructive ease-allowance for "body- jacket" system.

10. Test the results in real for validation.

Object of research - women's body, jackets and its' sleeve with different spatial shapes, the coordinate and grayscale fit evaluation process.

Subject of research - the design parameters of flat pattern and 3D models of the "armhole-sleeve" assembly, whole sleeve, and sleeve grayscale.

Research field – the process of designing women's jacket sleeve.

Methods and tools of research. To study separate elements and the integrated system “women’s jacket sleeve” we used the following methods: method of measuring pressure of clothes on the human body, method of pattern parametric configuration, method of coordinate location, method of image recognition by grayscale.

We used the following experimental studies: CAD software ET (BUYI Technology, China) to digitize pattern construction; computer program CLO 3D, version 5.0.156.38765, (CLO Virtual Fashion, Republic of Korea) for generating virtual objects; ImageJ program to analyze grayscale images; The 3D modeling software MAYA (Autodesk, USA) was used for feature points coordinate measuring; FlexiForce sensor to measure pressure of clothes on soft tissues of human bodies.

Statistical processing of the measurement results was performed using SPSS software (IBM, USA), PASS15 (NCSS LLC, USA) was used for sample size calculation, Python language was used to write the models for feature point fit evaluation criteria and sleeve parametric combination. Graphpad (Graphpad software, USA) were used for plotting.

Scientific novelty of the research consists in the development of a scheme for the sleeve fit evaluation and prediction, which includes coordinate with flat pattern parameterization, five principles for the whole sleeve fit prediction, and fit evaluation and defect identification by grayscale.

Provision for defense:

1. Designed databases of women's classic jackets.
2. Geometric model of the "armhole-sleeve".
3. Five basic principles for the whole sleeve fit prediction.
4. grayscale criteria for sleeve fit evaluation and defect identification.

Theoretical significance of this research is to establish the theoretical and experimental foundation for the fit evaluation and prediction of simulated women's jacket sleeve.

Practical significance of this research is to develop a system of virtual design of women's jacket sleeve with predictable indexes for fit evaluation. The technology and methods can be used in traditional design practice, CAD software modules development, and virtual twins of women's jacket sleeve generation. The results were implemented in undergraduate training of Heyuan Polytechnic Institute (Heyuan, China).

Reliability degree of the results of the thesis is provided by the consistency of the results of experimental studies of the initial elements (material, women's body, parameterized indexes of pattern and simulated sleeve, and grayscale values) and the used research tools (3D CAD for technological research, image analysis for grayscale research).

Approbation of the results. The main results of the work were reported at conferences: Proceedings of the international scientific and technical conference “Modern science-intensive technologies and advanced materials for textile and light industry (progress)” 2013 **(Ivanovo)**; Information environment of universities: materials of XXIV international scientific and technical conference, November 22th-23th, 2017 **(Ivanovo)**; International conference on advanced materials, Electronical and Mechanical Engineering AMEME, 2020, September 27th-28th, 2020 **(Xiamen, China)**; Scientific and Technical Inter-university Conference of Postgraduates and Students (with international participation) “Young Scientists - the development of national technology initiative” (SEARCH), 2020 **(Ivanovo)**; International Scientific and Technical Conference on innovative development of textile and light industry, March 29th-31th, 2021 **(St. Petersburg)**; XXIV International Scientific and Practical Forum SMARTEX-2021, October 12th-14th, 2021 **(Ivanovo)**, International Conference on Techniques, Technologies and Education ICTTE 2021, November 3th - 5th, 2021 **(Yambol, Bulgaria)**; In the educational curriculum "Digital looks: artistic and industrial design of 3D clothing in virtual reality" of national project "Education" 2020 **(Ivanovo, IVGPU).**

The computer program "remote clothing customization system (abbreviated: clothing customization)" is registered by the national copyright administration of the PRC, No.: 03006712 dated 14.09.2018, registration number 2018SR745971. The database "drawings of designs and design parameters of women's classic jackets: application" is registed in Russia federation (database No:2022621167).

Publications. Based on the results of the dissertation research, 9 publications were published, 2 of them in publications indexed in the international citation and analytical databases of VAK and Scopus, and 7 in the proceedings of conferences at various levels. The total volume is 2.625 p.l. (personal contribution 1.4688 p.l.)

Structure and volume of the dissertation. The dissertation consists of an introduction, six chapters, conclusion, list of references and appendixes. The content is set out on 224 pages of typewritten text, including 66 figures and 62 tables. The list of references used includes 163 titles.

BRIEF INTRODUCTION

This study devotes to developing the fit evaluation and prediction system of digital twins for women's classic jacket sleeve. The aim is to develop the databases, knowledge, and rules to evaluate and predict the sleeve fit in a virtual sleeve before real sewing.

Digitalization processes of creating a new method demand addition and filling study with new information to traditional design methods and constructive pattern making. Virtual "sewing" of clothing is performed with the participation of two lines, which can be divided into several groups. When assembling the sleeve into the armhole, the connection of two curvilinear closed lines is the most difficult both from the design point of view and the appearance of fit quality. The armhole-sleeve in many classic clothes (jacket, suit, coat) indicates design quality and is a source of assembly defects. The process of connecting the sleeve and armhole from virtual simulation requires study of many factors, which will be provided the necessary three-dimensional position of the armhole and the sleeve under the influence of those factors.

The sleeve cap and armhole line are initially designed on flat pattern. After transfer from 2D to 3D space, the lines change their configuration and take shape under the complexly directed force field. Mathematical modeling of an armhole requires the formalization of many factors. Include the ease of sleeve and bodice, materials stiffness and thickness, production process, etc.

Several basic principles of sleeve fit were proposed and verified to fit the whole sleeve after virtual sewing, including pattern, avatar, and dummy with subjective and objective evaluation experiments. Meanwhile, image analysis technology also is utilized for automatic fit evaluation. The grayscale databases of sleeve with representative indexes were constructed. The databases and the associated derived deviation distance, grayscale offset, weighted subjective score, etc., can be applied to automatically evaluate the sleeve shape, help find the misfit reason, and explore the relation between subjective and grayscale fit evaluation.

Virtual simulation,2D and 3D CAD pattern making, Python, and FlexiForce ergonomic pressure sensor, real garment fitting, and grayscale evaluation were used in this study, which desired to process defects and deficiencies in sleeve assembly to armhole from a structural parametric perspective.

CHAPTER 1. CONTEMPORARY SITUATION OF REAL AND VIRTUAL DESIGN OF CLASSIC WOMEN JACKET

The jacket was formed in the middle of the 19th century. Since then, the prototype of the modern jacket has emerged. In those days, jackets were worn only by men on various occasions. In 1930, the famous Hollywood actress Marlene Dietrich wore a simple men's tuxedo jacket in the movie "Morocco"[91], which sparked a fashion craze in Hollywood for women to wear men's clothes. Coco Chanel was also a great proponent of promoting women wearing men's jackets and thus casting away the conservative clothes that women would wear at that time [32, 102].

After World War II, women left their families for work, then the jacket was accepted by more and more working women for their practicality and convenience. Frankly speaking, it was less than a century before women started wearing the jacket.

As a traditional labor-intensive industry, the jacket developing process was performed manually by the experienced pattern maker or tailor, which was time-consuming, materials-using, and sometimes unsatisfying. With the development of intelligence, digitization, virtual reality, and automation technology, the jacket is undergoing rapid iteration and improvements such as illustration design, pattern construction, mass production, sales, and service. The traditional jacket development process and experience-based pattern making and sewing technology need to be reformed to meet the requirements of contemporary digitalization.

However, contemporary fit evaluation for women's classic jacket sleeve is lacking. The sleeve structure will be more complex than other parts of the jacket because the sleeve needs to assemble with armhole. Some structural problems can be detected only after assembly. In addition, although the structural design and fit evaluation are shifting more attention to virtual platforms, the existing virtual fit evaluation study still needs to be improved to reflect the real fit situation. Consequently, the new method of pattern making and database should be investigated to develop women's classic jacket sleeves.

The purpose of this chapter is to present the existing information from literature and resources to exam the scientific research status, practical situations, and existing problems of fit evaluation to enlighten new databases and methods of women's classic jacket sleeves.

1.1. Shape and style of classic women's jackets and its sleeves

1.1.1. The definitions of classic women's jacket

The object of this research is classic woman jackets and their sleeves. Traditionally, classic jackets would have been more structured or tailored and made from wool fabrics [86]. Many jackets have lapels or revers like a traditional gentleman's jacket, but many have not (as Chanel style). Jackets can be collarless, fitted, boxy, long, short, structured or unstructured. The fabric choice is also endless. However, when we query the fashion dictionaries and related encyclopedias. There is no such thing, but several concepts are related to it. There are several definitions of jacket and related words.

Jacket: Jackets are generally long-sleeved and fastened with buttons snaps down the front. From Middle French"Jacquet", diminutive of old French "Jaque", there are several explanations of jacket.

- Jacket means a piece of outside clothing worn on the upper body a shirt or blouse, often waist to thigh length. It is a piece of a person's suit, besides trousers and, sometimes, waistcoat; coat [64].

- Jacket means a piece of clothing worn on the top half of the body over a shirt, etc., that has sleeves and fastens down the front; a short, light coat [66].

- A garment for the upper body usually has a front opening, collar, lapels, sleeves, and pockets [65].

Classic: There are several explanations of the classic. Classic means something that's very high quality, particularly if it has lasting value. Classic also is continuity, a classic style from decades ago looks aesthetically pleasing today.

- Exemplary of a particular style; defining a class/category [25].

- Characterized by simple tailored lines in fashion year after year [24].

- Timelessly elegant Items of clothing; never look old-fashioned and, although subtly reworked from time to time, retain discerning purchasers. Trench coats, cashmere jumpers, tweed jackets, and brogue shoes belong to the classic style [33].

Classic women costume: The English classic women costume are jacket, shirt and vest as a prototype. Women costume collars and ties were borrowed from the men classic suit in the 1850s. By the beginning of the 20th century, women's classic suits became the benchmark of urban day outfits. In the 20th century, it also underwent some changes as the office or business outfit.

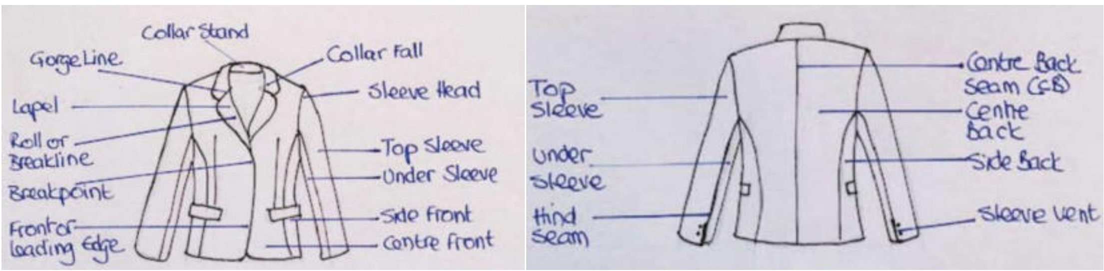
Sleeve: It means a section of a garment that encloses all or part of the arm and is attached to the arm-hole of an upper-body garment by ties or stitching. Many variants in size and style are existing, such as set-in sleeve, raglan sleeve, kimono etc. [51, 110].

Women's jacket: Women's jacket is designed like a men's jacket and made of materials similar to men's, designed for working businesswomen. The Fair child's Dictionary interpretation of the classic female suit cites the male suit, which classic men suit and jacket with conservative style, designed for wearing during the daytime in the office or other cases, including formal and semi-formal cases. Checkered and bright fabrics are unacceptable. It can be with one, two or three buttons [83]. There are two types of women's jackets, namely unisex jackets and jackets with more feminine traits. Women have been wearing men's jackets for a long time, which led to some women's jacket being unisex, loosely, semi-fitted, or oversize. Others are considering the women's figure, which is slim and meant to complement the curves of the person who wears it [127].

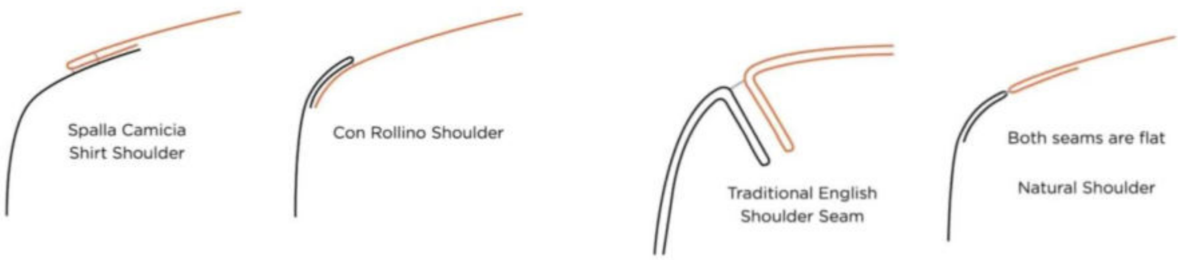
Those explanations define the classic women's jacket literally. However, none of the concepts contains a quantitative index relating to the jacket. Obviously, the measurable properties of the different parts of the jacket are not constant in different periods of fashion history. In the long course of fashion history, attributes of women's jackets are under modification.

Figure 1.1 - Women jackets of classic style (1940s) [26]

The women's jackets in classic style are shown in Fig. 1.1, classic jackets are constructed of multiple panels. The sleeves have a slight natural curve and are made of two pieces of panels to make it comfortable to move in and suitable for daily life. Due to the underdeveloped artificial fibre industry at the time, classic women's jacket (CWJ) was made from a combination of different types of wool. The buttons are attached at the centre front for the jacket, which the quantity depending on the style. The most common colors of materials are black and gray in different shades.



a



b

Figure 1.2 - The structure of classic women's jackets: *a* - jacket structure, *b* - sleeve assembly seam on shoulder [86, 120]

As shown in Fig. 1.2,a, CWJ is a comprehensive vocabulary. Reviewing the structure of a jacket with terminology description can help the reader better understand what a classic women's jacket is. The focus of this study is sleeve part. The sleeve is divided into two pieces, named as top sleeve and under sleeve respectively, the sleeve and bodice assembly seam around the shoulder point (sp), front armpit points, and back armpit point, this kind of sleeve is named set-in sleeve. The shoulder confirm the body's shoulder, not particularly exaggerated, but the shoulder pad and sleeve head are filled for a better look [7]. As shown in Fig. 1.2,b, Con rollino shoulder and Traditional English shoulder seam will be adopted for sleeve assembly seam. The Spalla camicia shirt shoulder and Flat nature shoulder are excluded because they do not meet the CWJ requirement of sleeve sewing [63].

Ye hongguang has made fruitful contributions to CWJ research from image recognition [137]. Fig. 1.3 shows the geometrical parameters of CWJ with total 20 measurement indexes (internal and external shape).

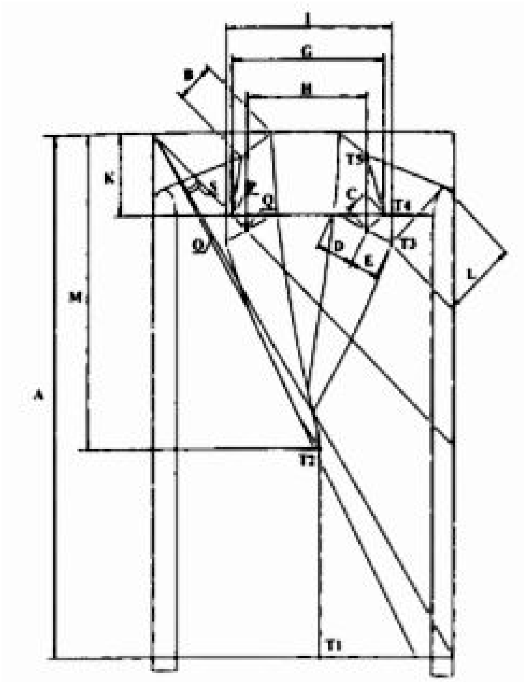


Figure 1.3 - Geometrical parameters measurement of CWJ [137]

Based on the measurement indexes of Fig 1.3, Table 1.1 shows the more popular proportions existing between geometric parameters to recognize the time when each jacket has been designed.

Table 1.1 - Basic proportion of design solution for women's classic jacket [137]

Time period	The proportional relation between several parameter indexes				
	M:A	I:M	G:I	H:I	SHW:W_{w}:H_w
1950s	/ $A = 52.8$	/	/	/	1:0.81:1.11 $Sh_w = 38.4; W_h = 34.2$
1960s	1:2.04 $A = 58.3$	1:1.52	1:0.95	1:1.3	1:0.88:0.98 $Sh_w = 41.8; W_h = 35.9$
1970s	1:2.22 $A = 59$	1:1.15	1:0.9	1:1.39	1:0.85:1.04 $Sh_w = 35.4; W_h = 34.7$
1980s	1:1.89 $A = 67.6$	1:1.64	1:1.03	1:1.47	1:0.8:1 $Sh_w = 41.7; W_h = 38.4$
1990s	1:2.08 $A = 65.3$	1:1.37	1:1.1	1:1.54	1:0.75:0.94 $Sh_w = 44.7; W_h = 39.2$
2000s	1:1.95 $A = 57.3$	1:1.18	1:1.03	1:1.39	1:0.73:0.97 $Sh_w = 38.7; W_h = 36$

Notes: 1. M - first buttonhole height ; A - jacket length , I - distance between the corners of lapels, G - distance between the collar corners H - , distance between the extreme point of lapel and collar (Fig. 1.3,a), SHW - Shoulder width, W_w - waist line width, H_w - hip line width, W_h - waist line height. 2. 1950s jacket predominant with offset side buckles, the ratio could not calculate, which marked.

As shown in Table1.1, the characteristics of women's jackets have been evolving in eras from the 1950s to the 2000s. on the basis of these proportions, the corresponding geometric algorithm and automatic identification software of women's classic jacket style are established [137], The characteristics of CWJ sleeve can be described in several words: set-in sleeve, two pieces sleeve (TPS) of top and under, sleeve length ending just at the wrist bone, suitable geometrical parameters proportion, and correct sleeve assembly seam.

1.1.2. A brief history of women's jacket

The women's jackets have originated from men's wear. It may be worth mentioning that a suit comprises the jacket and pants (even a vest) with matching fabric that forms a set. Meanwhile, from mid -17th to the present, the meaning of jacket is constantly changing, which the language words reflect the thought of times changes.

The jacket's history can be traced back to the Justaucorps of Louis XIV in the second half of 17th century. The Justaucorps meant fitted garments and were used as military uniforms since the 16th century [69]. Considering the convenience of military training, these kinds of sleeves were designed as two pieces. At that time, the sleeves of women's clothing were one piece. Therefore these kinds of sleeves of Justaucorps also were called men's sleeves. Fig. 1.4,a shows the set-in sleeve prototype of Justaucorps.

Figure 1.4 - The “jacket” in different eras: *a* - Justaucorps in 1700s, *b* - Tailless lunge jacket in 1850s, *c* - The women jacket in 1910s-1920s, *d* - Bar jacket from Christian Dior's new look in 1947, *e* - Chanel jacket of tweed and collarless, *f* - “Le Smoking" tuxedo jacket of YSL, *g* - the jacket style of Angela Merkel [2, 6, 70, 78, 123, 124]

The jacket undergoes constant change, which include Forck, Macaroni suits, Morning coat, Tail coat, etc. These clothes are significantly different from the classic style jacket we know today. Until the Victorian era in the 19th century, the tailless lunge jacket (sack jacket) was similar to what we know as a classic style jacket, which can be observed visually in Fig. 1.4,b. As the name implies, although men have worn this loose style jacket, it is only used for casual, informal occasions such as lounges resting, travel outings, walking, etc. During this period, George Bryan Brummell (1778-1840), Edward VII (1841-1910), Disraeli Benjamin (1804-1881) contributed significantly to the popularity and development of men's jacket [34, 37, 56, 57, 122].

World War I resulted in the death and injury of a large number of men. During this period, an unprecedented number of women have to into the workforce. After the war, the women's rights movement developed and broke through the male-dominated society. Women socialize by imitating men's behaviour and wearing and in psychology and consciousness. With the development of society, women demanded the same social status as men (e.g., Women's suffrage). Between 1918 to 1945, the jacket was accepted by most British women as daily wearing [130]. During World War I, clothing styles changed considerably. Designs became simple, and gender-based fashion boundaries started to blur [30, 138]. As shown in Fig. 1.4,c, the lady wearing the plaid suit tailored by Robert Heath's of Knightsbridge, The skirt can be buttoned when she walks.

The outbreak of World War II and the occupation of France cut off all contact Parisian fashion with foreign countries for several years. It was the era of substitute materials. During the post-war era, Dior's fashion-forward design helped uplift the gloomy mood. As shown in Fig. 1.4,d, until the surprise of the "new look" (bar jacket) introduced by Christian Dior in 1947. the women's silhouette once again became waisted and feminine [14, 70].

As shown in Fig. 1.4,e, Coco Chanel wanted women to exude elegance while allowing them to move freely, which led to the birth of the tweed jacket in the 1920s. The tweed was inspired by the sportswear that belonged to her then-boyfriend, the Duke of Westminster. The slim skirt and the collarless jacket were dubbed "Chanel's uniform" [123].

Yves Saint Laurent stepped onto the fashion scene in 1966 with the creation of the "Le Smoking" tuxedo jacket. As shown in Fig. 1.4,f, this style is inherent to the brand's aesthetic today, and it pioneered long, minimalist, androgynous styles for women [75].

Getting dressed for work can be a struggle for women. Professionalism is most important in high-powered fields like statesman, law, business, and finance. People expect women to look conservative and traditional. In this expectation, women's jackets are essential.

Pre-Britain's first woman Prime Minister Margaret Thatcher developed her signature style of Downing Street, which is blue uniform, swept-back hair, and pearls necklace [60]. Meanwhile, regardless of fashion trends, Angela Merkel's style rule constantly is the same jacket model: single-breasted straight cut with three (or four) buttons, sometimes lapels, sometimes none. Hamburg-based designer Bettina Schönbach is the author of the iconic wardrobe item. As shown in Fig. 1.4,g, in her 16 years as German chancellor, she had quietly forged a functional personal style that has enabled her to get on with being one of the world's most powerful women [6].

Through a comparison between Fig. 1.4,c to 1.4,g, it can be seen that the style of women's jackets is in continuous evolution, but they are almost no changes in the sleeve part. The two pieces set-in sleeves have been preserved by women's jackets.

In summary, through the investigation of the definition and history of classic women's jackets, the purpose and object of this study can be determined. The women's jacket would live on to become the symbol of fashion style and the representation of the liberated woman.

1.2. Methods of sleeve pattern block constructing and drafting

The pattern drafting process plays an important role in clothing development and production, which is the extension of the fashion illustration and the basis of the sewing process. Paper patterns became very common in the 19th century and were available in the market [36]. Traditional pattern making is empirically oriented. Some index parameters are known only by the empirical values but not by the reasons behind the values. The parameter's value needs to be considered together with body size and ease-allowance to obtain an appropriate jacket pattern to provide a good fit and appearance [11]. Nowadays, some middle-aged women are less satisfied with their jackets because their bodies are no longer slender, reflecting the lack of consideration for body size in pattern making [71]. Current pattern construction methods rarely explicitly state the levels of ease incorporated in patterns, which lead difficult to retain pattern shapes objectively.

The earliest known tailoring manuals are Spanish. These are Juaan de Alcega's Libro de Geometric Practica y Traca of 1589 and La Rocha Burguen's Geometricay Traca of 1618, which introduces mathematical standardization in clothing pattern making. In 1834, German mathematician Henry Wuber for the first time in his textbook introduced proportion pattern skill. In 1871, "Mathematical proportion and structural for gentleman's clothing" was published in Britain. This book brought the clothing structure skill into the modern science and technology category [45]. the most revolutionary technological development in the history of pattern making is the tape measure in the 1800s. Until that time, tailors developed their own non-standardized measurement system, which made it difficult to copy patterns [121].

Pattern block of sleeve and bodice can be constructed in many different styles and silhouettes. Sleeve structure is dictated by fashion and style at any given time. For historical reason, set-in TPS commonly used on women's jacket. Fig. 1.5 shows the sleeve style, which needs trial and error by basting, adjusting, and stitching for a perfect fit appearance, thus presenting a more professional, formal, and high-quality appearance.

Figure 1.5 - Contemporary CWJ TPS under basting for fitting [31]

There is a tight relationship between pattern making and anthropometry. To get a satisfactory pattern, it is necessary to get the correct body size [35]. The pattern dimension can be calculated by the following equations (1.1) and (1.2):

Firstly, from body measurement and ease:

$$P = M+E, \tag{1.1}$$

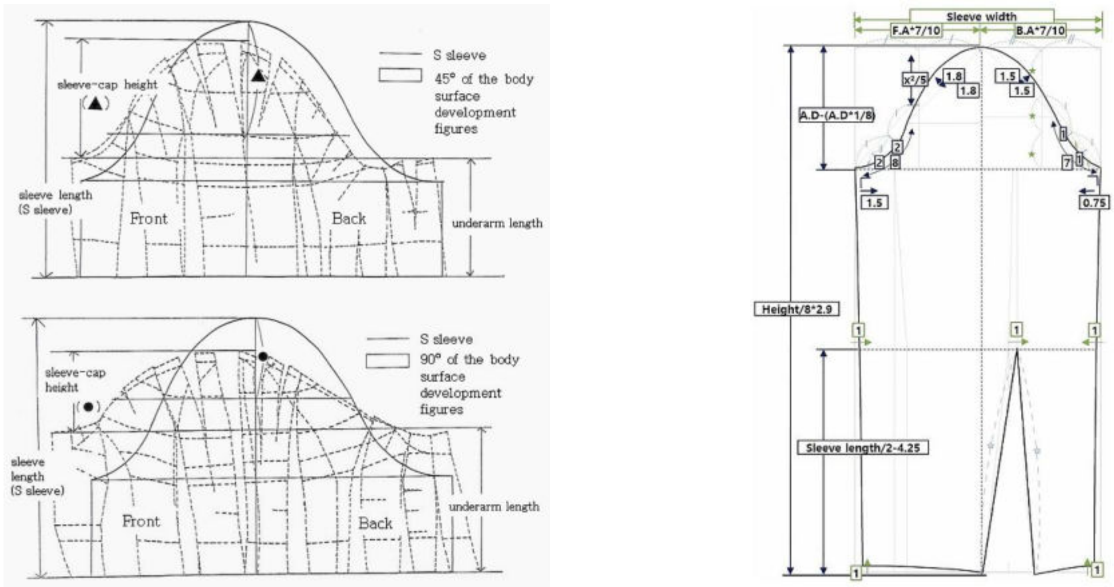
where *P* is the pattern dimension, *M* is the body measurement, *E* is the ease-allowance of movement and style requirement;

Secondly, from body measurement and ease with related coefficient and constant value:

$$P = aM + bE + c, \tag{1.2}$$

where *P*, *M*, and *E* remain the same meaning as equation (1.1); *a*, *b* are the coefficients, *c* is the constant value.

For sleeves pattern making, the equation (1.1) is directly determined by body measurement and ease-allowance. The equation (1.2) is determined by the empirical coefficient. Both of these two ways are usually adopted for pattern block construction.



a *b*

Figure 1.6 - Sleeve pattern construction: *a* - sleeve basic pattern and the arm skin surface of different posture, *b* - the example for parametric sleeve patternmaking method [23, 55]

For sleeve pattern drafting, Cho Kyunghee obtained the relation between the arm skin surface changing and sleeve pattern indexes in standing and different arm posture situation [23]. The relationship theory of the body surface development with the pattern was derived by reviewing the suitability from the wearing state. As shown in Fig. 1.6,a, the different body postures corresponding to different sleeve cap heights. Base on the parametric theory, Hyunsook Han proposed the novel sleeve pattern making method that enables mass customization [55]. As shown in Fig. 1.6,b, the sleeve pattern example can be drafted by Hyunsook Han's method. In this study, the existing pattern making methods and expert appearance evaluation were analyzed. The method of procedural sleeve pattern making by defining the main points and lines of the sleeve pattern was put forward.

In addition, Simeon Gill et al. designed a comparison experiment to reveal the ease-allowance difference between several widely used pattern construction methods. The results indicate that the acceptable ease range of each parameter index can be ascertained and guided pattern construction [48]. Yu Chen et al. propose a new method of ease-allowance generation for individualized pattern design, which uses fuzzy techniques and sensory evaluation of wearers. This new method allows estimating more suitable values of ease-allowance for patternmaking [21].

Hwang Seon-Ha et al. investigated pattern parameter size of sleeve cap height (SCH) and armhole depth (AHD), which give the proper index values of good appearance of 20 females' basic posture and allowing light sports in industrial production [59]. This fit evaluation study includes three kinds of wearing conditions in six experimental jackets. In the calculation, bust width of pattern (BW_p) is used to calculate AHD, and armhole length (AHL) is SCH. Table 1.2 lists the equation of values calculation, the recommend combination of AHD and SCH can be used as experience to help production.

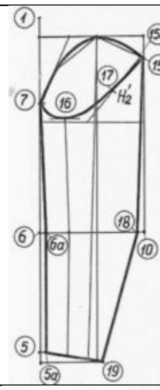
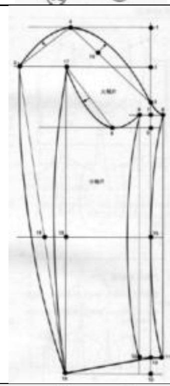
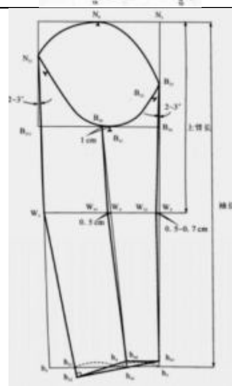
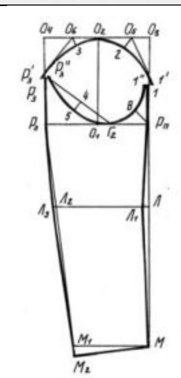
Table 1.2 - Recommendation values of armhole depth and sleeve cap height [59]

	Recommend values of good external appearance			
	For basic posture		Allowing light sports	
AHD	$BW_p/4-1$	$BW_p/4-1$	$BW_p/4-1$	$BW_p/4$
SCH	AHL/3+2	AHL/3+1	AHL/3	AHL/3

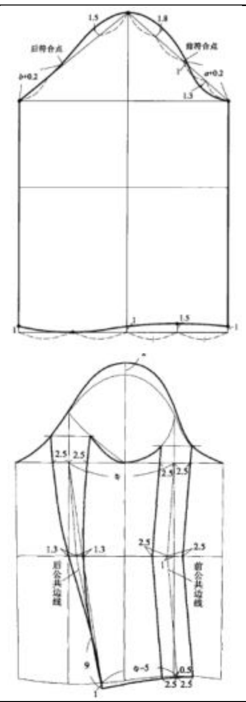
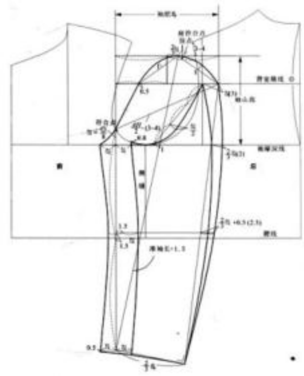
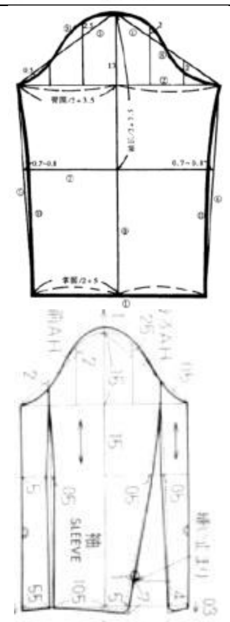
There are two pattern making methods in terms of current sleeve patterns. The first is to make the TPS pattern directly, and the second is to construct a one-piece sleeve prototype and then transform it to desired TPS.

Due to historical, regional, and ethnic reasons, there is not a uniform method of worldwide pattern making. The TPS pattern construction method varies in different countries: Germany (Müller and son); the UK (Aldrich); Russia (MGUDT); Russian (COTSHL); China (BIFT); China (Traditional); Japan (Sugino), and Japan (Bunka). Table 1.3 lists all methods of the TPS pattern making.

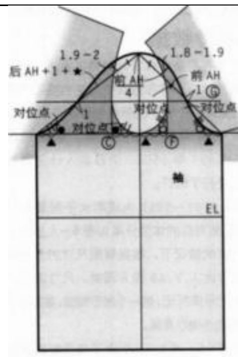
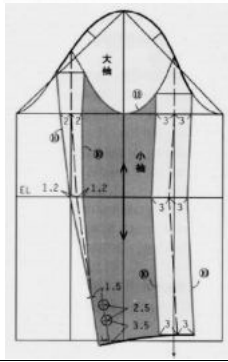
Table 1.3 - Eight pattern making methods of two- pieces sleeve

No.	Pattern making method	Pattern draft method	Scheme of sleeve
1	2	3	4
1	Müller and son, Germany [149]	Draw directly	
2	Aldrich, United Kingdom [3]	Draw directly	
3	MGUDT, Russia [13, 139]	Draw directly	
4	COTSHL, Russia [147, 148]	Draw directly	

Continue Table 1.3

1	2	3	4
5	BIFT, China [83]	Draft from one-piece prototype, than transform to two pieces	
6	Tradition, China [84]	Draw directly	
7	Sugino ,Japan [115]	Draft from one-piece prototype, than transform to two pieces	

Finish Table 1.3

1	2	3	4
8	Bunka, Japan [88]	Draft from one-piece prototype, than transform to two pieces	 

Notes: for flat pattern techniques a basic pattern, called prototype.

Table 1.4 shows which body measurement and pattern indexes are required in the eight methods of pattern construction.

Table 1.4 - Body measurements and pattern indexes pattern making method for armhole-sleeve

No.	Index	Symbol	Application in pattern making							
			Müller (DE)	Aldrich (UK)	MGUDT (RU)	COTSHL (RU)	BIFT (CN)	Tradition (CN)	Sugino (JP)	Bunka (JP)
1	2	3	4	5	6	7	8	9	10	11
Body measurements										
1	Bust girth	BG	√	√	√	√	√	√	√	√
2	Arm girth	AG	-	√	√	√	-	-	√	-
3	Elbow girth	EG	-	-	-	-	-	-	-	-
4	Wrist girth	WG	√	-	-	√	√	-	√	√
5	armscye girth	ASG	-	-	-	-	-	-	-	-

Finish Table 1.4

1	2	3	4	5	6	7	8	9	10	11
6	Chest girth	CG	-	-	-	√	-	-	-	-
7	Neck girth	NG	√	√	-	-	-	-	√	-
8	Shoulder line	SL	√	√	√	√	-	-	√	-
9	Shoulder width	SHW	-	-	-	-	-	√	-	-
10	Back width	BW	√	√	√	-	-	-	√	-
11	Chest width	CW	√	√	√	-	-	-	√	-
12	Armhole depth	AHD_B	-	-	√	-	-	-	-	-
13	Cap height of body	BCH	-	-	-	-	-	-	-	-
14	elbow length	EL	-	-	√	-	-	-	-	-
15	Arm length	AL	√	√	√	√	√	√	√	√
16	Back length	BL	-	√	√	-	-	√	√	-
Bodice parameter measurement										
17	Armhole length	AHL	√	√	√	√	√	√	-	√
18	Armhole depth	AHD	√	-	√	√	-	√	-	-
19	Armhole width	AHW	√	-	√	√	-	-	-	-
	Total	**10**	**9**	**12**	**9**	**4**	**6**	**9**	**4**	

Notes: "√" represent the index required for the patternmaking. "-" represents the index not required for the patternmaking, which the pattern making method adopts another way to instead.

As shown in Table 1.4, BIFT and Bunka method make the lowest demands of anthropometry and pattern indexes: only four measurement indexes take part in sleeve and related armhole construction. However, when reviewing process, several indexes will facilitate assessment.

The Müller method needs ten indexes. It has a special feature in which some index values can be measured and calculated by equation both, suggesting comparing these two ways when pattern drawing.

Aldrich's method provides a simple introduction to pattern making, in sleeve construction, nine indexes are required.

MGUDT method requires 12 indexes, which is the most method of any others. Russian patternmaking methods of structural design are based on complex theories, which complicated formulas are the right way to really analyze the relationship between garments and the human body. The reason for COTSHL is similar to MGUDT, which requires nine indexes.

Sugino method requires sorting the size table for prototype first and then pattern making. That is why this method requires nine indexes. Patternmaker commonly uses the traditional China method to draw directly on the materials for cutting.

As shown in Table 1.4, bust girth and whole arm length are required for all methods, which means that these two indexes are the basis for pattern construction. Seven methods require armhole length, which indicates that most methods use AHL to construct sleeve cap.

All methods are geometric drawing. Using the pattern indexes based on anthropometry will undoubtedly make the result more accurate. However, the empirically geometric ways (proportions, auxiliary lines, and shapes) are easy to learn and remember.

In order to investigate the difference between eight pattern making methods (from Table 1.3), Fig. 1.7,a shows the superimposing sleeve of all methods for one armhole. In accordance with algorithm of each method the sleeve were drawn for one armhole with AHL = 42.5 cm (the armhole was drawn by Bunka method for Chinese typical body size), for comparative convenience, all sleeve cap are closed, all sleeve length are 51 cm, and cuff width are 13 cm. The sleeve patterns are superimposed in following way.

1. Sleeve redrawing.

2. Determining the lowest point of sleeve cap.

3. Drawing the line of sleeve cap width (SCW).

4. Superimposing the sleeve by the lowest point of sleeve cap.

5. Measuring the indexes of SCH, SCW, Sleeve cap curvy length (SCL), sleeve sloping (Ss), distance between down sleeve cap curve and SCW - elbow seam across (l1), and distance between down sleeve cap curve and SCW - front seam across (l2) for comparison.

6. Calculating distance between sleeve cap curve and armhole length (Sleeve Δ).

7. Calculating corresponding data of top point of sleeve elbow seam (SE), top point of sleeve front seam (SF), and top point of sleeve cap (ST).

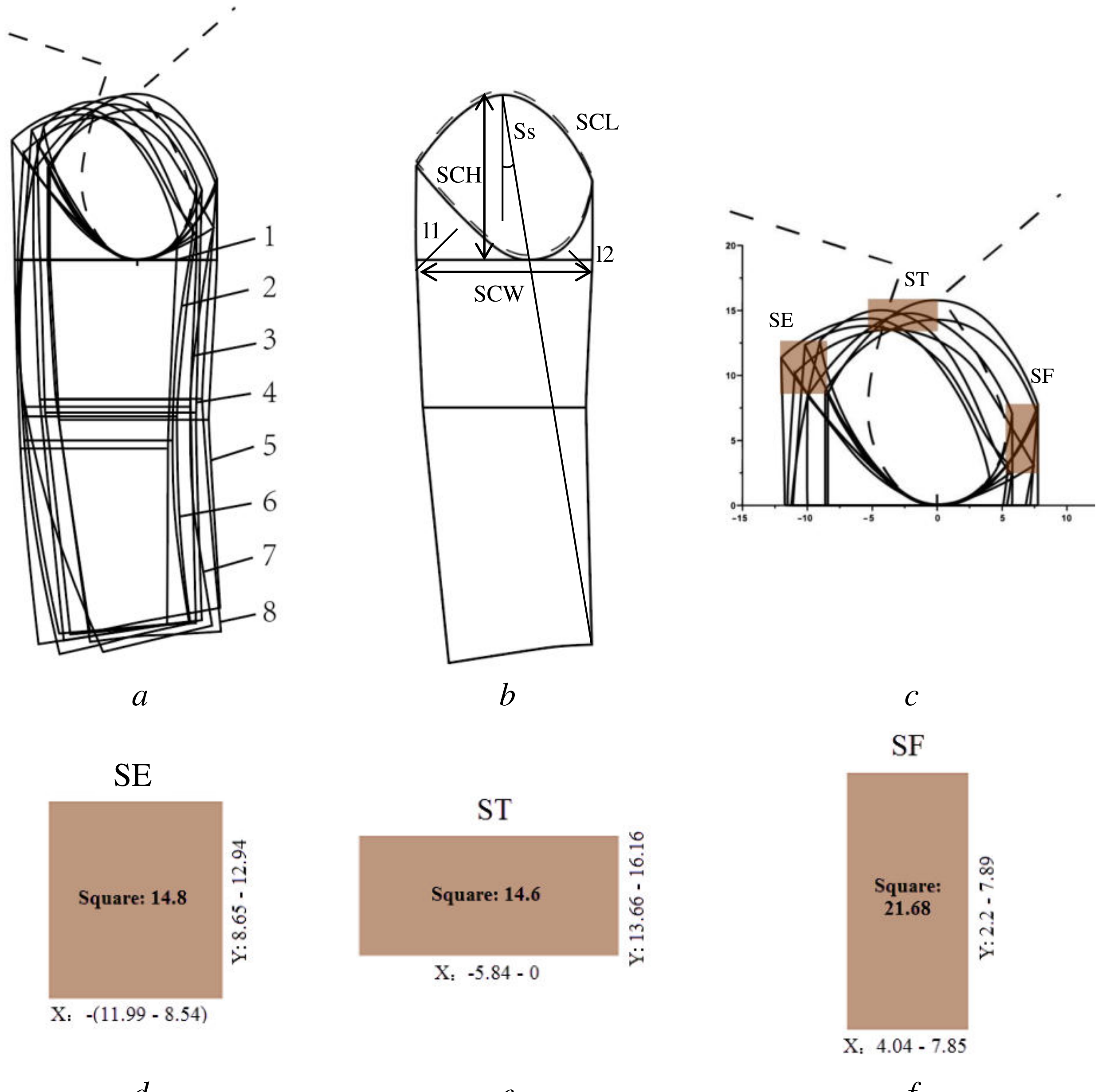


Figure 1.7 - Superimposing sleeve pattern block by eight method: *a* - sleeve pattern overlapping, *b* - several key pattern indexes, *c* - sleeve feature points coordinate range, *d* - detail of SE, *e* - detail of ST, *f* - detail of SF

As shown in Fig. 1.7,a, the overlapping point is at the lowest point of the armhole and sleeve cap (the pattern number is identical to Table 1.3). Note that, with the exception of sleeve cap and armhole, the rest of the sleeve is different for the different methods. In order to better reveal these differences, six parameters of SCH, SCW, SCL, Ss , l1, l2 were marked on Fig. 1.7,b.

As shown in Fig. 1.7,c,d,e,f, the SE, SF, ST are selected and marked. The detail of each points are SE (x: -11.99 ÷ -8.54 cm, y: 8.65 ÷ 12.94 cm, square: 14.8 cm^2), SF (x: -5.84 ÷ 0 cm, y: 13.66 ÷ 16.16 cm, square: 14.6 cm^2), ST (x: 4.04 ÷ 7.85 cm, y: 2.2 ÷ 7.89 cm, square: 21.68 cm^2). The comparison reveals that the dispersion of SE and ST are similar. However, the dispersion of SF is significantly larger than SE, ST. This result illustrates that the eight different pattern-making methods are even more dramatic when drawing the front sleeve cap part.

Table 1.5 - Sleeve indexes of sleeves from different pattern making methods

No	Patterning method	Sleeve parameters						
		SCH, cm	SCW, cm	SCL, cm	Ss,°	l1, cm	l2, cm	Sleeve Δ, cm
1	Müller	14.74	16.00	46.49	9.58	6.90	1.40	4.06
2	Aldrich	14.16	16.44	45.32	12.04	6.98	1.93	2.89
3	MGUDT	15.56	15.76	47.47	9.21	6.01	2.96	5.04
4	COTSHL	15.06	16.10	46.47	8.93	5.76	2.65	4.04
5	BIFT	16.16	16.39	48.61	9.49	4.72	3.88	6.18
6	Tradition	15.34	16.88	45.94	10.86	7.27	1.94	3.51
7	Sugino	13.66	18.78	48.73	12.61	6.60	2.41	6.30
8	Bunka	14.63	16.10	46.69	9.30	5.00	3.51	4.26
	Total range	13.66 - 16.16	15.76 - 18.78	45.32 - 48.73	8.93 - 12.61	4.72-7.27	1.4-3.88	2.89-6.30
	Average	14.91	16.56	46.97	10.25	6.16	2.59	3.59
	Stand deviation	0.80	0.96	1.22	1.41	0.94	0.84	1.22
	Coefficient of variation, %	**5.33**	**5.80**	**2.59**	13.74	15.35	32.55	33.97

As shown in Table 1.5, all methods have different parameter values. However, based on experience, these differences are not enough to cause serious misfit. In coefficient of variation part, the parameter SCH, SCW, and SCL are stable, other rest are highly discrete.

It is well known that SCH, SCW, SCL are the essential parameter for sleeve construction, comparing the values of each method with the mean values in these three parameters, the results show that Bunka' values are the closest to the mean value (SCH: 14.63 → 14.91, SCW: 16.10 → 16.56, SCL: 46.69 → 46.97). Besides, this method is prevalent using in Chinese institutes and colleges. For the above reasons, the Bunka method will be used to build the pattern database of training samples in this study.

Different pattern block construction and drafting methods require different anthropometry levels, and the drafted pattern indexes values are also different. These differences will impact the final fit of the sleeve. As the jackets are worn on the body, it is necessary to consider both pattern construction method (previous experience), body size, and proper ease-allowance to obtain a satisfactory pattern. So, it is necessary to develop the a system which can evaluate and predict the fit of pattern before sewing real samples.

1.3. Contemporary computer-aided system for virtual try on

The computer-aided design (CAD) system has brought new opportunities for fashion industry, which help to reduce labor, material cost, production time and improve consumer satisfaction [117]. Compared with the manual method, the CAD system is much more productive, especially providing great advantages in responding quickly to multi-piece, multi-size orders in small quantities [93].

The CAD software can be divided into 2D and 3D. The application areas of the production process can also be divided into pattern drafting, sizing grading, pattern lay marker, cutting, production process control, display, and fitting direction, etc [151, 152].

1.3.1. 2D CAD

In terms of the development of CAD technology, the 1960s was the beginning of CAD. Since 1960, Ivan Sutherland developed the "SKETCHPAD" using the TX-2 computer built by MIT Lincoln Laboratory, which is considered to be the first step in the CAD industry [1, 17]. Meanwhile, before that time, Dr. Patrick J. Hanratty, had already designed the first numerically controlled CAM called PRONTO [9]. In the early 1970s, Hughes (corporation of United States) and Sojitz (corporation of Japan) sent commercial information on computerized patternmaking and scaling to China, which opened the link between the Chinese fashion industry with CAD technology [58, 111].

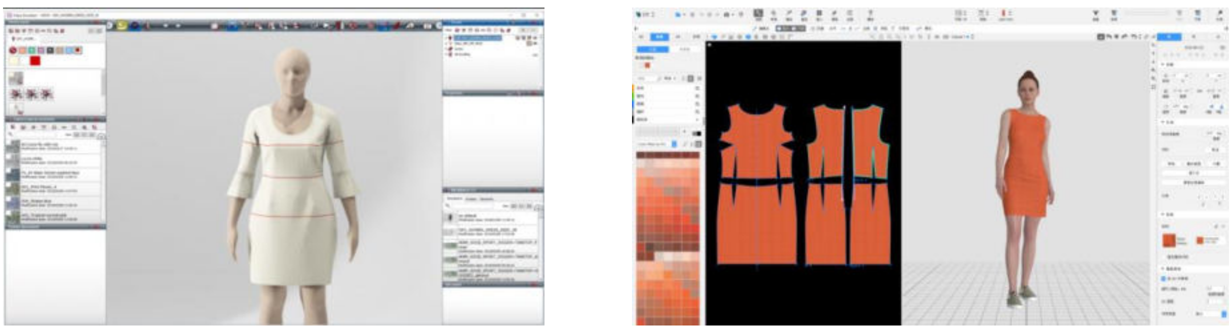
The popular 2D CAD software includes CAD Assyst (Assyst GmbH LLC, Germany), PAD System (Pad System LLC, Canada), GRAFIS CAD Clothing (GRAFIS Co, Germany), Modaris (Lectra LLC, France), Richpeace (Richpeace Co, China), TUKACAD (Tukatech Co, USA), Boke (Boke technology Co, China), ET SYSTEM (BUYI Technology Co, China), etc. [13, 16, 40, 50, 89, 94, 103]

The 2D CAD software usually includes three modules of pattern construction, grading, and marker making. The 2D CAD system iterating led to continuous improvements in mass production efficiency.

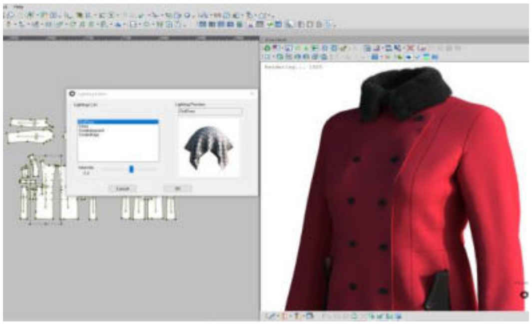
1.3.2. 3D CAD

Industry 4.0 includes many fundamentally new components offered by modern technology. The most important task of their rational use is to integrate the enormous volume of human knowledge accumulated by this time in narrow professional areas, which include fashion design, into computer technology. Generating digital twins (DT) at different product life stages by 3D virtual simulation is a hot topic for the fashion industry [144].

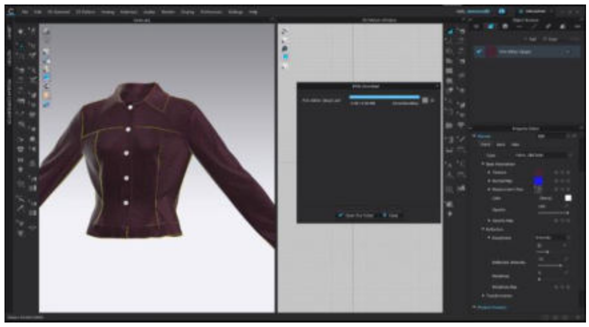
Several CAD software companies have branched out 3D modules and systems to meet the fashion industry's requirement of virtual simulation. Fig. 1.8 presents the popular existing 3D CAD software, which are Vidya (Assyst GmbH, Germany), Vstitcher (Browzwear Solutions Pte Ltd., Singapore), PDS (Efi Optitex Ltd, USA), and Clo3D (Clo Virtual Fashion LLC., Korea) [27, 99, 128, 129].



a *b*



c



d

Figure 1.8 - Contemporary popular existing 3D CAD software: *a* - Vidya, *b* - Vstitcher, *c* - PDS, *d* - Clo3D [27, 99, 128, 129]

As shown in Fig. 1.8, these softwares are usually composed of similar modules, which realize the function of pattern drafting, 3D avatar editing, 3D fashion design, materials property editing, 3D sewing, 3D virtual fitting, etc. The modules for the sleeve-armhole part are described as follows.

a. Pattern drafting: 3D CAD software comes with a built-in pattern module, but now its' function is not as improved as 2D CAD, usually the pattern drawing in 2D, then import to pattern editing module of 3D CAD for checking.

b. 3D avatar editing: The module can generate the default built-in avatars and be modified to adapt individual requirements (e.g., athlete's arms).

c. Materials property editing: This module includes editable properties of digital materials, which will affect the sleeve's draping effects. Meanwhile, several accessories related to sleeve part (e.g., sleeve head, sleeve pad, adhesive interlining, etc.) also affect the draping effect.

d. 3D sewing and simulation: These modules can effectively sew and simulate the sleeve with armhole into 3D shape, which express the high visualized quality of the sleeve.

Each of the four 3D CAD software has its own characteristics. The specifications are as follows:

Browzwear is the pioneer of fashion in 3D software companies. The Vstitcher is across platform of Windows or Mac based computers. Browzwear's software is not a one-stop-shop. The designer often uses Vstitcher and Lotta both. However, this software is mainly available only if you are working for a corporate company. The indie program needs tedious apply (not easily available), and the price of using is not friendly for indie or freelancer designers [28].

Optitex offers a holistic approach to fashion design. The PDS is the cutting-edge pattern design software of Optitex company, which combines robust 2D design with realistic 3D visualization. However, the software only works on Windows and the usage costs of $1,000 or more per quarter are still not friendly enough for the indie designer, not even to mention students [132].

Vidya sketch is used for pattern simulation and modification, which shows new 3D possibilities in design and product development. However, it is the most difficult to access free tutorial videos and resources. The YouTube channel named Assist GmbH (consistent with the name of the company) has less than 50 subscribers (December 1st, 2021). The latest update of these 28 videos was one year ago, not for tutoring [10].

CLO Virtual Fashion LLC has two branches of simulation software. One is the Marvelous designer, famous in the computer graphics and gaming industry, and the other is Clo3D which focuses on the fashion industry. Clo3D remains the cheapest option, and the student discount is also available, which is friendly to the indie designer and student. It is convenient to download the trial version, access the tutorial video, and explore the official guide, without registering or logging in. The user will find what they need on the official website or YouTube channel. They are more than 37000 subscribers and 400 videos on Youtube [29]. Tips and tricks can also be free to obtain through the official channel. In addition, in every update (twice a year), they will hold online seminars for new functions introduction (global departments provide more than nine languages).

The simulation result of Clo3D may not be the best, but its network media promotion, free tutoring, pricing, and accessibility are the best. During the 30 days free trial, most users already learned some software operation skills through free guidance of videos and web pages, which will encourage clients to pay for software. For these reasons, the Clo3D is adopted in this study.

The crucial part of 3D CAD is simulation and try-on, where the fit is predicted and accordingly pattern modified through virtual try-on. Therefore, CAD software must build the appropriate DT of body to meet the requirement of morphological sizing system. Table 1.6 compares body dimensions for generating an avatar of sleeve design.

Table 1.6 - Body dimension for generating an avatar for sleeve design

No.	Dimensions	Presence dimensions in sizing system		
		Chinese standard [22]	Russia standard [150]	Clo3D
1	2	3	4	5
Shoulder area				
1	Shouder width (side neck point (snp)- sp)	-	+	-
2	Shouder width (sp - back neck point (bnp) - sp, surface distance)	+	-	+
3	Shouder width (sp - sp, back surface distance)	-	+	+
4	Shoulder width (sp-sp diameter through body)	-	+	-
5	Surface distance of back central point of WG to sp	-	+	-
6	Surface distance form bnp - back armpit level (central back)	-	+	-
7	Front width (between two front armpit point)	-	+	-
8	Back width (between two back armpit point)	-	+	-
9	Shoulder height (bnp - sp) or shoulder sloping	-	+	+
Area between the arm and torso				
10	Distance of back armpit level - sp - front armpit level	-	+	-
11	Vertical distance of arm section	-	+	-
Arm area				
12	AG	-	+	+
13	EG	-	+	+
14	WG	-	+	+
15	Arm position (forward angle)	-	-	+
16	Arm diameter (front to back, on back armpit level)	-	+	-
17	Distance of sp - elbow level	-	+	+
18	Distance of sp - wrist level	+	+	+
	Total / Matched with Clo3D	**2/2**	**16/7**	**9**

As shown in Table 1.6, the dimensions of standards in the sizing system are presented. These are two dimensions of Chinese standard requirement, 16 dimensions of Russia standard requirement, and nine dimensions of Clo3D offering. Each dimension is specifically illustrated in Fig. 1.9. By comparison, it can be found that the Clo3D can fully meet the two dimensions' requirement of the Chinese standard. However, the Russian standard needs 16 dimensions and Clo3D cannot match it. Therefore, the sizing of avatar will be in Chinese standard.

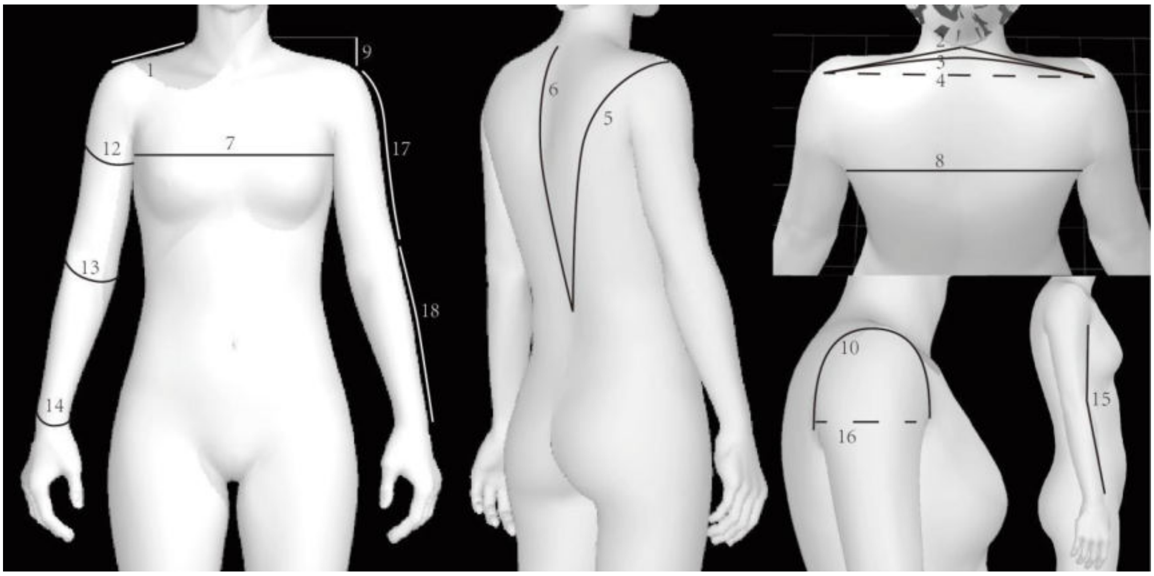


Figure 1.9 - Schematic picture of body dimension for generating an avatar for sleeve design

Table 1.7 - Avatar size table for subsequence experiment

The dimension indexes of avatar which relative to the sleeve	Size value, cm
Height	160
Bust girth	84
Neck girth	36.8
Height of shoulder neck point	136
Shoulder width	36.4
Shoulder sloping,°	3.6
Arm length	50.5
Central back- sp - wrist	71
Arm girth	27
Elbow girth	22
Wrist girth	15

Table 1.7 lists the corresponding avatar size dimensions for the sleeve, which follow the Chinese standards typical size. Due to the small number of dimensions of Chinese standards, several remaining dimensions were determined through internal algorithms of Clo3D and similar Russia dimension [22, 148]. The morphology of the arm

and related shoulder of Clo3D is comprised by shoulder width, shoulder sloping, arm length, arm girth, elbow girth, wrist girth, and arm position etc. Arm position needs to adjusting by avatar joint. Others are fine-tuned by avatar editing interaction windows. In addition, Clo3D supports the intelligent algorithm for avatar size generation and adjustment. Other standard uncovered dimensions will automatically generate after a few key dimensions are set.

One of the biggest expenses in fashion and most wasteful is making samples. In order to demonstrate the superiority of 3D CAD, previous researchers designed a series of experiments to demonstrate the advantages and limitations of 3D CAD [95,101,96,19,76]. Generally speaking, the 3D technology of virtual simulation beneficial can be summarized in the following five aspects.

1. It saves time by eliminating the lag between handing off a tech pack and making a sample.

2. It allows overseas and domestic teams to hold virtual fitting together and make changes in real-time.

3. It cuts down the turnaround time for seeing the first sample by doing it virtually.

4. Once the pattern maker sees the physical prototype, it increases the possibility of recognizing clothing fit.

5. It saves money by cutting out the expense of making a physical garment that will most likely not fit the first time around.

In conclusion, contemporary 3D CAD provides much more possibilities for the fashion industry. Comprehensive consideration variety of reasons, the Clo3D is adopted in this study. Through Clo3D, the flat patterns can be simulated into DT for objective and subjective fit evaluation, which gives the possibility of study.

1.4. Criteria of good fit

For customers who purchase clothes, fit is important. In other words, clothes fit can be regarded as the most significant conclusion to reach satisfaction [5]. A study presents that nearly 50% of women claimed that they could not find fit clothes [49]. In general, fit evaluation consists of two types of subjective and objective evaluation of clothes appearance (e.g., surface wrinkles, surface strain, seam appearance, garment balance, etc.), and other forms of fit evaluation (e.g., tension map (stress), moire, gap between body and garment, seam drop, etc.) [41].

1.4.1. Fit definition and evaluation criteria

There are various definitions of fit and evaluation criteria. The fit definitions differ due to the fashion culture, industry norms, and personal perceptions [41]. The fit evaluated criteria differ from the aspect of subjective and objective. The subjective evaluation is conducted by wearing and observing of evaluator. For objective aspect, numerical indicators are adopted in describe the fit and appearance [140, 143]. Table 1.8 presents several general definitions of the term fit.

Table 1.8 - Definition about fit

No.	Author	Definition about fit	Reference
1	2	3	4
1	Erwin and Kinchen	Fit is defined as a combination of five factors; ease, line, grain, balance and set.	[39]
2	Hackler N	Clothing should fit the body smoothly with enough room to move easily and be free from wrinkles.	[53]
3	Shen L and Huck J	Clothing which fits, provides a neat and smooth appearance and will allow maximum comfort and mobility for the wearer.	[107]
4	Chamber H and Wiley E	Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer.	[20]
5	Liechty, Pottberg and Rasband	Fit is a term used in apparel design to describe how a garment sets on the body. Correct fit is evaluated by giving attention to line (an art element), balance (an art principle) and fabric ease (a fitting principle).	[80]
6	Merriam-webster Dict	1. To conform correctly to the shape or size (e.g., These jeans don't fit me anymore). 2. To measure for determining the specifications of something to be worn (e.g., The tailor fitted him for a new suit).	[43]

Finish Table 1.8

1	2	3	4
7	Oxford learners' Dict	The right shape and size for somebody(e.g., I tried the dress on but it didn't fit).	[44]
8	Victor Kuzmichev	Fit is the indicator by which to judge design, construction, tailoring, and production, which are integrated with comfort, clothing appearance, pattern.	[135]
9	Mason, A. M	Fit is the “apparel items” silhouette and size being right for the human's body shape and dimensions.	[85]

As presented in Table 1.8, the different definitions of the term fit reflect the lack of consistency in the terminology, at least within the fashion industry. Therefore, it is necessary to know the application situation of "fit" word in detail.

In the aspect of subjective fit evaluation, Jelka Gersˇak [46] divides elements for qualitative evaluation of garment appearance quality into two parts: mechanical and physical properties of the fabrics used and consequence of garment manufacture quality. The criteria of garment appearance quality are established in four parts: mechanical properties, visual form of the 3D shape, quality of the fit, and aesthetic appearance garment draping. Fig. 1.10 shows the interrelationship between those four parts.

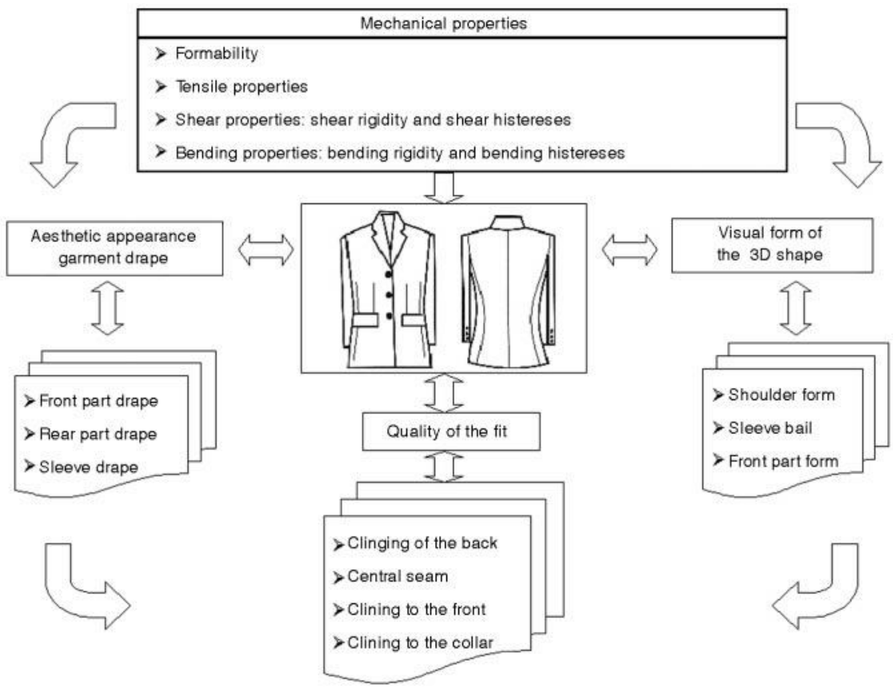


Figure 1.10 - Criteria for qualitative evaluation of clothing fit [46]

With the exception of physical fit, fit in the psychological field is also important. In the subjective fit evaluation aspect, Shin Eonyou uses five qualitative themes to understand fit perceptions of young consumers feeling, which are (1) physical fit, (2) aesthetic fit, and (3) functional fit related to (4) social context and (5) social comfort [108]. Jennifer Aklamati explores the factors affecting the evaluation of clothing fit. A total of 400 participants (half male, and half female) were recruited to complete the questionnaire about fit. After a series of statistical analyses, the result shows that: (1) Aesthetic and functional factors determine the clothing fit; (2) size, ease, fabric, comfortable feeling, and other factors are also related to fit; (3) the fit evaluation result of male and female are different [68].

The AATCC method is commonly used in the subjective evaluation of fabric appearance, while ISO 7770 method is similar to AATCC method, which has a clearer and detailed test condition description [62,104]. Fig. 1.11 shows the appearance of the button placket with five grades by the method.

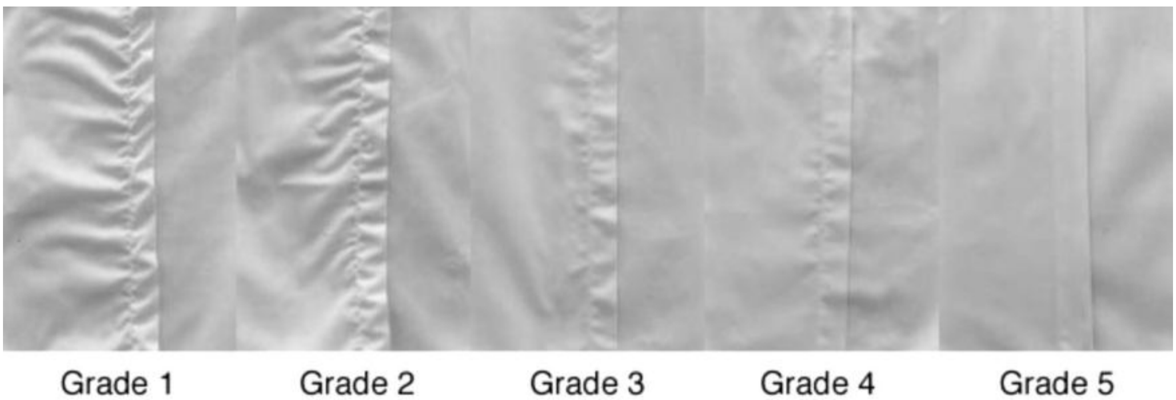


Figure 1.11 - Photographic comparative grade scale of button placket position by ISO 7770, 1985 [56]

For sleeve subjective fit evaluation, It is necessary to imitate AATCC method to construct the grade scale of sleeves, which can effectively help to improve the accuracy of subjective evaluation.

The criteria of well-fitted garment have been suggested by Simeon Gill. which include five parts [47].

(1) Grain: relating to the fabric structure (mainly woven) and how well it drapes according to the principles of grain alignment.

(2) Line: relationship between silhouette and construction and styling lines.

(3) Set: the smooth appearance of the garment, without stress folds or unnecessary creases.

(4) Balance: related to the symmetry around and over the body.

(5) Ease: the difference between garment and person; this is extensive discussion concerning sizing and pattern construction.

Gill's benchmark of fit assessment criteria suitable for all garment types, materials, shapes, etc. Because the object in the study is the sleeve of classic women jacket. Therefore, the criteria are modified as follows:

(1) Posture: The jackets are worn on the typical size models or dress form, which is standing with resting arms posture.

(2) Set: the acceptable appearance without wrinkles or folds by stress or unnecessary creases.

(3) Line: classic silhouette and styling lines of jacket, contain no special design elements.

(4) Balance: wearing jackets on the dress form or models keeps symmetry without slope. The side seam and hem are vertical.

(5) Sleeve: while following the above criteria, the sleeve needs suitable ease-allowance to address the needs of arm movement.

Wearing ease is the fullness needed for comfort and freedom of movement, permitting the garment to accommodate natural body movements like breathing and swinging the arms. It often involves minimal dimensional additions. Başak Sayğili et al. conducted the comfort evaluation of men's jackets with five daily movements as Fig. 1.12 [105].

a *b* *c* *d* *e*

Figure 1.12 - Movement posture for jacket fit evaluation: *a* - arm lateral raise 90°, *b* - tie fixing, *c* - handshake, *d* - pull backhand, *e*- arm lateral raise 90° [105]

Lin Yuehling et al. presents a novel approach for evaluating clothing fit on 3D human models, which proposes the fitting index to evaluate the fit of the garment by subjects wearing different-sized shirt patterns. Describing how the fitting index is calculated as equation (1.3):

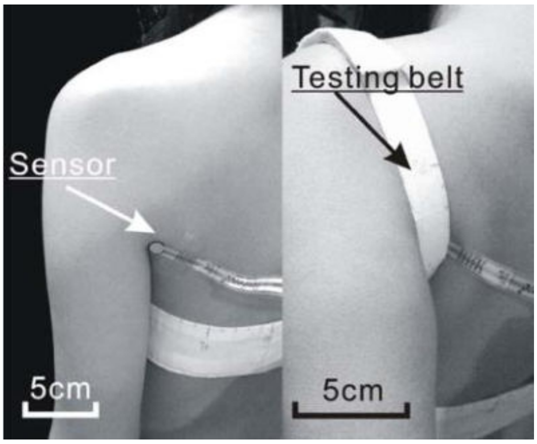
$$F(\%) = \frac{A_{clothing} - A_{body}}{A_{body}}, \quad (1.3)$$

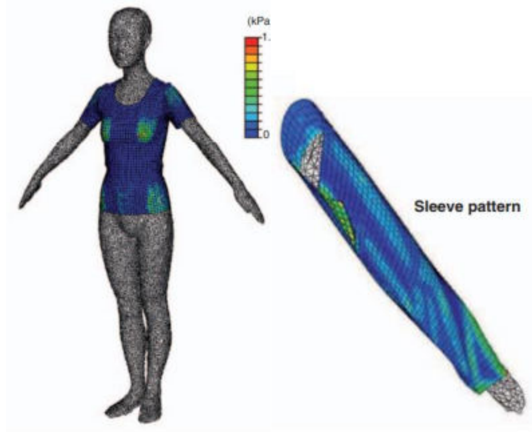
where F(%) represents the fitting index, $A_{Clothing}$ represents the value of the clothing area, and A_{Body} represents the value of the human body area.

In addition, the study result shows subjective evaluations of the clothes fit are often inconsistent and inaccurate. Because the results are influenced by the evaluator's personality, experience, background, and mindset, it is necessary to evaluate the clothes fit through the objective method [81].

With the progress of instruments and techniques, various objective fit evaluation techniques have been developed, which are increasingly adopted by scientists.

Guo Mengna and Victor Kuzmichev established a basic database for investigating easing values (five additional scales) that describe the comfort and pressure on the female torso, which consider the daily movement (eight movements with the dress) [52]. Fig. 1.13,a, shows the numerical pressure indicator evaluation by Flexi Force. This study analyses the relationship between the designed ease on 2D pattern and the wearer's pressure perception, which try to supply the theoretical reference for 3D virtual try-on system fitting amendment. The result coincides with the view of Mullet K, which ease is the garment fit principle that allows body movement [92].





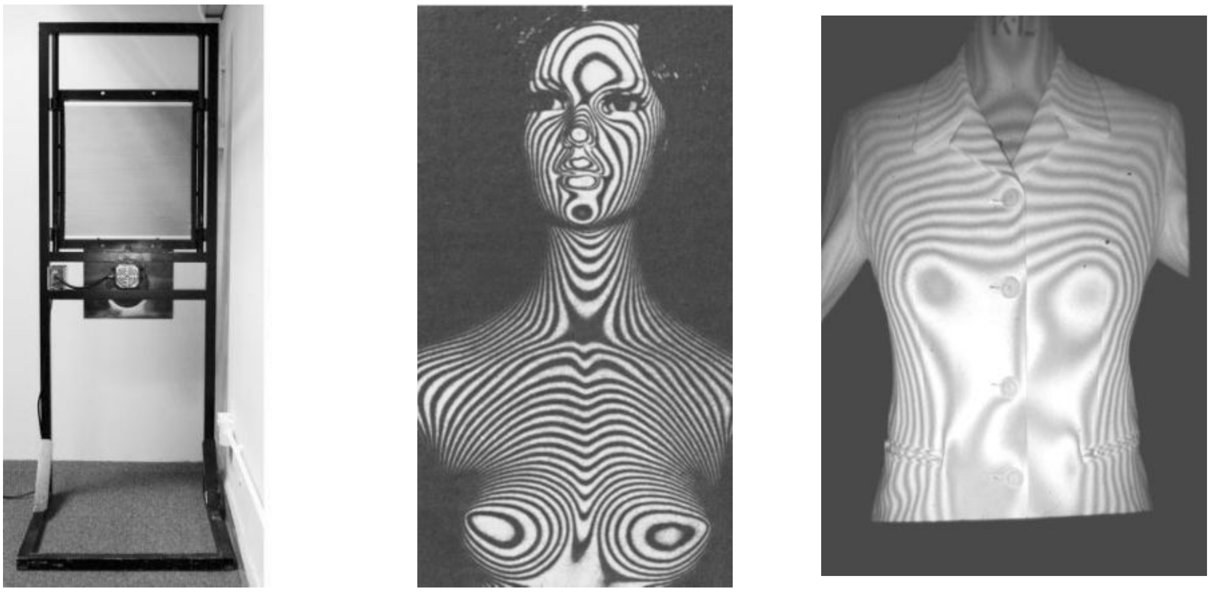
a *b*

Figure 1.13 - Objective fit evaluation of numerical pressure: *a* - pressure for real body, *b* - pressure for virtual model [52, 61]

Sonoko Ishimaru et al. developed a numerical-analysis-based technique to simulate clothing pressure distribution without sewing the material into clothes, which can be utilized for perfect fit clothing design [61]. As shown in Fig. 1.13,b, this study extended the pressure into the virtual environment.

Liu kaixuan et al. propose a remote clothing fit evaluation model based on machine learning techniques and digital pressure information to evaluate clothing fit without actual try-on [82]. The study considers that using Naive Bayes as a classifier is better than SVMs in digital clothes of pressure machine learning cases. Meanwhile, Zhang built a mechanical model of dynamic pressure for garment wearing. The finite element method was used to analyze the fit situation with the garment contact human body [136].

Fig. 1.14, a,b,c, express the moire Â topographic measurement system, the moire contours on the human body, and moire contours on jacket surface, respectively. if the jacket fits well, the moire contours are circular and symmetrical. Otherwise, the contours are distorted.



a *b* *c*

Figure 1.14 - Moire system for evaluation of fit: *a* - moire system for jacket: measurement, *b* - moire image of human, *c* - moire image of jacket [133,118]

As shown in Fig. 1.14,c, the upper bust area is symmetric. However, the lower bust area has a slight distortion and wrinkle appearance) [51]. Similarly, Yoshiko Taya tries to illustrate the clothes fit situation by the amplitude of waveform, which is relative to acoustic theory and symmetrized dot pattern [119].

The objective technique is quantitatively compare method. Therefore, it will be more accurate in comparing the clothes fit. Moreover, compared with the subjective qualitatively method, quantitatively ways require less fashion evaluation experience. The quantitative method of fit evaluation is also helpful for parametric pattern construction.

In summary, the criteria of garment fit are divided into objective and subjective evaluation. The objective method is less dependent on personal experience, and the result is neutral, but the realization threshold is high. Subjective evaluation is easy to implement. However, it is influenced by expert experience and subjective differences. The fusion of subjective and objective methods is an effective fit evaluation technique, which will allow for a more comprehensive fit evaluation. With the development of virtual simulation technology, more research projects of clothes fit will result from virtual technology.

1.4.2 Fit survey for contemporary women's classic jacket

There was still lack detailed investigation of fit appearance for contemporary selling women jackets. A survey of contemporary selling classic jackets and their sleeves fit was conducted to analyze the defects distribution. Therefore, the producers can be reminded to pay more attention to the high-risk areas and avoid defects in pattern making and production.

Five experts (three Ph.D. students of IVGPU, two teachers of Heyuan Polytechnic) who are professional in clothing and pattern design were enrolled to identify the misfit wrinkles subjectively. To ensure the consistency of subjective evaluation, all experiments related to subjective evaluation in this article are conducted by them.

The investigation samples are the photos of contemporary women's jacket in classic style. Through several processes and filters, 302 samples were collected and inspected from online store. The example of defects and detail of each jacket defect destitution were shown in appendix A, the jacket surface appearance was divided into 19 areas of three views. This survey aims to find out the high-risk parts of defects.

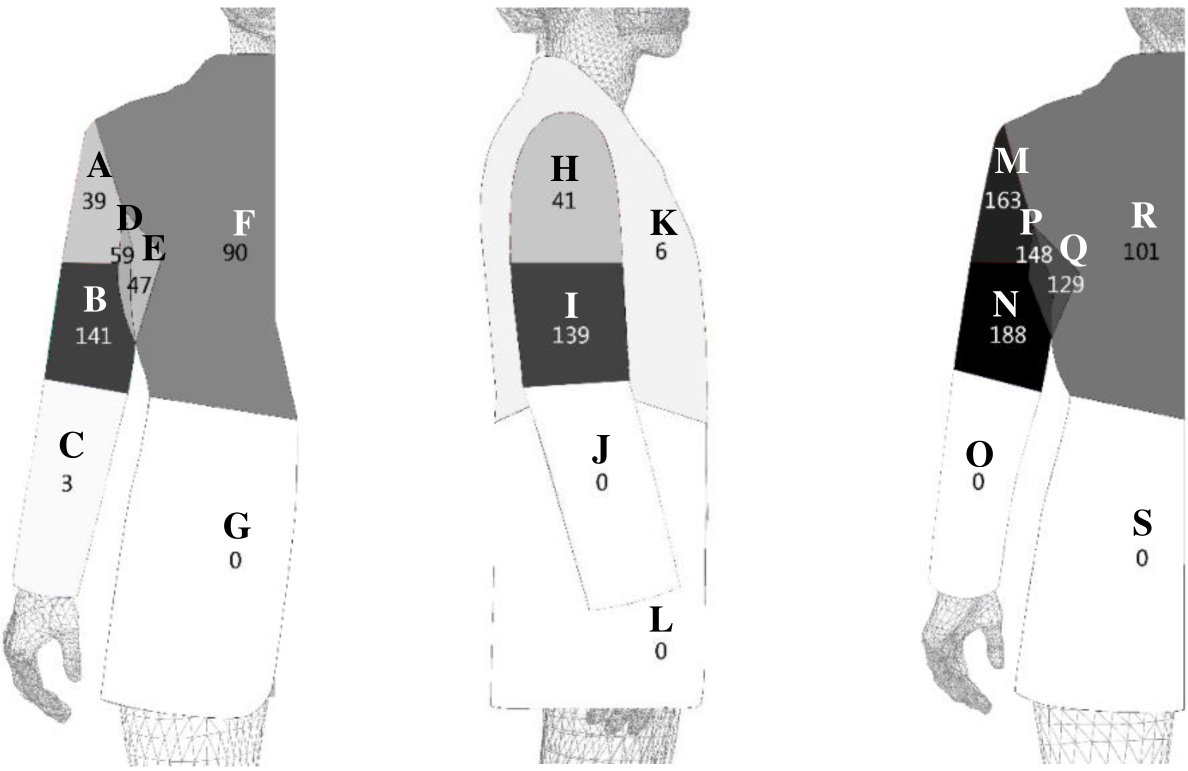


Figure 1.15 - Distribution of defects in risk area: *a* - front, *b* - back, *c* - profile

Fig. 1.15 illustrate the distribution of defects in 302 jackets, in Fig. 1.15, the darker color, the more defects' appearance. Table 1.9 lists the defects distribution. The defects distribution analysis is as follows.

(1) Comparing the front and back defects, there are 379 on the front and 729 on the back, indicating that manufacturers pay more attention to the front view in production.

(2) "Part of sleeve between sleeve cap and elbow" has more defects than others. This area defected 468 times in three views, 188 times in the back view. It is the highest-risk area of the whole jacket. This area is influenced by the defects of the sleeve cap and down part of armhole. Therefore, it is sensitive to defects and becomes the area with the most defects.

(3) "Sleeve cap" part on the back is the second risk area (163 times).

(4) "Down part of bodice area" is the best fit area without defects in this part. "Part between elbow and cuff" is the second fit area, with only three defects on three views.

(5) The area near the sleeve and armhole assembly line is gathering with high risk. Therefore, the pattern makers need to pay more attention to those areas in the making and amending patterns.

Table 1.9 - Distribution of defects of contemporary women jackets

Area of jacket (Fig. 1.15)	Number of defects in three view			
	Front	Profile	Back	Total
Sleeve cap (A, H, M)	39	41	163	243
Part between sleeve cap and elbow (B, I, N)	141	139	188	468
Part between elbow and cuff (C, J, O)	3	0	0	3
Armhole connection area of sleeve(D, P)	59	/	148	207
Armhole connection area of bodice(E, Q)	47	/	129	176
Upper part of bodice area(F, K, R)	90	6	101	194
Down part of bodice area(G, L, S)	0	0	0	0
Total of whole defects	379	186	729	
Total of sleeve part defects (%)	242 （64%）	180 （97%）	499 （68%）	

Notes: "/" represent this area that cannot be identified.

The defects distribution is revealed through the fit survey of contemporary women's classic jackets.

1.5. Main factors for rule the jacket fit

Discerning and quality-conscious consumers demand that their clothing to meet their requirements and expectations in appearance, fit, and comfort. Meanwhile, clothing manufacturers claim for less difficult production. Therefore, it is necessary to find the main factors that affect the garment's appearance, fit, and comfort, then avoid them in clothing manufacturing [131]. Table 1.10 shows the main factors of the garment fit are distilled.

Table1.10 - Main factors for rule the fit

Factors names	Detail of each factors	Scheme
Pattern making	Right pattern	Length, distance, ease-allowance of sleeve-armhole
Body morphology	Anthropometry and morphology	Accuracy anthropometry of arm and shoulder part.
Materials and accessories	Rigidity and thickness	The stiffness and thickness of material influence the sleeve fit
	Elastin	Less or none Elastic fabric allowing
	Shrinkage	Material pre-shrinking before cutting
	Interlining	Avoid low quality by heat shrinkage of the adhesive interlining
	Lining	Lining allowance could not less than crust material
	Accessory	Sleeve pad, Sleeve head Adhesive stripe for armhole
Production process	Tailoring or industrial cutting	Tailoring hand cutting, Industrial fabric cutting table, automatic cutting plotter
	Sleeve-armhole assembly skill	Sewing technique for setting in the sleeve
	Ironing and final pressing	Proper ironing and finishing for improving quality, special industrial ironing machines

Olga Surikova et al. investigated the factors influencing the fit and suit of women's clothing. The main reason for the misfit is nonconformity between the front and back width of pattern block. The special test and device were designed to predict the behavior of textile fabrics shear deformation and wrinkles appearing in real clothes [116]. Song Wonyoung et al. suggested the optimum sleeve cap height for women's jackets by comparing the designed sleeve cap jacket and surveying the jacket appearance, consumer wearing feeling, and preference [113]. Several common types of sleeve defects are listed in Table 1.11.

Table1.11 - Basic defects of sleeve and armhole [42]

No.	Defects	Schematic image	Reason of defects
1	Horizontal wrinkles on sleeve cap		Excess SCH, Insufficiency SCW.
2	Vertical wrinkles on sleeve cap		Insufficiency SCH, Inappropriate SCW
3	Bulges wrinkles around sleeve armhole assembly seam		Excess ease distance at sleeve-armhole assembling seam, Excess SCW
4	Stretch wrinkles at back sleeve cap, dis comfortable when arm movement.		Insufficiency volume at back armhole, Insufficiency volume of back sleeve cap.

As listed in Table 1.11, The sleeve pattern needs to be constantly amended to fit the wearer's body. The internal pattern misfit reflects on the wrinkles of the sample. Those relationships are sorted by several Chinese and Japanese specialist books [38, 42, 125].

Significant influence of body morphology on the jacket fit, Monobe et al. used a four body size deformed dummy to evaluate the suitable ranges of ease-allowance for women's jackets [90]. Meanwhile, he presents a novel solution of mathematically quantifying for body shape and garment fit. Besides, Emma Scott et al. explain why traditional anthropometry of 2D patterns with a poor fit and develop a novel pattern making method [106].

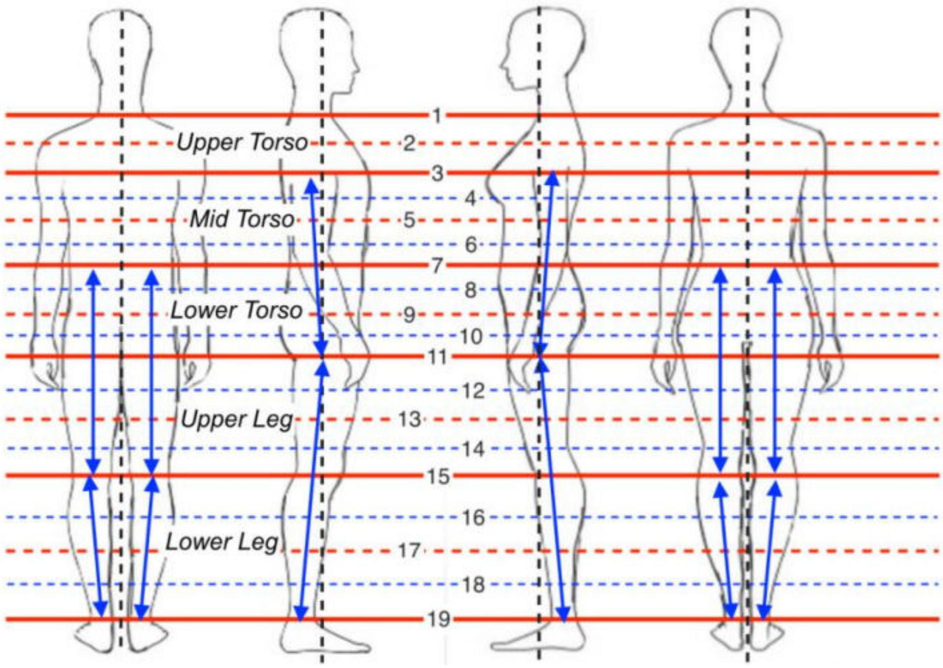


Figure 1.16 - Body segmentation for body morphology and anthropometry [106]

As shown in Fig. 1.16, the body is segmented vertically into quarters and horizontally into five main areas, which are further proportionally sub-divided for static landmark locations (total 19 clone landmark lines). Meanwhile, the effectiveness of this method for accurately copying body anthropometry shapes is verified.

Ease-allowance relates not only to the body dynamic and garment style but also to materials and fabric properties [134]. Pier Minazio develops a test method and instrumentation for fabric pressing performance. The experiment consists of 25 fabric materials, two subjective evaluation indicators (blown seam , seam pucker), and five fabric propensities (weight, warp formability, weft formability, warp crease angle, weft crease angle). After relation analysis, the study revealed that the fabric properties of weft crease angle and warp formability are most important for predicting the appearance of high-quality men's suits [87]. U. Biglia et al. developed a simple method of fabric pressing performance, which can be applied to predict the wool and wool blend tailored jacket appearance [12]. The fabrics' mechanical properties also influence the ease-allowance distribution. Agen Lage et al. investigated the fabrics' mechanical properties and corresponding ease distribution in virtual try-on software. The study gives the fabric recommendations for avoiding wrinkles on the waist and hip area, which are fabrics with tensile strain lower than 10% and ease allowance more than 2cm [74].

In order to deeply understand the contemporary fabric of material for CWJ, an investigation of its material composition was conducted, which is a way to understand CWJ's material. The investigation samples are the same as the previous fit survey of chapter 1.4.2. (the detailed material composition was listed Appendix B). The bar chart of Fig. 1.17 shows the proportion of fabric adoption.

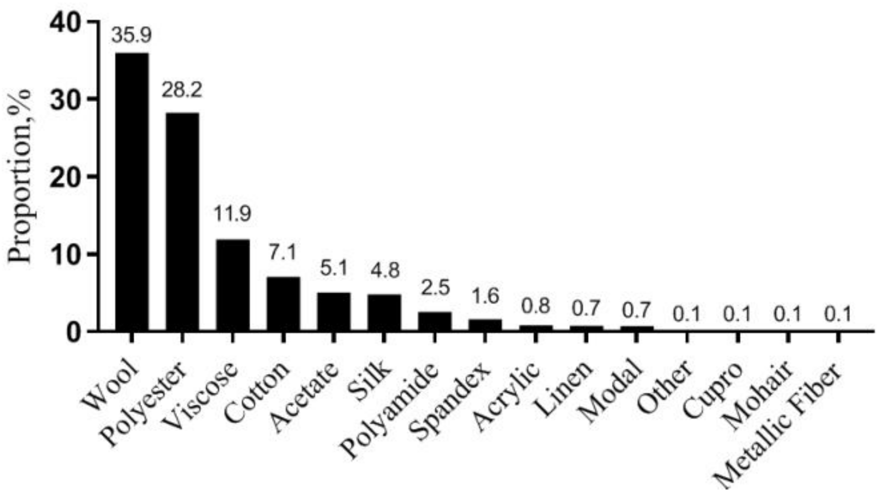


Figure 1.17 - Material composition of CWJ

To calculate the proportions of Fig. 1.17 include three steps: first step is regarding each fabric proportion as score; second step is adding all scores of each fabric together; third step is calculating the final proportion of the fabric. For example, a jacket fabric composition is 98% wool 2% spandex, regarding them as score 98 and 2 first, adding all wool and spandex together (there are 302 samples, the total score is 30200), the total wool score divided 30200 to get the proportion of wool.

As shown in Fig. 1.17, the first four major parts were wool 35.9%, polyester 28.2%, viscose 11.9%, and cotton 7.1%—these four materials occupied over the 80% composition of the shell material.

In addition, the material survey also found several interesting features.

1. Wool was undoubtedly the largest proportion. There was a tendency for wool to be more subdivided marked in composition labels: virgin wool, fleece wool, or lambswool.

2. International brands trend to use natural fabric, while Chinese without this trend. The famous international and Chinese fashion brand was collected for this survey. As was well known that the famous luxury brands of China are still under development. Therefore, the international famous luxury brands trend to adopt nature fabric to support its best quality.

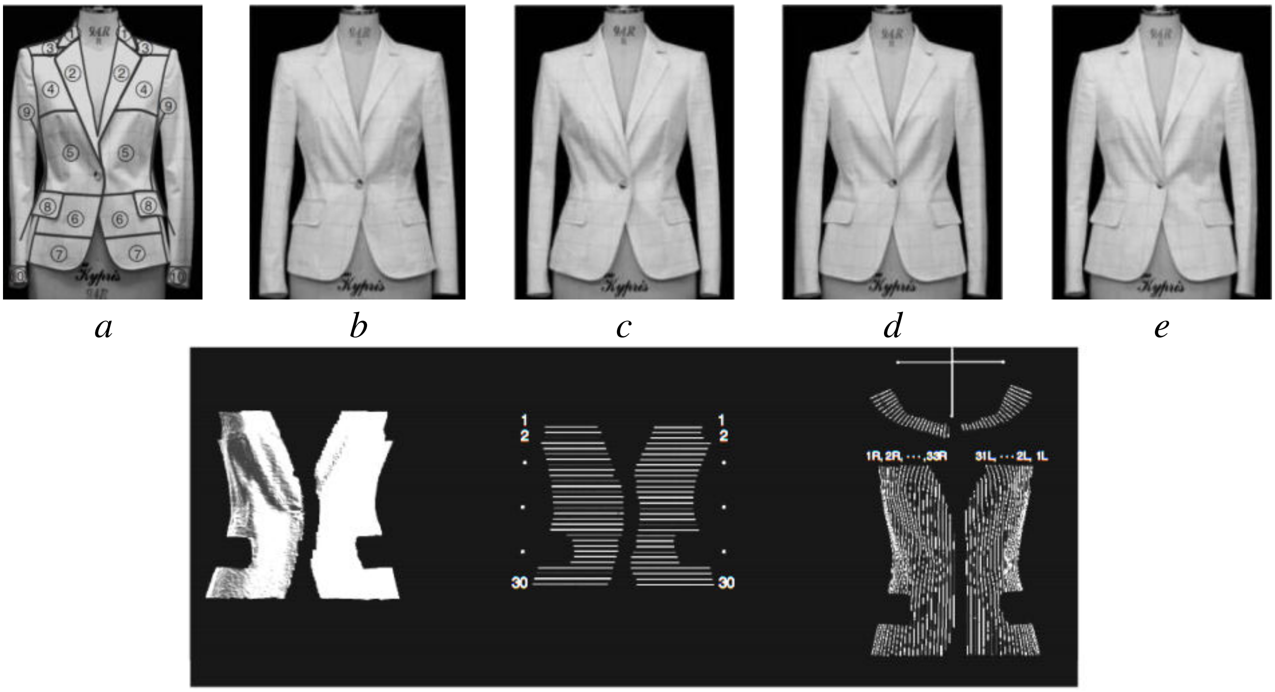
3. Material of fabric blend was widespread, while 100% wool also.

4. Because of the blending, the viscose occupied near 12%, which even surpassed cotton. This situation indicated that viscose might be more popular than cotton in the jacket shell material. As a manufactured regenerated cellulose fiber, viscose was neither truly natural (like wool, cotton) nor truly synthetic (like polyester), which fell somewhere in between.

5. In synthetic fabric, except polyester, the rest of the fabric had a low occupation, which was found in blending material.

Except of shell materials, the interlining and accessory will also rule the jacket fit. The interlining is a kind of fabric that is sewing or fusing to the inner layer of the crust material that give it shape and stability. The most important quality of an interlining is that it should provide stability and shape to the crust without altering the original appearance of the crust material [4].

Kyoung Kim et al. proposed quantifying method for the women's jacket appearance with different adhesive interlinings. Fig. 1.18 shows the different interlining with various jacket appearances [72].



a *b* *c* *d* *e*

f

Figure 1.18 - Parts of a jacket evaluated and jackets with different interlinings: *a* - jacket divide into 11 parts for fit evaluation, *b* - no interlining, *c* - soft interlining, *d* - normal interlining, *e* - hard interlining, *f* - 3D data of scanning [72]

As shown in Fig. 1.18,a, segmenting the jacket into 11 parts for subjective evaluation. Meanwhile, the jacket's interlining has four types: no interlining and hard interlining (as Fig. 1.18,b,c,d,e). Since the impact of different interlining on the appearance is kindly subtle, the study adopts 3D scan for further step of quantifying appearance evaluation (as Fig. 1.18,f). This study proposes a new method for evaluating the jacket's appearance with different adhesive interlining, which sheds light on how interlining materials rule the jacket's fit.

The lining is a fabric covering the inside of a jacket. Usually ignored by consumers, the misfit lining will pull the jacket out of shape or deliver wrinkles to shell appearance [67]. Kim Myoung Ok surveyed the jacket lining manufacture and suggested lining extra ease-allowance for men's jackets with different styles [73]. The suit jacket's recommended extra ease of chest, waist, hem, and bicep are 5.6, 3.8, 2.7, and 2.7 cm, respectively. The casual jacket's recommended are 2.4, 1.3, 1.3, and 1.1 cm, respectively.

The sleeve head is one of the indispensable parts for sleeve fit. Youngja Park et al. designed and developed the suitable sleeve heads for sleeve caps by comparing and analyzing current sleeve head products [97, 98]. Until 1931, designer Elsa Schiaparelli introduced the sleeve pad in women's jackets [135]. The shoulder pads can effectively enhance the aesthetic of sleeves- armhole. Several sleeve pad attaches methods were introduced for different kinds of sleeve [100]. Stretching armhole lead to misfit defects appearance. Before the sleeve setting, the armhole need to be reinforced by adhesive stripe (edge tape) and interlining.

The process of sleeves stitching into the armhole is complicated. A confident sewer allows the sleeve ease to be equally spread around the top of the jacket armhole. Only the top part of the sleeve cap needs to be eased, and there is never any easing done on the underarm part of the sleeve [15, 86, 100]. Ironing and finishing the jacket could improve the quality. In China, there is a proverb, "three parts depend on sewing, seven parts depend on ironing," which reflects the importance of ironing [79]. With the mass production requirement, several inventions and devices were developed for efficiency ironing different parts of the jacket.

In summary, all of the factors in Table 1.10 rule the fit of the jacket sleeves. However, only the pattern directly determines the fit. It is not difficult to find that the fit pattern is indispensable. Other factors are built on the pattern to enhance and improve the fit of sleeve.

1.6. Main aim and direction of this science research

Considering the contemporary research status, the existing research result still needs improvement due to the lack of research in the sleeve-armhole field. There are many studies devoted to the improvement the virtual garment fitting. Most of them belong to skirt, dresses, shirts, etc. However, the “sleeve -armhole” system has more complex construction and details than other parts.

This research aims to develop a novel system for fit evaluation and prediction of sleeve-armhole. in order to achieve this aim, necessary steps should be conducted following the framework of this research (Fig. 1.19), the new steps or results are labeled with a star (★).

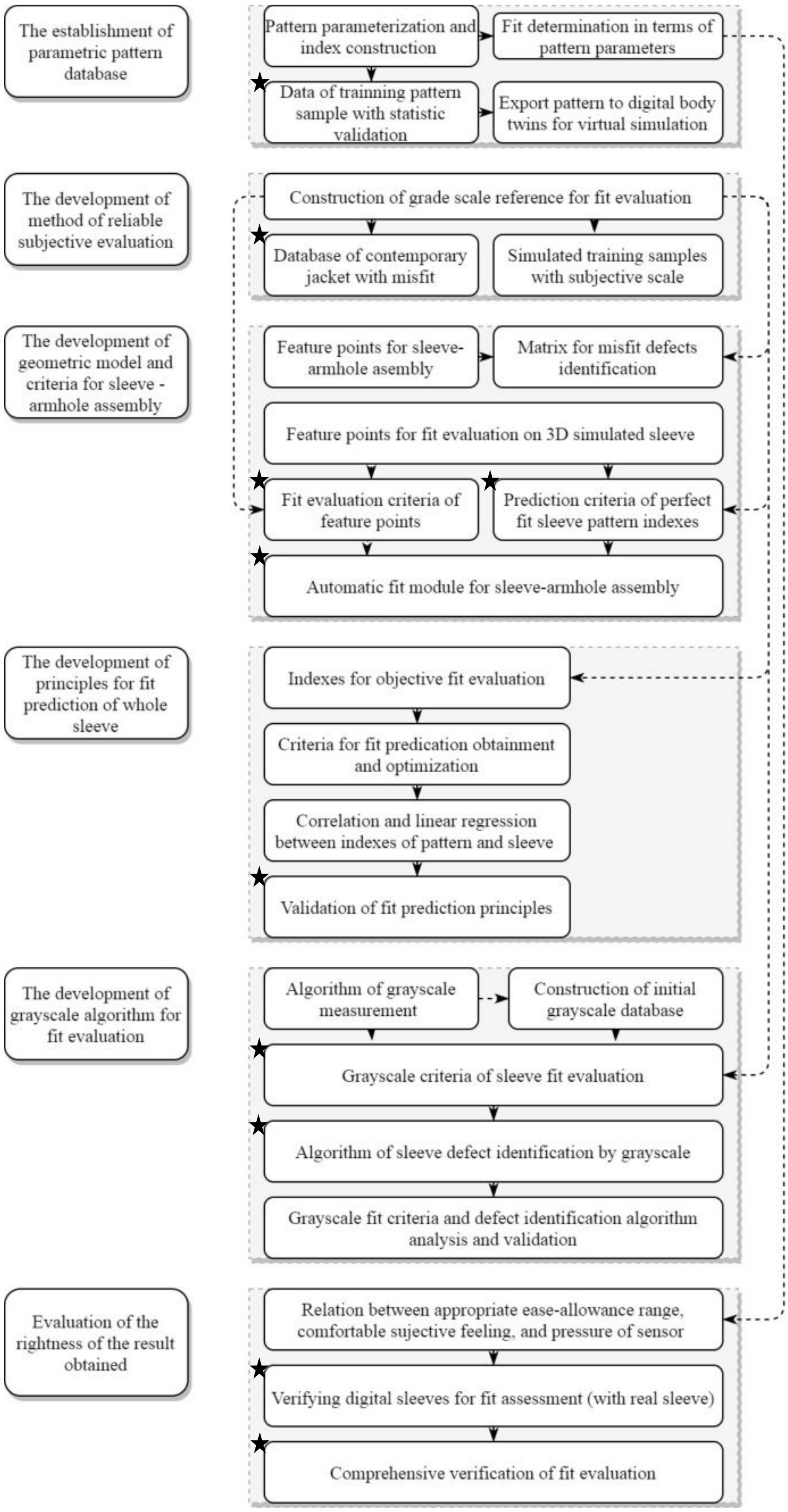


Figure 1.19 - Framework of developing fit evaluation and prediction system for women jackets sleeve

1. The parametric pattern of CWJ should be established. The adequate CWJ patterns should be first redrew by CAD as the initial pattern database. Parameterization of the redrawn pattern by measuring the pattern indicators. Meanwhile, the ease-allowance of each index was also calculated and sorted. For confidence in the subsequence study, the estimated sample size of pattern was calculated. These patterns were exported to the simulation software for generating DT.

2. The method of reliable subjective evaluation should be developed. The subjective evaluation was often inaccurate and unreliable, influenced by multiple factors. In order to make the subjective evaluation as reliable as possible, the grade scale of fit evaluation reference was constructed and adopted. Meanwhile, the grade scale was used to investigate the misfit distribution of contemporary CWJ as its validation.

3. The geometric model and criteria for sleeve-armhole assembly should be developed. Analysis of the known design techniques showed that the existing production procedure has to undergo several times try-on of real sample and pattern amendment, which cost time, human, and materials. Therefore, the matrix for misfit defects identification, fir evaluation criteria of feature points of armhole-sleeve assembly, and prediction criteria of sleeve pattern indexes with perfect fit will be developed. The automatic fit evaluation and prediction module for sleeve-armhole assembly were also developed to facilitate the result use.

4. The principles for fit prediction of the whole sleeve should be developed. Several fit prediction principles were proposed through the indexes of objective fit evaluation with designed DT. After fit prediction criteria were obtained and optimized, and correlation and linear regression between pattern and simulated sleeve constructed, the fit prediction principles were validated.

5. The grayscale algorithm for fit prediction should be developed through grayscale measurement on several set lines on the sleeve, the initial grayscale database and fit evaluation of grayscale criteria constructed, the algorithm of sleeve defect identification by grayscale was also developed and validated. Thus, the relationship between defect identification, grayscale value, pattern deformation, and subjective evaluation will be defined.

6. The rightness of the study result should be validated. In the ergonomics part, the relation between subjective feeling, sensor pressure, and ease-allowance of pattern will clarify. DT and real sleeve comparing for replacement validation. The comprehensive test will verify the correctness and applicability of all conclusions obtained.

CHAPTER 2. THE GRAPHOANALYTIC PATTERNS DESCRIPTION OF WOMEN'S JACKETS WITH SUBJECTIVE SCALE

Apparel structural design is an art of how fabrics can better fit into the surface of the human body, which is a technique for transforming clothing between 2D and 3D. There is a clear difference between structural pattern design and fashion illustration design, in which the structural value must be reflected in the form of the human body. The study of CWJ TPS was based on the parametric structural method. In order to find the relation between shape and structure. These relations and methods had wide applicability and good operability to structural design. It was the basis for the follow-up virtual simulation.

The results obtained in this chapter are published in two works [154, 162].

2.1. Methods and materials of research

2.1.1. Software of research

In order to obtain the graphoanalytic pattern, the ETCAD (Buyi technology, China) software was utilized for pattern drafting. Software Excel (Microsoft, USA) and SPSS (IBM, USA) were used for pattern parameterization database construction and relative statistical analysis. PASS15 (NCSS LLC, USA) was used for sample size calculation,The Clo3D (Clo virtual fashion LLC, Korea) simulated the designed deformity sleeve pattern, aiming to explore misfit tolerance.

2.1.2. Object of research

Since the avatar size was based on Chinese standards size (described previously in Table 1.6) [22], therefore, the corresponding patterns also need to be based on this size. Since the Bunka style priority (described previously in Table 1.5), the pattern collected from Bunka style.

The CWJ patterns were composed of the front piece, front side piece, backside piece (some of them are combining), back piece, collar, lapel, sleeves, and pockets cover.

The source of samples came from the magazine of "Lady Boutique", "Female", "Style Book", and "Shanghai Style", a small part was derived from garment production industries and pattern teaching books, which sourced from both Japan and China publishers.

The detail of pattern sample selection was under following:

1. Full sleeve length.

2. Single-breasted jacket: the jackets can divide into double-breasted and single-breasted. This research only involves single-breasted with TPS of CWJ.

3. The collected pattern samples need to be consistent with the classic style shown in Fig. 1.1 to avoid singularity problems.

4. Some collected patterns do not match the Chinese size, thus the pattern needs to be adjusted during the redrawing process.

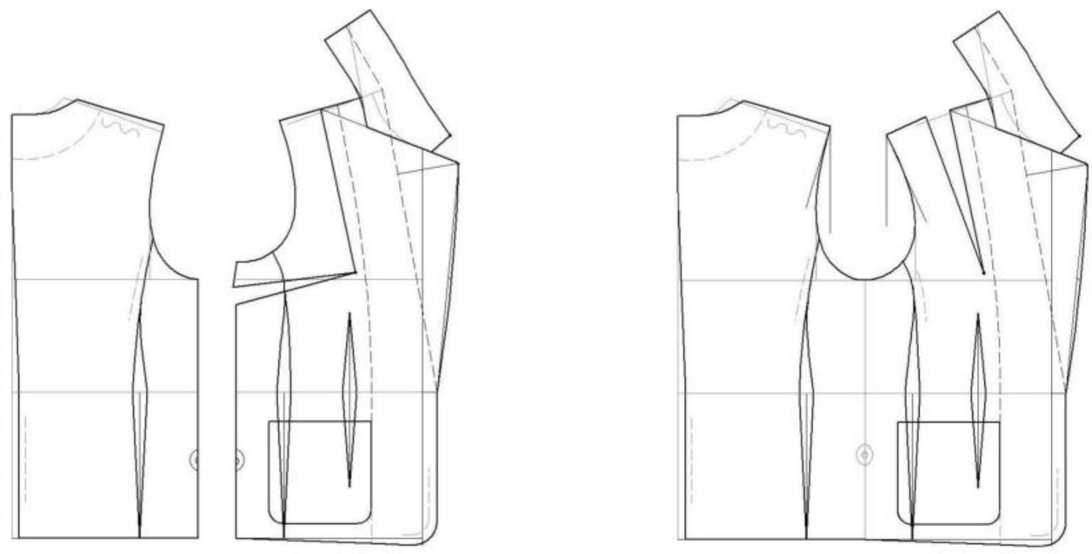
Finally, 82 women's classic jackets of Bunka style were selected as samples to construct the pattern database.

2.2. Methods of pattern preparing

The collected patterns could not be directly used because some do not meet the Chinese size, which needs to be adjusted, accommodating later parameterization measuring and analyzing.

2.2.1. Method of chest dart preparing

The bodice pattern was mainly composed of the front piece, front side piece, backside piece, back piece, collar, hanging surface, pocket cover, and the two sleeve pieces. All samples need to be modified due to the differences in the location and distribution of bust darts. The detailed operation kept waist darts then transferred all the chest darts to the shoulder line. Fig. 2.1 showed the dart transfer process, which facilitates the pattern parameterization data accession under the same condition.



a *b*

Figure 2.1 - Operation process of pattern block bodice: *a* - original pattern, *b*- pattern after chest dart transferring

2.2.2. Method of armhole analyzing

There are many parametric indexes relative to the armhole, which need to be closed first and then analyzed. Fig. 2.2 shows the schematic picture for armhole part measuring.

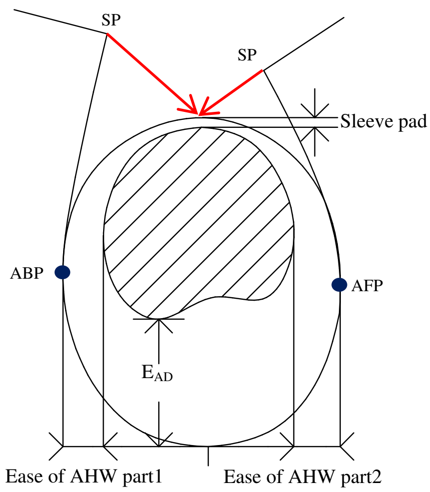


Figure 2.2 - Operation process for armhole related parametric indexes measuring

For armhole analysis, several steps were required, which were detailed below.

Step 1: Two SP were merged as one (red allow). The AHL was same before and after armhole closing.

Step 2: Marking two points of the most back point of armhole (ABP), and the most front point of armhole (AFP). The horizontal distance of these two points represented AHW. Meanwhile, the ease of AHW could be obtained in the case of combining with arm base cut.

Step 3: The AHD and ease of armhole depth (E_{AD}) could be obtained by calculated depth of armhole close, sleeve pad thickness, and depth of arm base cut.

2.2.3. Parameterization of pattern blocks

There was a total of 29 indexes participated in pattern block parameterization. Fig. 2.3 and Table 2.1 show the schematic of each parameter index's location and measuring scheme, respectively, to better exhibit where these parameters are located on the patterns.

Table 2.1 - Structural parameters of pattern block

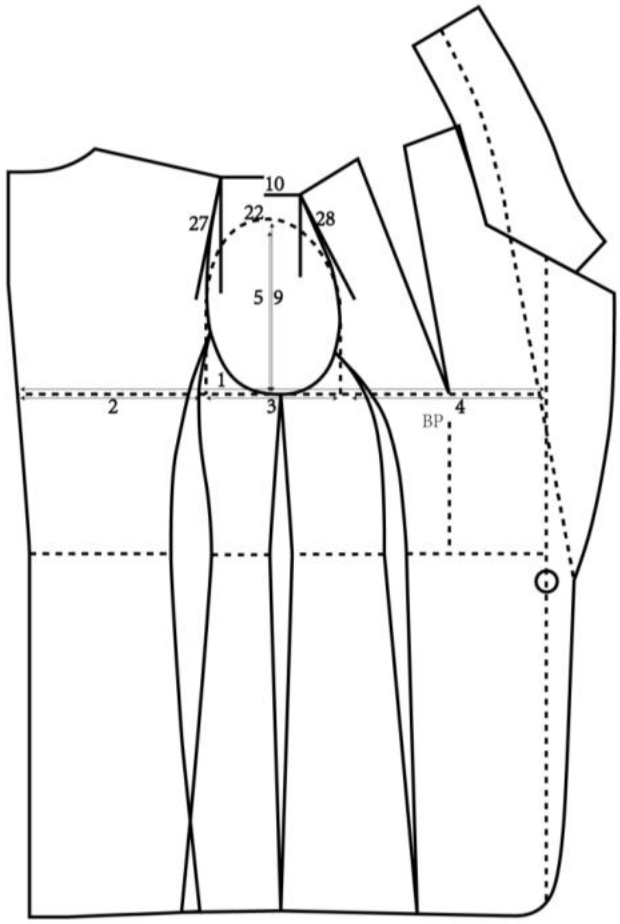
No.	Parameter index	Scheme of measuring
1	2	3
1. Eases		
1	Ease of Bust girth	Difference between bust width of pattern and half bust girth of body.
2	Ease of back part in Bust girth	Difference between back width of pattern and back width of body.
3	Ease of armhole width in Bust girth	Difference between armhole width of pattern and distance of front and back armpit point of body.
4	Ease of front part in Bust girth	Difference between front width of pattern and front width of body.
5	Ease of armhole depth	Difference between armhole depth in pattern except shoulder pad thickness
6	Ease of arm girth	Difference between sleeve cap width of pattern and arm girth of body.
7	Ease of elbow girth	Difference between sleeve width on elbow level of pattern and elbow girth of body.

Continue Table 2.1

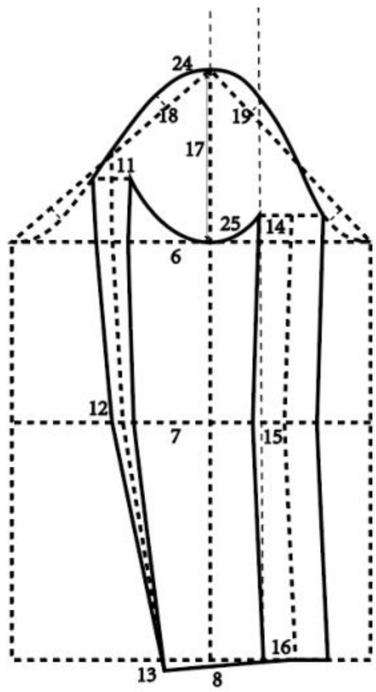
1	2	3
8	Ease of wrist girth	Difference between pattern sleeve width on the wrist level and wrist girth of body.
	2. Distances	
9	Armhole depth	Special method to close Armhole for measure the armhole depth in vertical.
10	Vertical distance of SP in front and back	There are two SP in pattern block, which is on the front and the back, respectively. Measurement they vertical distance.
11	Distance of elbow seam on arm	As shown Figure 2.3
12	Distance of elbow seam on elbow	As shown Figure 2.3
13	Distance of elbow seam on wrist	As shown Figure 2.3
14	Front seam distance on arm	As shown Figure 2.3
15	Front seam distance on elbow	As shown Figure 2.3
16	Front seam distance on wrist	As shown Figure 2.3
17	Sleeve cap height	Cap height of sleeve pattern
18	Sleeve Cap curve distance B	As shown Figure 2.3
19	Sleeve Cap curve distance C	As shown Figure 2.3
20	Distance between sleeve elbow seam and back width of bodice	As shown Figure 2.3
21	Sleeve cap height with armhole depth	Distance between peak point of sleeve cap and peak point of armhole closed
	3. Length	
22	Armhole length	Full measurement along the armhole.
23	Ease allowance of length of sleeve cap and armhole	Difference between the curve length of sleeve cap and armhole of pattern.
24	Curve length of upper sleeve	Measurement the curve length of upper part sleeve in pattern
25	Curve length of down sleeve	Measurement the curve length of down sleeve in pattern

Finish Table 2.1

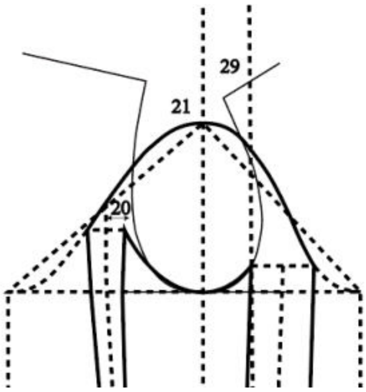
1	2	3
26	Whole length of sleeve cap curve	Total curve length of down and upper of sleeve cap.
	4. Angles	
27	The degree of SP on back shoulder line of pattern	Special method to define and measurement the tile of back shoulder line of pattern.
28	The degree of SP on front shoulder line of pattern	Special method to define and measurement the tile of front shoulder line of pattern.
29	Sleeve slope	As shown Figure 2.3 , Extending the sleeve height upward, connection and extension the highest and lowest point of down part sleeve front edge.



a



b



c

Figure 2.3 - Parametric measurement introduction: *a* - bodice, *b* - sleeve, *c* - sleeve cap

All parameterized data of pattern blocks of Table 2.1 were sorted and analyzed by Excel and SPSS. The data files construction is the primary task of data management and statistical analysis. Creating accurate and high-quality data files can ensure the accuracy and scientific validity of the analysis results. In addition, editing checks are performed on the data, which include:

(1) If the data was missed, try to recollect and complete it. If we still could not find the data in this index, mark it on a missing tag "/". When data analysis, SPSS will automatically skip it.

(2) If the data was duplicated in one file, delete.

(3) The outlier value was analyzed. If it was determined is not an incorrect value, keep it. If incorrect, regard it as missed data.

After those steps, the database of pattern blocks parameterization could be constructed. All parameter indexes of Table 2.1 were measured, sorted, and analyzed. For more details of the parameterization database, see Appendix C. Meanwhile, the corresponding database was constructed using Microsoft Access and licensed in Russia [163].

2.2.4. Database of parameterization training samples for subsequent virtual try-on

It was well known that ease-allowance determined the fit of wearing, several ranges of ease-allowance for training sample were listed in Table 2.2. It was the original state. Some included potential misfit defects, which were necessary to combine with the result of subsequent fit experiments to exclude.

The parametric indexes of Table 2.2 which include ease of bust girth (E_{BG}), E_{AD}, AHD, AHD_B (since the Chinese standard does not have this index of AHD_B, the similar Russian standard was used, AHD_B=10 cm [150] and sleeve pad thickness was 0.5 cm), ease of arm girth (E_{AG}), ease of elbow girth (E_{EG}), ease of wrist girth (E_{WG}), distance between sleeve cap curve and armhole length (sleeve Δ), and percentage of sleeve Δ (P sleeve Δ).

Table 2.2 - Ease-allowance range of several main parametric indexes

Name of patterns parametric index	Parametric range, cm	
	Minimum	Maximum
E_{BG}	7.48	19.12
E_{AD} = AHD - AHD_B - sleeve pad thickness	4.3	9.2
E_{AG} (arm girth is 27 cm)	3.64	12.27
E_{EG} (elbow girth is 22 cm)	6.02	14.63
E_{WG} (wrist girth is 15 cm)	8.96	18.72
Sleeve Δ = SCL - AHL	1.5	5.13
$\text{P sleeve}\triangle = \frac{\text{SCL - AHL}}{\text{AHL}} * 100\%$	3.16%	11.18%

Current pattern construction systems rely heavily on trial and error to obtain satisfactory results and seldom objectively point out easy-allowance requirements or insights into pattern parameters. The training sample database was built to provide parameter indexes to reveal the potential underlying pattern misfit.

2.3. Statistic validation of the parametric training sample indexes

82 jacket samples were selected. For the purposes of the validity of the following experiments, the training sample size was calculated using the software PASS15, by Equation (2.1) [54].

$$n = \frac{Z^2 + SD^2}{d^2}, \quad (2.1)$$

where *n* is the numbers of estimated sample size, *Z* is the standard normal variate (in this study, using 90% confidence interval, *Z* = 1.645). *SD* is standard deviation of variable. *d* is absolute error margin (in this study, *d* was set as 5% of average value, which is sufficient for the experiment).

Table 2.3 - Sample size of training sample

No.	Measurement index	Sd, cm	Mean, cm	d, cm	n
1	E_{BG}	1.18	6.74	0.34	35
5	E_{AD}	0.79	15.97	0.80	5
6	E_{AG}	1.74	6.72	0.34	**73**
7	E_{EG}	1.58	7.92	0.40	45
8	E_{WG}	1.81	10.97	0.55	32
9	AHD	0.79	16.47	0.82	5
17	SCH	0.67	16.29	0.81	4
20	Distance between sleeve elbow seam and back width of bodice	0.56	2.95	0.15	40
22	AHL	1.84	46.89	2.34	4
23	sleeve Δ	0.67	3.56	0.18	40
24	Curve length of upper sleeve	2.65	31.93	1.60	10
25	Curve length of down sleeve	2.27	18.40	0.92	19
26	SCL	1.98	50.28	2.51	4
27	The degree of SP on back shoulder line of pattern	2.6	12.68	0.63	48
28	The degree of SP on front shoulder line of pattern	2.97	30.62	1.53	13

According to the experiences of pattern makers, the essential measurement indexes of pattern parameters were selected from Table 2.1 for sample size estimation. As shown in Table 2.3, the minimum estimated training sample size was 73. Therefore, the selected 82 samples of Bunka style were sufficient for subsequent experiment.

2.4. Reliable subjective evaluation system construction

Effective fit evaluation is beneficial for the fashion industry as it can reduce the number of garments rejected in the fitting room or returned after purchase. It is difficult to establish a precise definition of fit on subjective evaluation, although some general standards of fit are common throughout the industry evaluation. Those differences may derive from the fit perception of different evaluators and the type of fit in fashion. Everyone may have a valid perception of fit. However, the difference can prevent establishing a constant standard [8]. Therefore, it becomes necessary to establish several recommended rules for reliable subjective fit evaluation.

Two methods of subjective fit evaluation were proposed by us. one method extended from AATCC test method for fabrics (as Fig. 1.11), another method was from jacket appearance dividing (as Fig. 1.15). These two methods can be used in conjunction with one another to achieve reliable subjective evaluation result.

2.4.1. Subjective evaluation rules for reliability

Evaluators analyze fit by observing, which was an inherently subjective process [8, 77]. The difference of fit conception did affect fit evaluation. In this study, several methods were adopted to maximize the reliability of subjective evaluation.

1. Grade scale reference

Through a search of the literature, visually assessing the garment on a body or dummy was still an inherent fit evaluation method. However, it still lacks reliability for women's jacket sleeve evaluation. A frequently used method for assessing fabric wrinkles in material industry evaluations is the AATCC test. This method was first introduced by the AATCC (American Association of Textile Chemists and Colorists) to evaluate the appearance of fabrics in 1963 [62]. The sleeve grade scale reference learned from and built upon the idea of AATCC to access the appearance of the women's jacket into five grades. This grade reference could effectively help the subjective evaluator make a reliable result.

As shown in Fig. 2.4, the women's jacket was set into five grades. During the process of fit evaluation, the evaluator could compare the grade reference image with the sleeve, which was helpful to improve the reliability of the evaluation.

a *b* *c* *d* *e*

Figure 2.4 - Grade scale reference and corresponding semantics for fit evaluation: *a* - Perfect, *b* - Good, *c* - Appropriate, *d* - Fair, *e* - Poor

2. Evaluation by experts

Consistent with chapter 1.4.2, five experts were involved in the subjective fit evaluation. Every evaluator had its own perception of fit, which challenged the reliability of fit evaluation. Using the consensus opinion of experts could enhance the evaluation reliability.

3. Trained in advance of evaluation

Although all five experts were adequately experienced, training was conducted to keep reliability as much as possible, aiming to adapt the women's jacket requirement. AATCC manual mentioned that the assessors should be trained well enough to rate the test specimen independently.

4. Surface appearance dividing for fit evaluation

The simplest perhaps was asking for a “yes” or “no” answer to a question for testing [109], grade scale reference alone was not enough because it was the overall comparison between the being evaluated jacket and reference. Using the same method and experts for the defect distribution survey of simulated jacket (chapter 1.4.2, appendix A). The simulated jacket surface appearance was divided into 19 areas of three views (as

Fig.A.2). Each area had two scores of "0" and "1", where "0" means the area fit well and had no defect wrinkles, while "1" means it had defect wrinkles. The surface dividing could further enhance the reliability. The simplest perhaps was asking for a "yes" or "no" answer to a question for testing. The grade scale reference alone was not enough because it was the overall comparison between the being evaluated jacket and reference.

2.4.2. Subjective evaluation procedure

Following the constructed rules, the parameterized patterns were undergoing subjective evaluation. Details procedure of this evaluation were as follows:

1. Training sleeve sample for evaluation

Software ETCAD to redraw the collected 82 patterns and measure parameterize indexes following Table 2.1, then export the common format file of ".dxf" for simulation. In the virtual environment of software Clo3D, the patterns were simulated and worn on the avatar for fit evaluation.

2. Subjective fit evaluation

The 82 simulated jackets were subjectively evaluated by grade scale reference and surface appearance dividing, respectively. Firstly, comparing the simulated sleeve and fit grade reference of Fig. 2.4 to obtain the basic evaluation result, the five expert evaluators independently graded the sleeve sample. All jackets were evaluated into five grades. Secondly, the jacket surface appearance was divided into 19 areas. Each area was asked with misfit "1" or without misfit "0", then summing all misfit scores. In this way, a more reliable subjective fit evaluation result could be achieved. Table 2.4 shows the fit level of all 82 simulated jackets.

Table 2.4 - Grading the simulated jacket fit level

Statistical indicators	Grade scale reference					Odd	Total
	Perfect	Good	Appropriate	Fair	Poor		
Area of misfit (19 areas, three views)	0	1-2	3-4	5-6	≥7	/	/
Number of samples	21	25	18	7	5	6	82
Proportion, %	26	30	22	9	6	7	100

As shown in Table 2.4, The subjective evaluation results of grade scale reference and area dividing ware corresponded. For example, defects less than 1 area indicate the perfect fit, between 1 and 2 areas indicate good fit, etc. The Table D.1 of Appendix D shows the fit grade detail of each sample.

Consistent the grade scale and dividing misfit area had a potential benefit: the grade could be easily adjusted. In other words, The five grades could recombine into two, three or four grades according to subsequent experiment requirements. For example, there were five grades listed in Table 2.4, since the more grades, less adjacent grades differences. Suppose an experiment only requires three levels. Redefining the misfit area could change five grades to three easily.

The 78% of sleeve samples are higher than the appropriate grade (including appropriate grade), which means most of the training samples used in this study are acceptable. This result indirectly demonstrates the rationality of training sample for study.

2.4.3. Misfit tolerance threshold of designed pattern

People's feeling for clothes misfit was different. Analogy the clothes misfit to the product price, when the price goes up a little bit, someone can accept it while some can not. The misfit was similar to the price but more complex because the form of price was number; however, the form of misfit was real clothes or pictures, which might lead to the possibility that people were more discrete for the misfit tolerance threshold.

In order to explore the tolerance threshold of the designed pattern of women's jacket sleeve in subjective evaluation, an experiment was conducted as follows:

1. Choose a perfect pattern from the pattern database (as Fig. 2.5,a shows), Using this pattern as the basis, the pattern parameter indexes were deformed in five aspects, which were SCH, SCW, elbow seam distance (ESD), front seam distance (FSD), and grain line.

2. The interval of ESD and FSD was 2 cm, the SCH and SCW was 1 cm, and the grainline was 45°. The second evaluation was conducted with half-interval if the expert felt it was hard to determine the threshold.

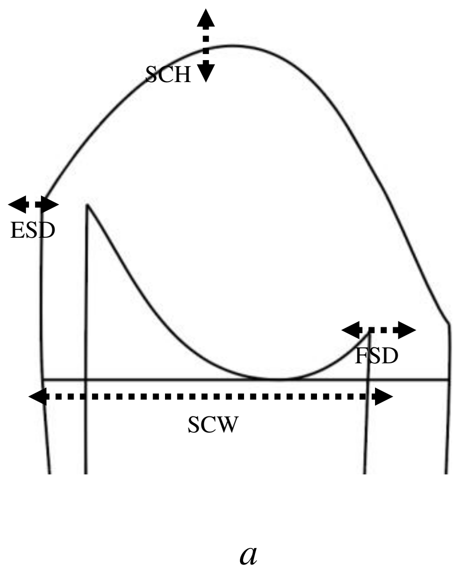
3. Clo3D simulated all designed misfit patterns. All simulated sleeves consisting of five enhanced contrast images were shown in Appendix E for better comparison.

Fig. 2.5,b shows the example of ESD deformation, which is deformed from 0 to 8 cm in sequence, and there is an obvious wrinkle at 4 cm (red x mark, located at the upper elbow of elbow seam). However, one expert pointed out a tiny wrinkle at 2 cm. Only one expert out of five thought it is misfit wrinkles, so 2 cm is still within the tolerance range.

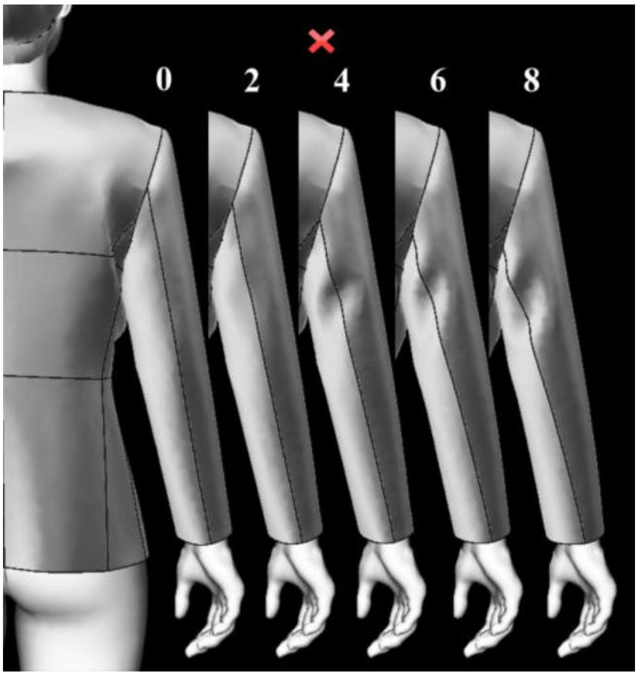
4. For grainline, the experiment found that the Clo3D regarded grainline as mapping, which means the grainline did not affect sleeve fit (in Appendix E).

5. Fig. 2.5,c shows the final result of the misfit tolerance threshold, the SCW range was -1 to 1 cm, the SCH range was -0.5 to 0.5 cm, the FSD range was 0 - 6 cm, and BSD range was 0 - 2 cm.

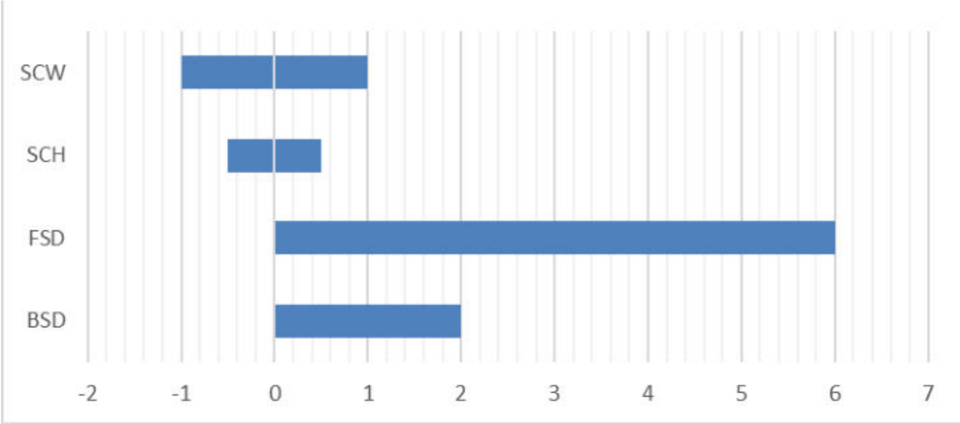
The experiment result showed that the tolerance for each expert was different. Using the final opinion of the five experts could obtain more accurate subjective evaluation results. Moreover, the different indexes for misfit impact were different. For example, guaranteed that no misfit wrinkles appear on the premise, SCH only accepted increasing 0.5 cm, while FSD accepted up to 6 cm.



a



b



c

Figure 2.5 - Experiment of misfit tolerance of people's feeling: *a* - scheme of SCH, SCW, ESD, FSD setting and deformation, *b* - simulated sleeve comparison of ESD deformation, *c* - misfit tolerance threshold of SCH, SCW, ESD, FSD

Conclusion after chapter 2

1. Based on the determination of the pattern size, avatar size, and pattern-making method, collect and organize training samples for the initial pattern database.

2. Graphoanalytic description of the patterns and construction of the measurement indexes database of the parametric pattern.

3. For the validity of the follow-up experiment, a validation was conducted to assess whether the sample size was sufficient.

4. The grade scale reference for subjective fit evaluation was established, setting the grade of fit to five levels., which combined with the previous method of fit survey, dividing the surface area into 19 areas for more reliability.

5. The range of misfit tolerance was explored, which demonstrated the tolerance of differently designed pattern deformation.

CHAPTER 3. GEOMETRIC MODEL OF "SLEEVE-ARMHOLE"

Armhole-sleeve assembly was a complex process from two-dimensional pattern to three-dimensional garment, which affected by pattern block structure; selection of fabric and accessories; warp and weft yarn direction of fabric cutting; conditions of sewing, etc. Traditional views hold that only after sewing can we know whether the fit or misfit of the sleeve then amends the misfit.

In this chapter, several new databases and criteria were built and utilized Python to facilitate result use, which helped predict the defects before sewing. Therefore, the time consumption of armhole-sleeve trial assembly can be significantly reduced.

The results obtained in this chapter are published in three works [155, 157, 161].

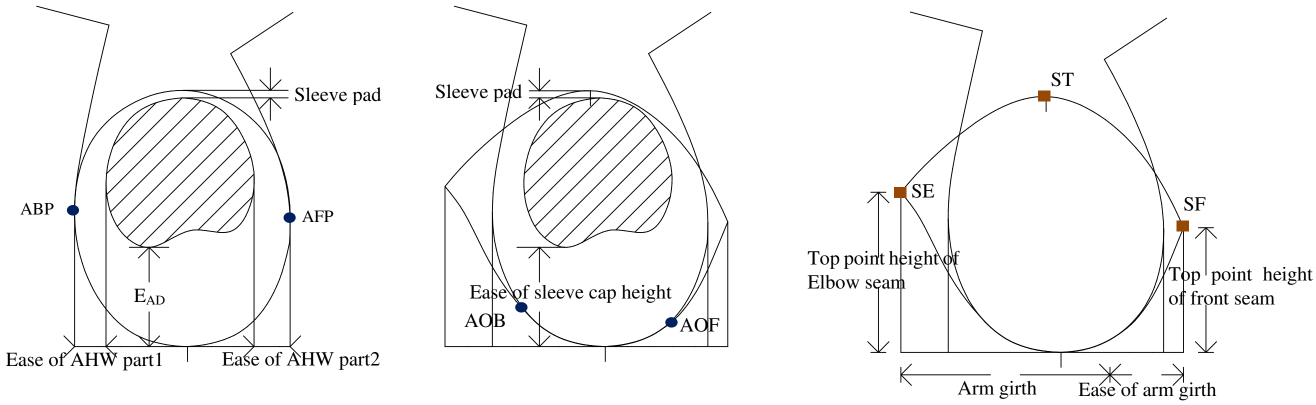
3.1. Methods and materials of research

3.1.1. Software of research

The 2D clothing CAD software ETCAD was utilized for jacket pattern drafting and feature point marking. The Clo3D was used for sleeve simulation. The 3D modeling software MAYA (Autodesk, USA) was used for 3D feature points coordinate measuring. Excel and SPSS were used for Statistical analysis of criteria construction. Python-Matplotlib for plotting and Spyder-IDE for computer modules developing, which facilitated the result utilization.

3.1.2. Feature points for matrix (2D criteria)

How sleeve cap closing was introduced in the previous Fig. 2.5,a,b, Fig.3.1 and Table 3.1 show four feature points on the armhole and three feature points on the sleeve cap, which are responsible for matrix development.



a *b* *c*

Figure 3.1 - Schematic picture of matrix feature points: *a* - ABP and AFP, *b* - AOB and AOF, *c* - SE, ST, and SF

Table 3.1 - Description of feature points for matrix

Symbol	Points of armhole scheme	Symbol	Points of closed sleeve cap scheme
ABP	the most on the back point	SE	top point of sleeve elbow seam
AFP	the most on the front point	ST	top point of sleeve cap
AOB	back-split point of overlapped	SF	top point of sleeve front seam
AOF	front-split point of overlapped	/	/

As shown in Fig. 3.1, the ABP, AFP setting inherit from Fig.2.2, and SE, ST, and SF inherit from Fig. 1.7. AOB and AOF were the new feature points for matrix exploring.

3.1.3. Feature points for sleeve-armhole assembly (3D criteria)

Fig. 3.2 and Table 3.2 show the feature points set for sleeve-armhole assembly, which have similarities and differences with the previous points setting for matrix.

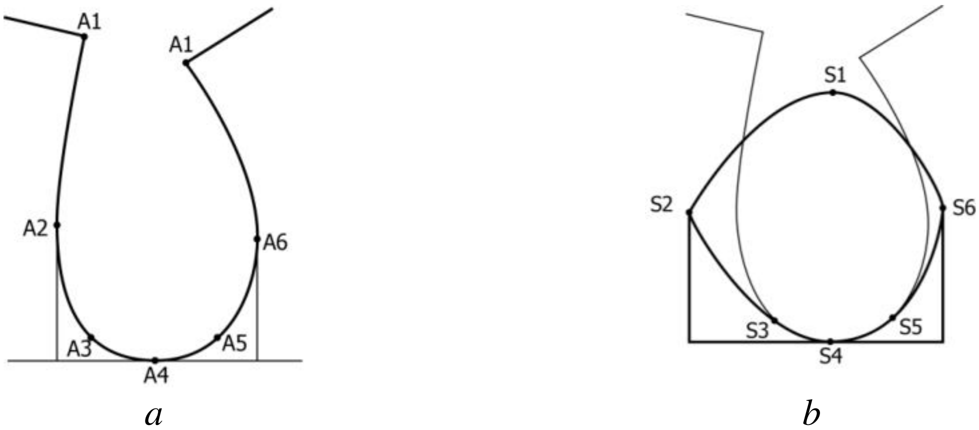


Figure 3.2 - Schematic picture of feature points of sleeve-armhole assembly: *a* - feature points at armhole, *b* - feature points at closed sleeve cap

Table 3.2 - Description of feature points for sleeve-armhole assembly

Symbol	Points of armhole scheme	Symbol	Points of closed sleeve cap scheme
A1	The top point	S1	The top point
A2	The most on the back point	S2	Finding the same distance of A4 to A2
A3	The most on the back-split point of overlapped armhole and sleeve cap closed	S3	The most on the back-split point of overlapped armhole and sleeve cap closed
A4	The bottom point	S4	The bottom point
A5	The most on the front-split point of overlapped armhole and sleeve cap closed	S5	The most on the front-split point of overlapped armhole and sleeve cap closed
A6	The most on the front point	S6	Finding the same distance of A4 to A6

As shown in Fig. 3.2, six points were located on the sleeve cap curve, and six points were located on the armhole. Those points will be used to acquire the coordinate location for assembly. As shown in Table 3.2, several feature points inherited the matrix setting of Table 3.1, which were A2, A3, A5, A6, S1. other points set were changed to accommodate assembly experiment requirement. For example, S2 (as Fig. 3.2,b) and SE (as Fig. 3.1,b) look quite similar, but S2 was finding the same distance of A4 to A2, according to the experiment's requirement.

3.2. Form the pattern matrix model for fit evaluation

Sleeve and armhole perfect joint is a complicated process. In general, empirical pattern construction methods want to give a fit sleeve, requiring continuous modification and sewing samples [112]. in order to speed up the process step of modification, the matrix was developed, which aim to predict the fit of armhole and sleeve cap before sewing and identification misfit problem.

The result of subjective evaluation grade scale of five grades was expressed in Table 2.4. However, five fit grades were too detailed for this experiment. In this study, only two grades, perfect fit and misfit.

The overlapping points were set at the lowest point of armhole and closed sleeve cap, respectively. Fig. 3.3 shows the feature points distribution and fit range square. For points, the blue and brown represented armhole and sleeve, and the dark and light represented fit and misfit, respectively. It was necessary to mention that the square constituted by points coordinate of means and stand deviation. This fit range applies to Chinese typical body size (as Table 1.7) and armhole length 43.32 - 54.35 cm.

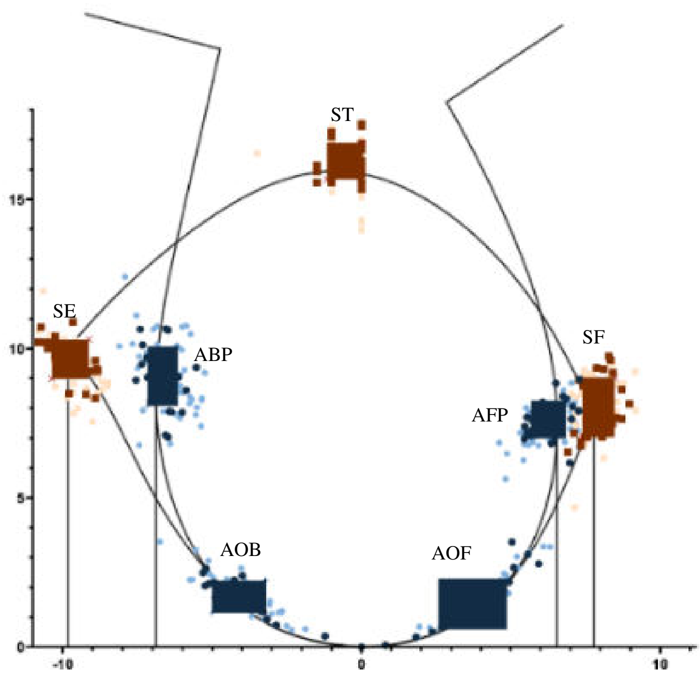


Figure 3.3 - Fit range of feature points at armhole and sleeve

As shown in Table 3.3, Each of these squares corresponded to two numbers of X-axis value and Y-axis value. Consequently, the matrix for misfit identification defects can be built, illustrated schematically in Fig. 3.4.

Table 3.3 - The coordinate range of perfect fit

Feature point	Location in X-Y coordinates	
	X	Y
ABP	-7.16 ≤ i ≤ -6.14	8.09 ≤ i ≤10.07
AOB	-5.01≤ i ≤-3.21	1.14≤ i ≤2.23
AOF	2.57≤ i ≤4.86	0.59≤ i ≤2.29
AFP	5.67≤ i ≤6.84	6.99≤ i ≤8.26
SE	-10.37≤ i ≤-9.13	8.99≤ i ≤10.31
ST	-1.15≤ i ≤0.03	15.67≤ i ≤16.89
SF	7.40≤ i ≤8.48	7.04≤ i ≤9.02

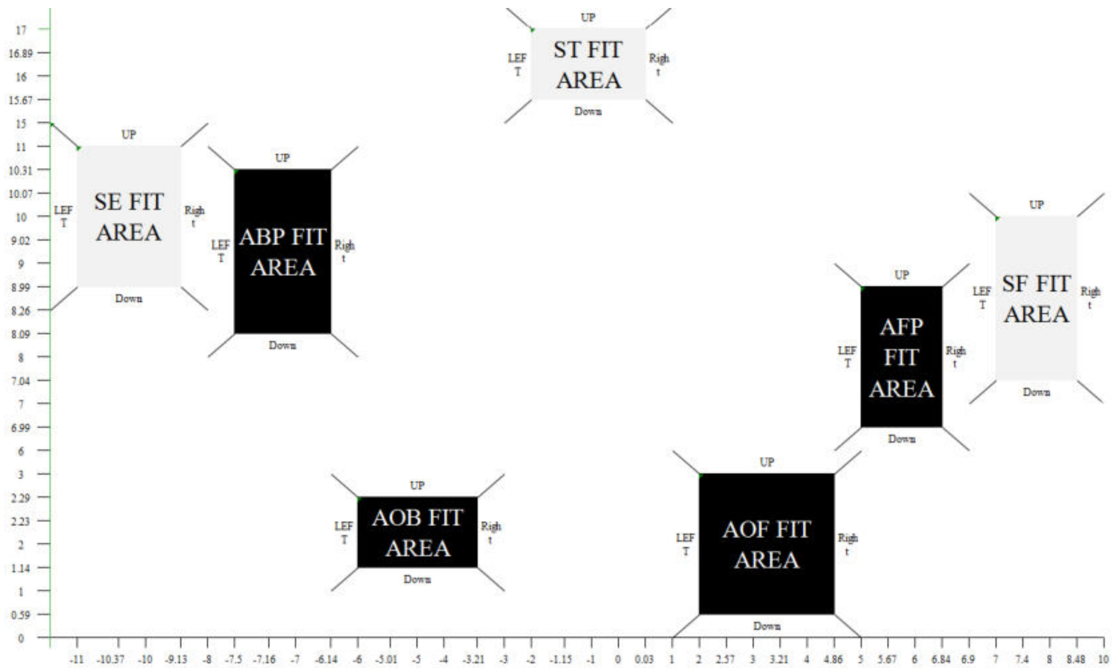


Figure 3.4 - Matrix for misfit defects identification

For example, suppose there was a completely new sleeve and bodice pattern, only three steps to know whether the pattern fits. First, feature points setting; Second, feature points coordinate measuring; Third, comparing with fit square range. If feature points were all located in the perfect fit square, the armhole jointed sleeve would fit. If not, Table 3.4 listed several common possibilities of misfit situations, which detailed the misfit name, expression, and possible locations of feature points.

This matrix experiment proposed a matrix of sleeve and armhole feature points to evaluate the fit and identify the potential misfit defects before sewing. Since the experiment was based on a flat pattern, the results were roughed and needed further exploration in a 3D environment.

Table 3.4 - Detail of misfit situation

Name of defect	The expression of defect	Possible locations of feature points
1. Depth of armhole not enough	Unsatisfied when arm lift	Point AOB at AOB fit area up, point AOF at AOF fit area up
2. Depth of armhole too much	wrinkles under the armpit	Point AOB at AOB fit area down, point AOF at AOF fit area down
3. Height of sleeve cap too much	excess horizontal folds at sleeve cap	Point ST at ST fit area up
4. Height of sleeve cap not enough	Wrinkles with stretch express at sleeve cap	Point ST at ST fit area down
5. Sleeve width too narrow	Horizontal wrinkles with stretch express at sleeve cap	Point SE at SE fit area left, point SF at SF fit area right

3.3. Constructing the simulated sleeve-armhole for fit evaluation

3.3.1. Training sample of sleeve simulated and formatted

Following conditions were selected for armhole assembly seam parametrization. The original point was set at the SP of avatar (Clo3D in-built), which connected with the front and back armpit by cutting plane. Fig. 3.5,a shows the DT of armhole formation. The plane corresponds to the natural turning in the joint line space of arm and torso. It has been assumed that the armhole seam line would lie on or close to this plane after sleeve insertion.

Fig. 3.5,b shows the feature points on the 3D geometrical model of sleeve cap curve and armhole. These points could obtain the required coordinates during virtual stitching. Meanwhile, there was a one-to-one correspondence between A1 to A6 and S1 to S6. In other words, after simulated sewing, A1 and S1 will become a sewed pair. The rest of the points were also.

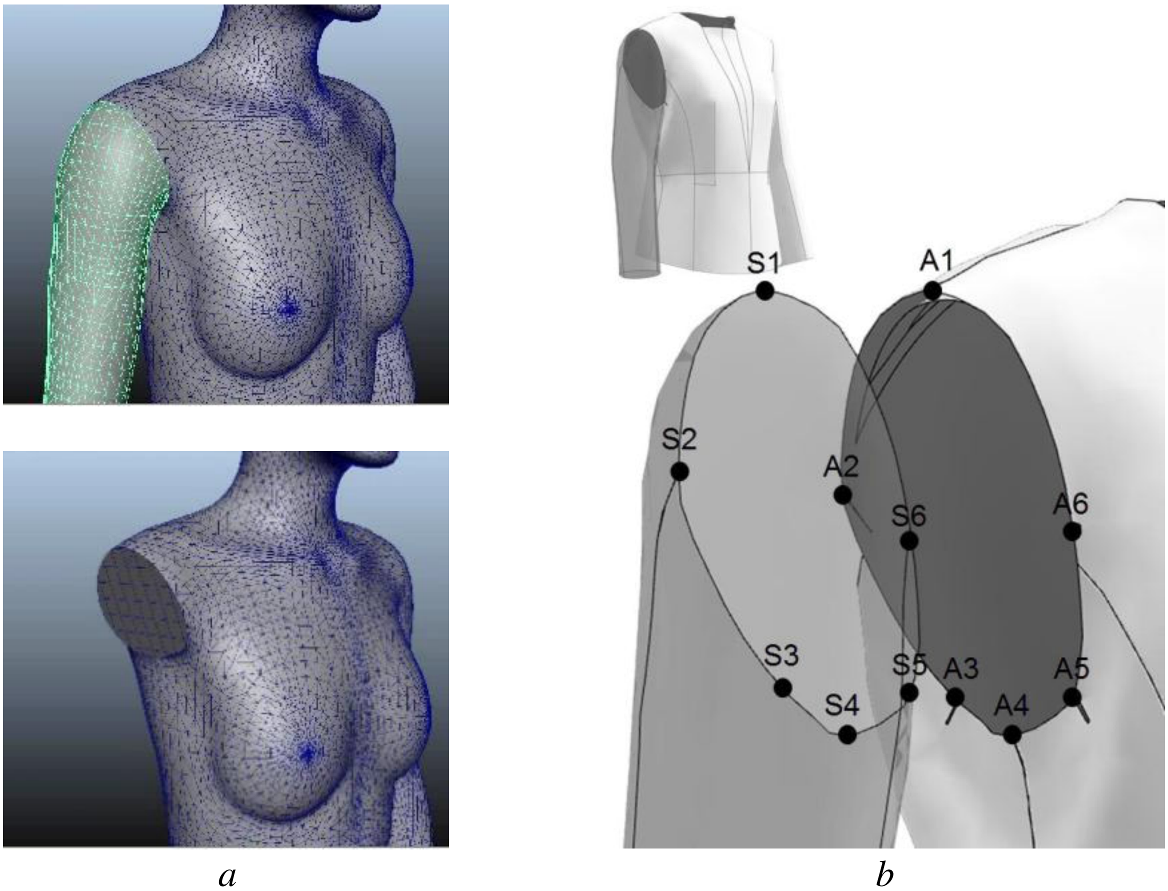
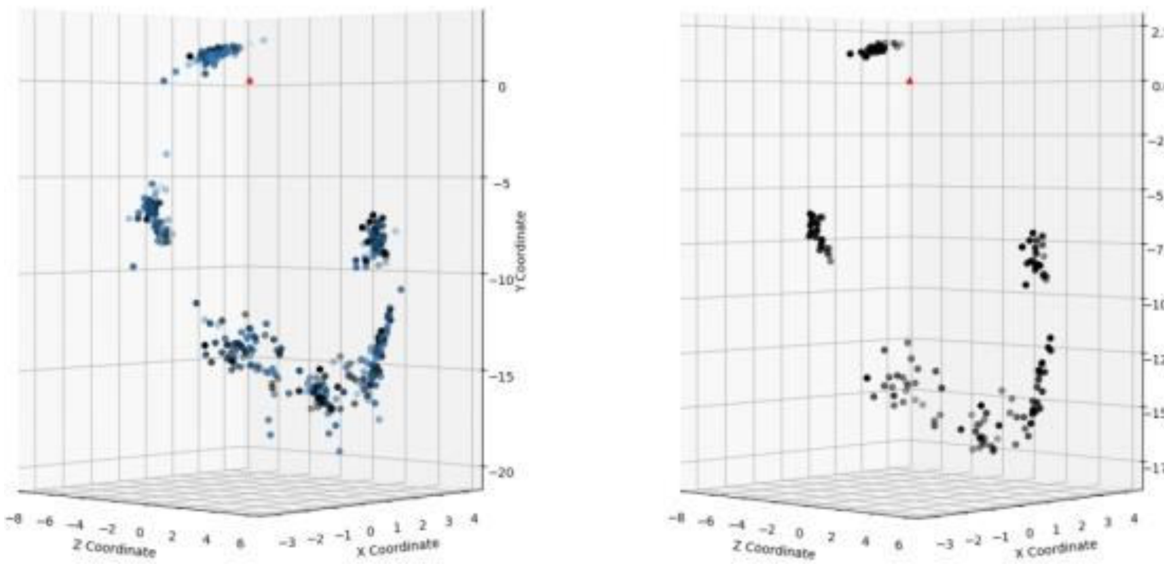


Figure 3.5 - Geometric model of connecting the sleeve and armhole: *a* - finding the SP, *b* - location of feature point at sleeve-armhole

3.3.2. Virtual try-on feature points location for fit evaluation and prediction

All training samples of 82 virtual jackets were simulated by Clo3D, which participated in the subjective evaluation. Following the previous subjective evaluation rules (as chapter 2.4) and actual experiment situation, five grades were adjusted into four (perfect, good, appropriate, poor) and two grades (perfect, misfit) adapted to the experimental demand. Two indicators were checked in this assessment: (1) the condition of textile materials - smooth or not smooth, with or without folds and wrinkles; (2) the conformity between the sleeve and the arm in the freely natural position.

Python-Matplotlib is a comprehensive library for interactive visualizations in the Python environment. The whole 3D-scatter plot coordinate of feature points could be built in Python environment with this library. After jacket simulation, Maya software was used to obtain the 12 feature points location, which was a sewed pair described previously. The preliminary experiments found that the coordinates of feature points (A1 - A6) were shifted and changed after assembly, which made the experimental results not satisfactory enough. Therefore, Fig. 3.6,a shows the points of armhole before assembly.



a *b*

Figure 3.6 - The space of feature points of the armhole seam: *a* - for all 82 virtual jackets, *b* - for 26 jackets with perfect fit

As shown in Fig. 3.6,a, all feature points of armholes were sorted into four kinds of colors (black, dark blue, blue, light blue), which reflect subjective evaluation grades. It can be found that although six feature points have different discrete degrees, the black (perfect fit grade) points were relatively concentrated.

As shown in Fig. 3.6,b, even the scatter plot of perfect fit category, the coordinates of feature points A3, A4, A5 were more discrete than A1, A2, A6.

The detail of feature points coordinate were sorted and analyzed in Table 3.5, the feature points coordinate and criteria Δ were determined within the perfect fit, which ensured a quality fit of the sleeve. The criteria were expressed as the fraction, the numerator represented points on the armhole, and the denominator represented points after assembled seam. The columns x, y, z represented the range of each feature point. Meanwhile, the columns Δx, Δy, Δz represented the means with tolerance. The sleeve fit can be predicted by checking the coordinates of feature points within or exceeding the tolerance range.

Table 3.5 - Fit evaluation criteria of feature points in armhole-sleeve assembly

№	Nominal coordinates of points (in numerator - on the armhole line, in denominator - on the pellet line), cm, and allowable deviations from them as criteria Δ, which not lead to defects					
	for front projection, cm		for frontal and profile projections, cm		for profile projection, cm	
	x	Δx	y	Δy	z	Δz
A_1 S_1	(0,26...1.78) -1.73...0.04	$\frac{-1.02 \pm 0.76}{-0.88 \pm 0.85}$	0.58…1.03 1...1.67	$\frac{0.8 \pm 0.22}{1.33 \pm 0.34}$	0.26…0.99 -(0,1..0.81)	$\frac{0.63 \pm 0.37}{-0.46 \pm 0.35}$
A_2 S_2	(0,13...1.03) 0.33…1.15	$\frac{-0.58 \pm 0.45}{0.74 \pm 0.41}$	-(6,54...8.76) -(6,22..8.49)	$\frac{-7.65 \pm 1.11}{-7.35 \pm 1.14}$	-(5,93...6.52) -(6,94..7.69)	$\frac{-6.22 \pm 0.3}{-7.32 \pm 0.37}$
A_3 S_3	(0,06...1.86) 1.76…3.61	$\frac{-0.96 \pm 0.9}{2.68 \pm 0.93}$	-(13,11..16.58) -(12,43...16.5)	$\frac{-14.84 \pm 1.73}{-14.46 \pm 2.03}$	-(0,79..5.07) -(2,78...6.04)	$\frac{-2.93 \pm 2.14}{-4.41 \pm 1.63}$
A_4 S_4	-2.61..+0.45 3.02…4.29	$\frac{-1.08 \pm 1.53}{3.65 \pm 0.64}$	-(15,08..17.59) -(14,61..17.41)	$\frac{-16.33 \pm 1.25}{-16.01 \pm 1.4}$	-0.64…0.74 -(0,18...2.23)	$\frac{0.05 \pm 0.69}{-1.21 \pm 1.03}$
A_5 S_5	-1.16..+0.61 2.79…3.84	$\frac{-0.28 \pm 0.88}{3.32 \pm 0.53}$	-(12,05..16.65) -(11,81..16.96)	$\frac{-14.35 \pm 2.3}{-14.38 \pm 2.58}$	1.25…5.41 -0.85...3.71	$\frac{3.33 \pm 2.08}{1.43 \pm 2.28}$
A_6 S_6	0.12…0.9 1.54…2.44	$\frac{0.51 \pm 0.39}{1.99 \pm 0.45}$	-(7,32..9.47) -(6,92..9.26)	$\frac{-8.39 \pm 1.08}{-8.09 \pm 1.17}$	5.82…6.26 4.17…4.79	$\frac{6.04 \pm 0.22}{4.48 \pm 0.31}$

Note: the "+" sign indicates the position of the point on the positive part of the axis and the "-" sign on the negative part.

The two most significant dispersion values were A3 and A5, which was consistent with Fig. 3.6,b. One reason for this was the normal error while determining points A3 and A5 (when marking points A3 and A5, the flat pattern needed to overlap as Fig. 3.2,b. However, this step was prone to error). Furthermore, point A4 got the second-largest dispersion. The cause was attributed to the point A4 hanging on the lowest of the armhole. It is affected by several forces' influence.

In contrast, the location of other points is relatively stable. The most stable point was A1 (located at the sleeve pad of shoulder). The sleeve pad limited this point movement.

Compare the tolerance of numerator and denominator in the columns Δx, Δy, and Δz. The majority of numerator tolerance was smaller than the denominator (the numerator represented the coordinate before sleeve assembly, the denominator represented after sleeve assembly), this result supported the previous preliminary experiment's finding that the feature point coordinate may shift after assembly. Therefore, the numerator with relative higher credibility for fit evaluation and prediction. However, higher numerator credibility did not imply that the denominator was excluded. Both of them were used for armhole-sleeve fit evaluation due to the complex assembly situation. In Appendix F, all training samples' feature point coordinates were detailed.

In order to analyze the assembled sleeve's feature points coordinate, criteria range, and misfit deviation, all feature points with three directions were converted into zero starting for convenient comparison. Fig. 3.7 shows that all coordinate values were divided into the fit range (dark blue) and misfit range (light blue). Two misfit ranges sandwiched the fit range. If the points coordinate values leave the fit range, defect appearance.

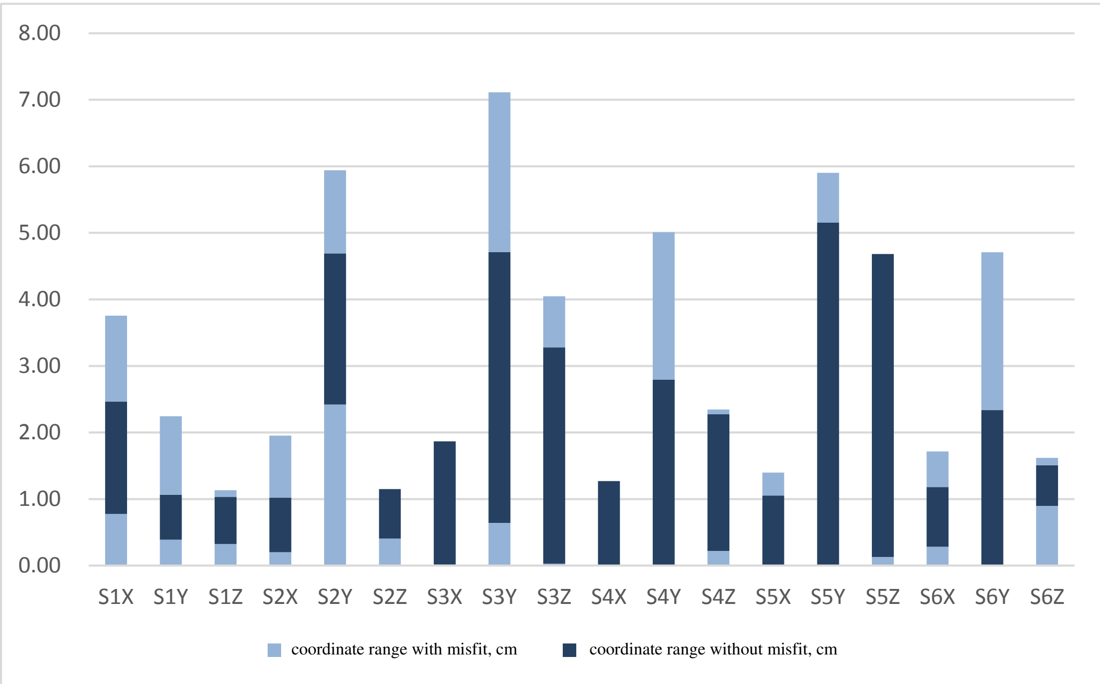


Figure 3.7 - Coordinate range after sleeve assembly

In this columnar chart, the ranges in y-direction were significantly more prominent than in other directions, which suggested that the feature points tend to misfit at y-direction. There was no misfit range on the columns S3x and S4x, which indicated that these two feature points do not move in the x-direction.

3.3.3. Prediction fit of sleeve

In the previous sub-chapter, it was possible to evaluate the fit in the virtual environment by using the features points. However, a virtually simulated fit evaluation could not be performed when the virtual environment was difficult to obtain. For this reason, it was necessary to derive the conclusion of the feature point to the measurement indexes of the flat pattern. It could expand the scope of use and lower the limits of evaluation results.

In the process of converting the results of 3D virtual fitting into 2D flat pattern, an additional variable was needed to divide for the sleeve selection, which is used to increase the accuracy of this method. Based on the result from the previous experiment, two variables were taken part in, which was sleeveΔ and AHL.

Table 3.6 shows the AHL has been clustered into five categories by the K-means method. This algorithm is an iterative cluster analysis algorithm that pre-classifies the data into K groups. The clustering center and the objects assigned to them represent a cluster. For each sample assigned, the cluster's center is recalculated based on the existing objects in the cluster. This process could be repeated until some termination condition is met. The termination condition can be that no (or a minimum number of) objects are reallocated to different clusters, that no (or a minimum number of) cluster centers are changed again, and that the error squared and local minimal are minimized.

Table 3.6 - K-means cluster of AHL of each sample

Sample Number	Cluster group	distance	Sample Number	Cluster group	distance
1	2	3	4	5	6
1	2	0.248	43	4	0.255
2	1	0.674	44	5	0.084
3	1	0.336	45	2	0.582
4	4	0.625	46	5	0.656
5	5	0.536	47	5	0.214
6	4	0.245	48	5	0.084
7	2	0.232	49	2	0.708
8	4	0.415	50	1	0.146

Finish Table 3.6

1	2	3	4	5	6
9	4	0.755	51	2	0.362
10	4	0.555	52	2	0.382
11	1	0.524	53	5	1.034
12	4	0.275	54	5	0.614
13	4	0.115	55	2	0.378
14	1	0.016	56	2	0.252
15	4	1.465	57	2	0.232
16	4	0.565	58	2	0.432
17	2	0.458	59	2	0.012
18	1	0.326	60	5	0.496
19	4	0.495	61	1	0.616
20	**3**	**0**	62	5	0.426
21	2	0.208	63	1	0.164
22	1	0.444	64	1	0.414
23	4	0.055	65	5	0.164
24	2	0.088	66	5	0.456
25	1	0.094	67	2	0.022
26	4	0.115	68	1	0.386
27	5	1.434	69	2	0.588
28	2	0.178	70	1	0.126
29	1	0.314	71	2	0.422
30	4	0.405	72	2	0.388
31	1	0.244	73	2	0.342
32	2	0.528	74	2	0.042
33	5	0.586	75	2	0.422
34	5	0.156	76	4	0.115
35	1	0.576	77	2	0.708
36	2	0.382	78	2	0.078
37	2	0.648	79	5	0.034
38	2	0.098	80	5	0.194
39	2	0.202	81	2	0.392
40	2	0.602	82	5	0.106
41	5	0.446			
42	1	0.336			

Table 3.7 - K-means cluster of AHL of cluster center and closest sample for ve rification

Four cluster center	Cluster A	Cluster B	Cluster C	Cluster D
AHL, cm	44.75	46.20	47.76	49.42
sample number.	79	59	14	23
sample AHL, cm	44.72	46.21	47.74	49.36

As shown in Table 3.6, the training samples of the flat pattern were divided into five categories according to the AHL. Sample No.20 was included in category three, and only it in this category. Therefore, the category was considered a singular value and was removed. Finally, AHL has been successfully classified by us into four categories.

As shown in Table 3.7, by calculating the connection values between each cluster, four clustered categories of AHL was achieved, which are (Category A: 43.3-45.4), (category B: 45.5-47), (category C: 47,1-48.5), (category D: 48.6-50.9). At the same time, the similar AHL values of training sample with the clustering center were selected to verify the clustering result. Four samples took part in the verification. The verification shows that the cluster classification was reasonable.

Table 3.8 includes the AHL cluster, subjective evaluation, pattern indexes, the armhole and sleeve assembly recommendation. Indexes of WBF, AHL, and AHD evaluate the fit of armhole. While SCH, SCW, SCL, and P sleeve Δ evaluate the fit of sleeve. This recommendation could roughly predict the sleeve fit before assembly and simulation. It was the simulated sleeve fit evaluation knowledge derived to the flat pattern.

For example, a new bodice pattern with WBF = 48 cm, AHL = 45 cm, and AHD = 16.5 cm, based on the range of Table 3.8, this armhole was considering as a suitable armhole, which belongs to category A. thus the potential sleeve pattern could be recommended as SCH = 15.6-17.7 cm, SCW = 31.5-37.8 cm, SCL = 48.7-50.4 cm, and P sleeve Δ = 8.5-11.1 %. If the sleeve indexes value within the above range, it was considered that the sleeve would be with perfect fit. If several values exceed this range, defects might occur. Since this bodice had a sleeve pattern, all sleeve index was within the recommended range after measuring. So the sleeve was considered fit for the bodice.

Table 3.8 - Recommendation for checking armhole and sleeve before assembly

<table>
<tr><th colspan="2">Bodice patterns index</th><th>Perfect fit</th><th>Good fit</th><th>Appropriat e fit</th><th>Bad fit</th></tr>
<tr><td colspan="2">Width of bodice pattern at bust level (WBF), cm</td><td>47.2-50.4</td><td>46.7-51.4</td><td>46.6-51.6</td><td>45.7-51.6</td></tr>
<tr><td rowspan="4">AHL, cm</td><td>category A</td><td>44.7-45.4</td><td colspan="3">43.3-45.4</td></tr>
<tr><td>category B</td><td>45.6-46.6</td><td colspan="3">45.5-46.8</td></tr>
<tr><td>category C</td><td>47.4-48.4</td><td colspan="3">47.2-48.4</td></tr>
<tr><td>category D</td><td>48.8-50.1</td><td colspan="3">48.7-50.9</td></tr>
<tr><td colspan="2">AHD, cm</td><td>15.5-18</td><td colspan="3">14.8-19.7</td></tr>
<tr><td colspan="6">Recommend sleeve pattern indexes</td></tr>
<tr><td colspan="2">SCH, cm</td><td>15.6-17.7</td><td colspan="3">14.3-18.4</td></tr>
<tr><td colspan="2">SCW, cm</td><td>31.5-37.8</td><td>31.3-39.3</td><td colspan="2">30.6-39.3</td></tr>
<tr><td rowspan="4">SCL, cm</td><td>category A</td><td>48.7-50.4</td><td colspan="3">46.4-50.4</td></tr>
<tr><td>category B</td><td>48.6-51</td><td>47.5-51.1</td><td colspan="2">47.5-51.6</td></tr>
<tr><td>category C</td><td>48.6-51.6</td><td colspan="3">48.6-52.5</td></tr>
<tr><td>category D</td><td>51.5-54.1</td><td colspan="3">51.5-54.9</td></tr>
<tr><td rowspan="4">P sleeve Δ, %</td><td>category A</td><td>8.5-11.1</td><td>4.7-11.1</td><td colspan="2">4.6-11.1</td></tr>
<tr><td>category B</td><td>6-9.4</td><td>4.5-9.5</td><td colspan="2">4.5-11</td></tr>
<tr><td>category C</td><td>2.5-7.9</td><td colspan="3">2.5-10</td></tr>
<tr><td>category D</td><td>4.4-8.5</td><td colspan="3">4.4-8.5</td></tr>
</table>

In this way, some potential defects related to sleeve-armhole assembly can be avoided before sewing.

3.4. Automatic fit evaluation and prediction module for sleeve fit

The main objective of this work was to design the modules of the computer program to facilitate the result utilization.

3.4.1. Module of armhole and sleeve points judgment

The result about fit evaluation of feature points and recommendation of armhole and sleeve range helped the pattern maker evaluate and predict the fit before sewing.

However, these results were prone to error when continuous comparison sample with criteria range. Meanwhile, they were time-consuming. Thus, it would be unrealistic to expect the pattern-maker to carry out such a procedure, which would be difficult, tedious, and time-consuming. So, compiling a module of the computer program to facilitate the evaluation result utilization seems necessary.

Fig. 3.8 shows the module was constructed in the environment of Python. The specific integrated development environment was Spyder-IDE [114]. Because it was a prototype module, no specific front-end interface was built for it, and it was running in the default interface port of Spyder-IDE.

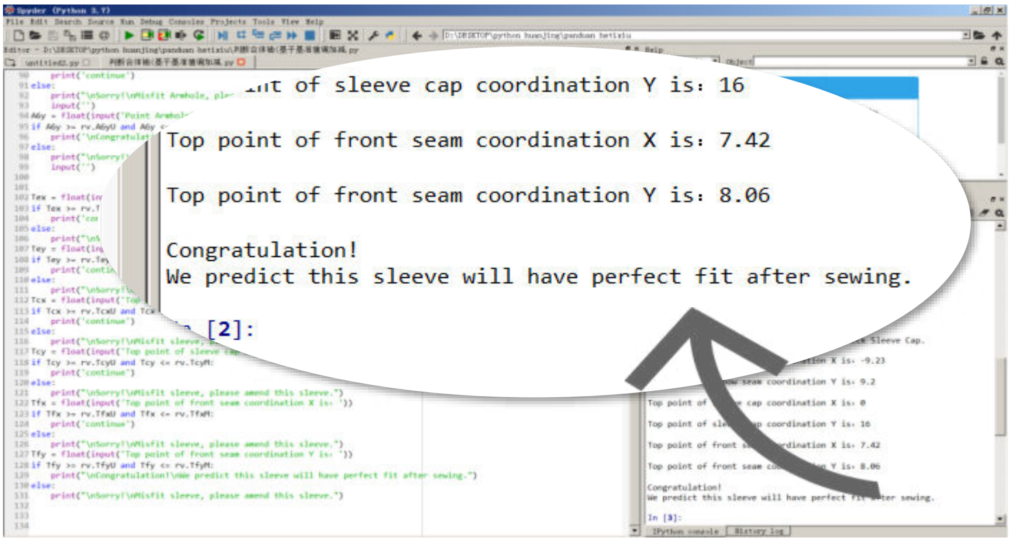


Figure 3.8 - Module interface window of Spyder-IDE

Fig. 3.9 shows the flowchart for automatic armhole and sleeve judgment. The detailed steps were as follows:

1. Creating the class for saving the coordinate threshold range of Table 3.3 listed, the next step can be taken only when the resulting data was compiled into the form that the computer can read correctly.

2. Input the feature point coordinate of the armhole. After that, the module would automatically compare the input value with the class threshold range. If the input value was within the range, continue. Otherwise, stop and tell the misfit on screen.

3. Input the feature point coordinate of the sleeve, which was similar to the armhole.

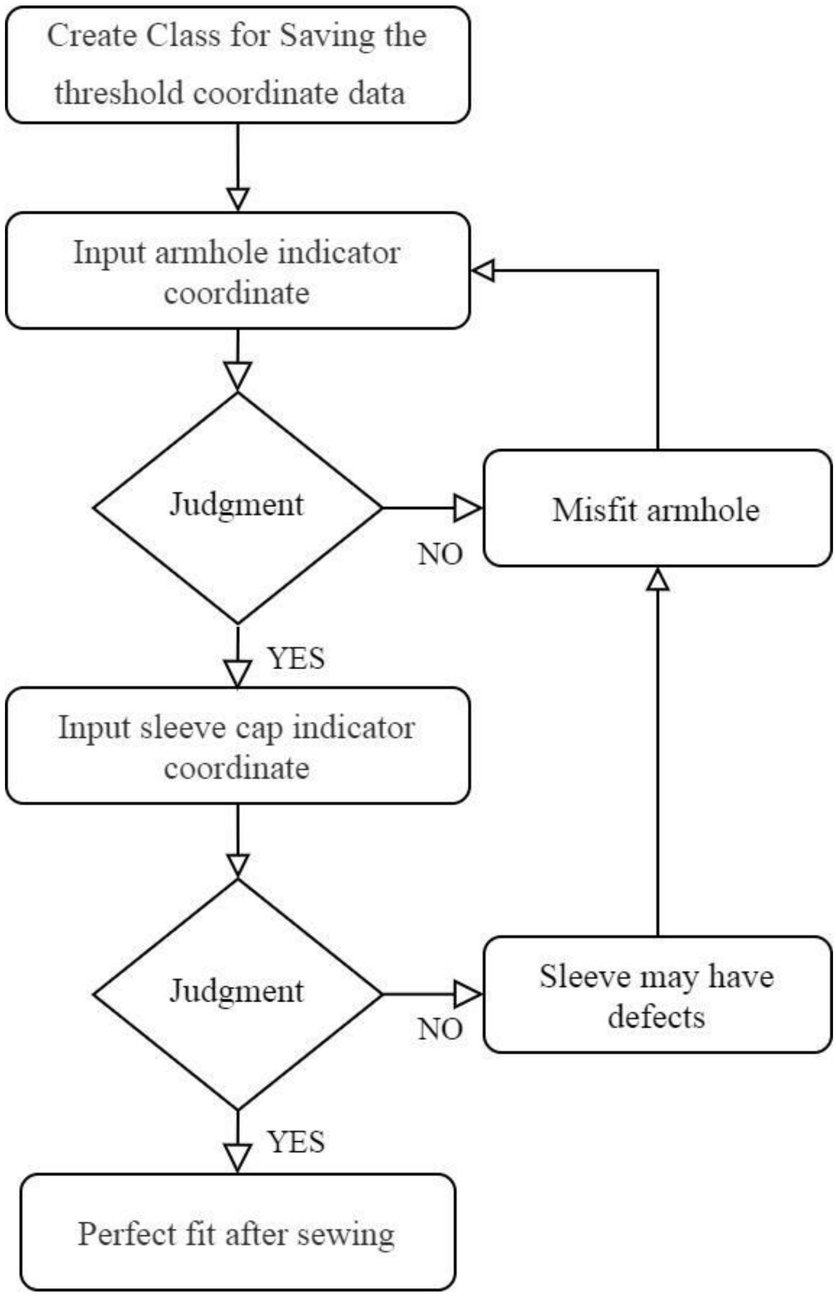


Figure 3.9 - Module for automatic judgement the fit by feature point coordinates

After this, the fit result of sleeve and armhole can be automatically acquired. Through this module, fit can be quickly determined. This module facilitated the result of "armhole-sleeve" feature points fit evaluation. The codes were provided in Appendix G.

3.4.2. Module of appropriate sleeve recommendation

Same with the previous module, the sleeve recommendation module was also compiled in the Python and Spyder-IDE environment.

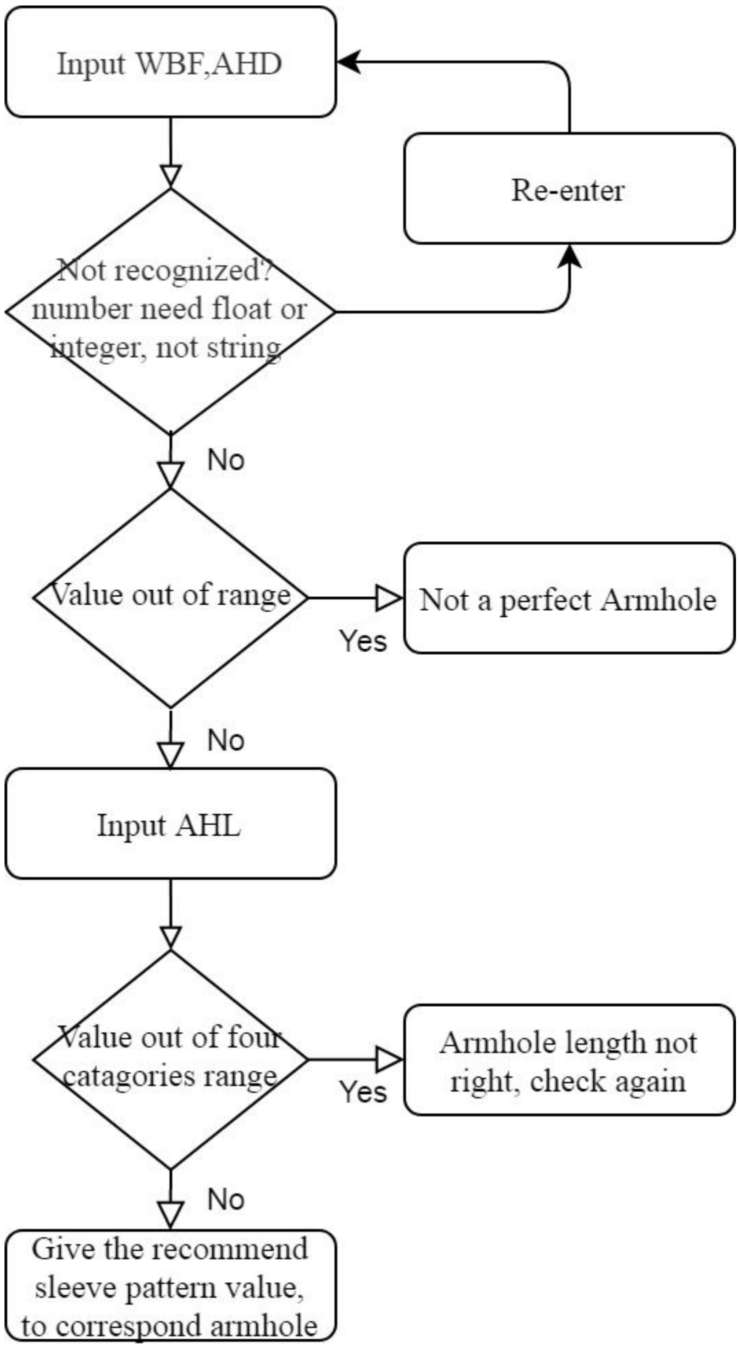


Figure 3.10 - Module for automatic recommendation of sleeve index range

As shown in Fig. 3.10, the recommended process module can be described by the flow chart. The detailed steps were as follows:

1. The bodice patterns parametric index of WBF, AHD detection. This step required calling the bodice patterns parametric index of Table 3.8. Since specific units of pattern were involved, the input format needs attention.

2. The computer module would automatically compare the input value with the compiled threshold. If the input value was within the range, continue. Otherwise, stop.

3. Since AHL was divided into four categories for accuracy, the module would automatically determine which category and replied the recommended sleeve indexes range after inputting the specific AHL value.

This module conveniently helped the pattern-maker get the desired sleeve range, which implemented the "smart manufacturing" concept. For more details of code, see Appendix H.

Part of the module code was applied and obtained the certification of computer software copyright (authorization by national copyright administration of China). It is a component of remote clothing customization system (as Appendix I shows).

To verify those two computer modules' facilitative. A trial validating test was carried out.

Five experts of patternmaking participated in this experiment as the evaluator. From the pattern database, 20 random patterns as samples were selected, indexes value measured, simulated, and feature point coordinate detected. Those samples were randomly and equally divided into two groups: one for traditional checking of comparing with tables, another for computer module. The time costing and accuracy was recorded to determine the superiority or inferiority.

This experiment aimed to obtain a preliminary result of whether the computer module was easily understood and used, which improved the efficiency of fit evaluation and determination.

The results show that the computer module improved the accuracy of judgement with time-saving. Especially in the feature point coordinates part, since up to 14 coordinate values were compared, the module saves up to 31% time and improves the 23% accuracy. For the part of appropriate sleeve recommendation, the comparison did not concern this part due to a few indexes.

The evaluator highly appreciated the computer module and found it was easy to understand and efficient when using. One expert felt that there was inadequate friendliness of default interaction of spyder-IDE. The independent interface of this module should develop to facilitate the actual usage.

Conclusion after chapter 3

1. A matrix for misfit detection was developed, including seven feature points of pattern. This matrix could evaluate the fit and identify the potential misfit defects before sewing.

2. A new geometric method to evaluate the fit of sleeve-armhole assembly has been developed. This geometric method includes 12 feature points, which could evaluate and predict the fit by 3D points coordinate.

3. Two new databases have been established. The first database was used for fit evaluation by 12 points coordinate. The second database recommends a suitable sleeve pattern range for the corresponding armhole. Those two databases could avoid potential defects before armhole-sleeve assembly.

4. Two computer modules have been developed to facilitate the resulting usability. A validating test reported that the modules made the result easy to use, saving up to 31% time and improving the 23% accuracy.

CHAPTER 4. BASIC PRINCIPLES FOR WHOLE SLEEVE FIT PREDICTION

The proposed geometric models for "sleeve-armhole" enhance sleeve assembly's evaluation and prediction capability to the armhole. However, this evaluation only focuses on the sleeve assembly stage - in other words, only in the sleeve cap area and armhole area, which was inadequate to accomplish the fit prediction of clothing (consisted of sleeve and bodice).

This chapter proposes five basic principles for virtual reality clothing fit prediction, which could predict the whole sleeve behavior and effectively predict several indexes influenced by the fit. The specific five principles were as follows:

1. The choosing of human body avatar.
2. The application of the same indexes of 2D pattern and 3D sleeves.
3. The applying of similar conditions for virtual and real sleeves generating, which include the similar textile materials, the sewing process, the posture, etc.
4. The combining subjective and objective methods for fit evaluation.
5. The finding of relationship between the similar indexes of the patterns and the simulated sleeves, the fit criteria range, the categorization of the indexes by sensitiveness, and the linear regressions to predict indexes of simulated sleeves.

The study results represent a further step towards sleeve fit, which constructs theoretical criteria for fit prediction. This study can integrate basting and amending steps for sleeve production, thus reducing the time and material consumption and acquiring high-quality sleeves more efficiently.

The results obtained in this chapter are published in two works [158, 159].

4.1. Methods and materials of research

4.1.1. Software of research

ETCAD software was used for pattern aspect measuring and marking, Clo3D software was used for digital twins of jacket (DTJ) simulation and DT construction. All coordinate aspects of digital twins of sleeve (DTS) were measured and transformed by Maya. Excel and SPSS were used for Statistical analysis. Adobe Illustrator (Adobe LLC, USA) and Graphpad (Graphpad software, USA) were used for plotting.

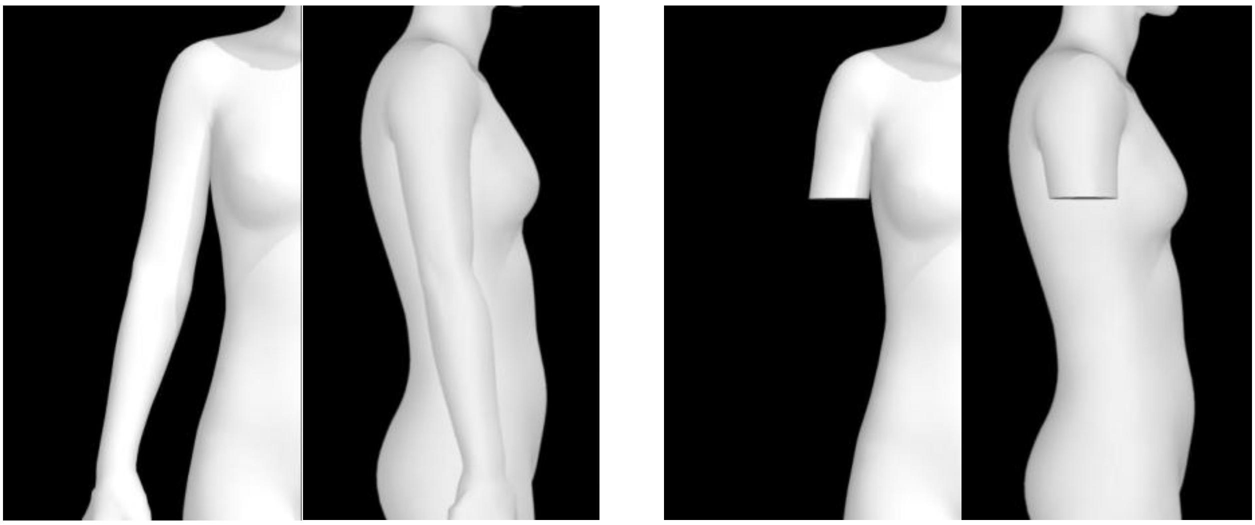
4.1.2. Objects of research

The avatar for simulation was determined by the typical size of the Chinese national standard, which was introduced in Table 1.7. The objects were generated by 82 real jacket patterns, which same as the previous experiment. Three types of women's jackets were explored as the objects in this experiment. The detail was as follows:

1. Real sleeve pattern (Sp).

2. Fig, 4.1,a shows the DT of full-arm avatar, the sleeve simulated for this DT named sleeve of avatar (Sa). The stable avatar arm may limit the behaviour of sleeve.

3. Fig, 4.1,b shows the DT of partly removed arm. Duo to this kind of DT was similar to dummy. The sleeve simulated for this DT was named sleeve of dummy (Sd). The sleeve can drape more freely and clearly to express the surface performance. All Sa and Sd were simulated according to the third principle.



a *b*

Figure 4.1 - DT for jacket sleeve simulation: *a* - sleeve generating on avatar with full arm, *b* - sleeve generating on avatar partly removed arm

4.1.3. Modified Subjective fit evaluation

The subjective evaluation result was expressed in Table 2.4. However, the five grades were too detailed. In this experiment, five grades were modified into three (1 - perfect, 2 - appropriate, 3 - poor) to evaluate the state of the fit. All sleeves were segmented into three groups according to their appearance quality. Table 4.1 shows the modified grades and misfit reasons, which could be ascribed as the following two aspects:

(1) Pattern aspect: Due to incorrect proportion or wrong pattern indexes setting,

(2) Body morphology aspect: The sleeve does not adapt in terms of arm position or its dimensions. In this study, the arm was in the default position of Clo3D (as Fig. 4.1,a).

Table 4.1 - The modified grades of subjective fit evaluation

Scale	Semantic expression	Areas of misfit	Reason of fit problems related to pattern construction
1	Perfect (Pe)	0	None
2	Appropriate (Ap)	1-5	Sleeve width too much, sleeve width not enough. Sleeve cup height too much, sleeve cup height not enough.
3	Poor (Po)	≥5	Mismatch shapes of sleeve and armhole during assembly, Mismatch lengths of sleeve cup and armhole during assembly. Sleeve width too much, sleeve width not enough. Sleeve cap height too much, sleeve cap height not enough. Deformation of sleeve cup. Deformation along elbow seam.

Before the formal experiment, the pre-experiment compared the Sa and Sd from same pattern. The wrinkles on Sa surface appeared obviously due to the limitation of the arm posture. However, Sd is unobvious to express wrinkles because of without arm restraint. The results revealed that Sa has several advantages in subjective testing by more clearly winkles expression.

So, although Sa and Sd could both apply for sleeve subjective fit evaluation, the Sa was chosen because of its' advantage, which was proposed in the first principle.

Fig. 4.2 shows the examples of the Sa with perfect and poor scale in five views. The perfect fit Sa without creases and folds on any view, in opposite, the sleeve with poor fit has many creases due to stress or fullness. These two example sleeves were simulated according to the third principle. Fig. 4.2,i shows series creases along the elbow seam in back view. The possible reasons for these creases could be: the sleeve shape is not adapted with arm natural position, the configuration of back edges were not adequate, and the sleeve width is too big, etc.

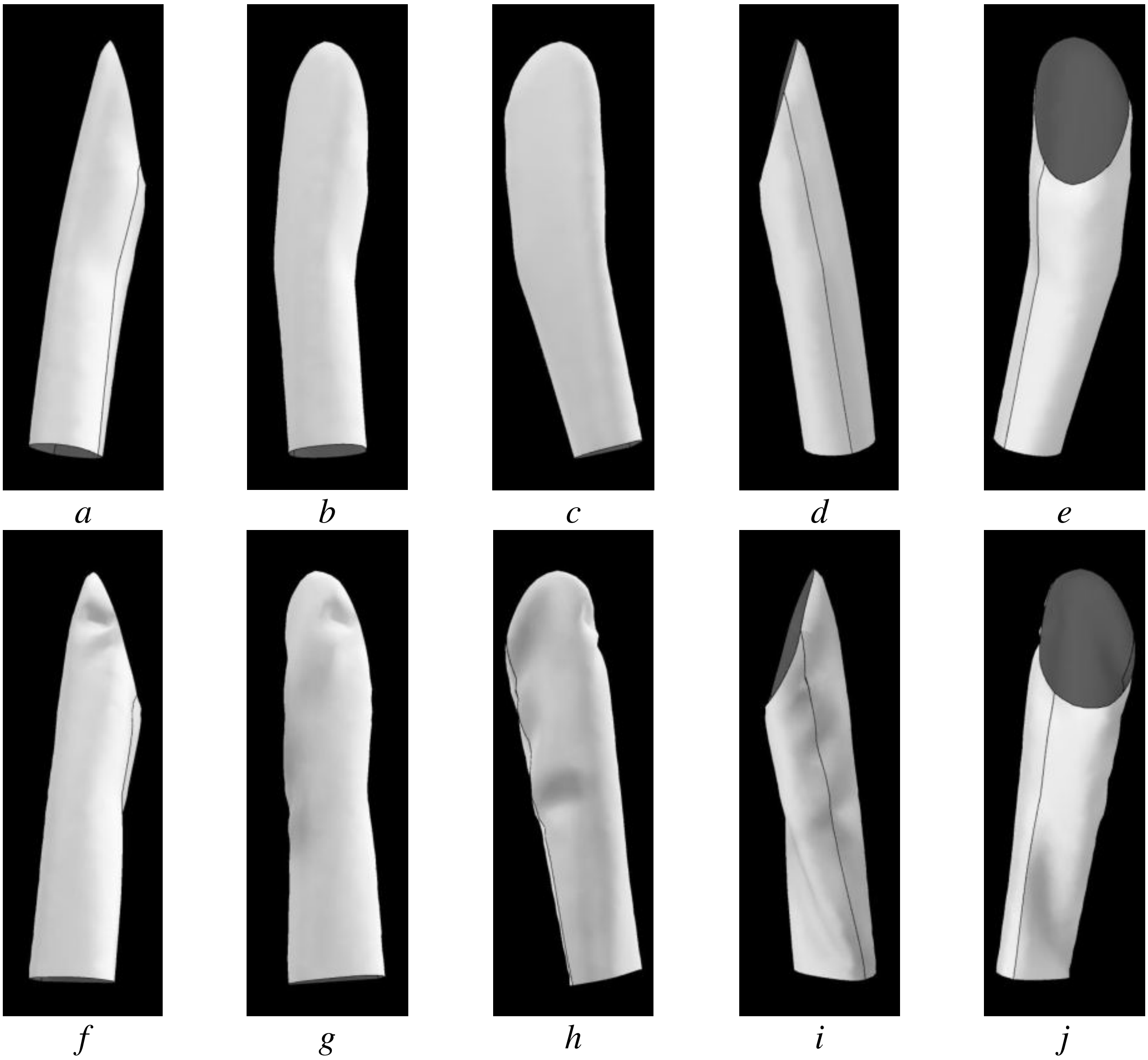


Figure 4.2 - Simulated Sa: *a, b, c, d, e* - perfect fit sleeve in front, half front , profile, back, inner; view, *f, g, h, i, j* - poor fit sleeve in front, half front , profile, back, inner, view

After subjective evaluation, 12 perfect fit sleeve and 12 poor sleeve were selected for experiment, respectively.

4.2. Objective fit evaluation setting and relation detecting

4.2.1. Objective fit evaluation indexes

The Sp, Sa, and Sd were involved in the objective fit evaluation. The index naming rule consisted of three parts: index name, subscript of index, and subscript of sleeve kinds, which were detailed in Fig. 4.3. Where $\angle\beta$ lacked subscript of index (no need to distinguish), D lacked sleeve kinds subscript of pattern (bust level and sleeve width overlapped on flat pattern).

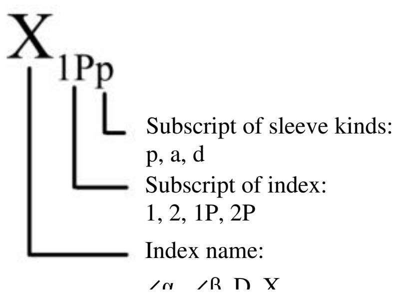


Figure 4.3 - Rule of indexes naming

According to the second principle and naming rule, 31 indexes were set to evaluate the fit of Sp, Sa, and Sd. These indexes show and list at Fig. 4.4 and Table 4.2, 4.3, respectively, which could be divided into several categories as follows.

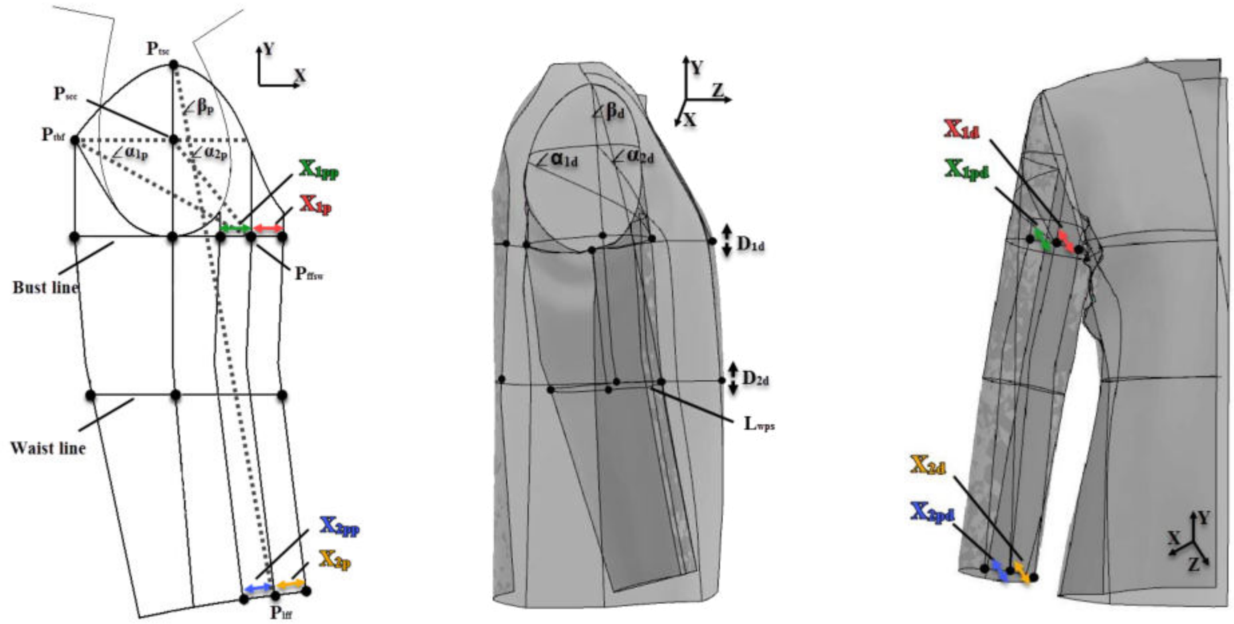
(1) The fullness of the cup sleeve ($\angle\alpha_1$, $\angle\alpha_2$),

(2) The concordance between the arm and the sleeve positions ($\angle\beta$),

(3) The rightness of front fold direction (X_1, X_{1p},X_2, X_{2p}, $|X_1-X_2|$, $|X_{1p}-X_{2p}|$),

(4) The concordance between the sleeve and the bodice (D_1, D_2).

Fig. 4.4,a shows the index setting of Sp, Fig. 4.4,b,c show the index setting of Sd for example. The adoption of the same indexes across Sp, Sa, and Sd demonstrate the suggested second principle of the same indexes application for 2D pattern and 3D simulation. All indexes of lengths, angles, and coordinate were measured by ET CAD, Screen Protractor, and MAYA, respectively.



a *b* *c*

Figure 4.4 - Universal indexes for objective fit evaluation: *a* - Sp, *b* - Sd in profile view, *c* - Sd in front view

Tables 4.2 and 4.3 detail the schedule of acquiring indexes of Sp, Sa, and Sd, respectively.

Table 4.2 - The indexes of Sp

No.	The index	Symbol (as Figure4.4, a)	Scheme of measuring	Range
1	2	3	4	5
1	Cup fullness in horizontal direction,°	$\angle\alpha_{1p}$	Marking the top point of the back fold ($P_{tbf.}$). Drawing the horizontal line through point $P_{tbf.}$ Marking the intersection point (P_{ffsw}) of the front fold on the sleeve width line. Measure the angle between the two lines	24.7-33.9
2	Half cup fullness in horizontal direction,°	$\angle\alpha_{2p}$	Marking the crossing point (P_{scc}) of the horizontal line from P_{tbf} and sleeve cap height from top point (P_{tsc}). Connecting P_{scc} and P_{ffsw} by a straight line. Measure the angle between two lines.	44.3-53.1

Finish Table 4.2

1	2	3	4	5
3	Position of sleeve,°	$\angle\beta_p$	Marking lowest point of the front fold (P_{lff}). Connecting P_{lff} and P_{tsc} by straight line. Measure the angle between two lines	10.2-13.2
4	Distance between fold line and upper sleeve edge at width area, cm	X_{1p}	Measuring the horizontal distance between the upper sleeve front edge and front fold at sleeve width line	1.5-5
5	Distance between fold line and under sleeve edge at width area, cm	X_{1Pp}	Measuring the horizontal distance between the down sleeve front edge and the front fold at sleeve width level	1.5-5
6	Distance between fold line and upper sleeve edge at cuff area, cm	X_{2p}	Measuring the distance between the upper sleeve front edge and the front fold at sleeve bottom level.	1.3-5
7	Distance between fold line and under sleeve edge at lower arm at cuff area, cm	X_{2Pp}	Measuring the distance between down sleeve front edge and front fold at sleeve bottom level	1.3-5
8	Difference of front fold and front edge at upper sleeve, cm	$\lvert X_{1p}-X_{2p}\rvert$	Calculating the absolute difference between X_{1p} and X_{2p}	0-1
9	Difference of front fold and front edge at down sleeve, cm	$\lvert X_{1Pp}-X_{2Pp}\rvert$	Calculating the absolute difference between X_{1Pp} and X_{2Pp}	0-1

Table 4.3 - The indexes of Sa and Sd

No.	The index	Symbol (as Figure4.4, b,c)	Scheme of measuring	Range	
				Sa	Sd
1	2	3	4	5	6
1	Cup fullness,°	$\angle\alpha_{1a}$ or $\angle\alpha_{1d}$	Measuring the angle which is similar $\angle\alpha_{1p}$. Do mark as $\angle\alpha_{1a}$, $\angle\alpha_{1d}$.	30.4-40.3	27-40.2
2	Half cup fullness,°	$\angle\alpha_{2a}$ or $\angle\alpha_{2d}$	Measuring the angle which is similar $\angle\alpha_{2p}$. Do mark as $\angle\alpha_{2a}$, $\angle\alpha_{2d}$.	59.4-68.9	52.9-68.5
3	Position of sleeve (profile view),°	$\angle\beta_a$ or $\angle\beta_d$	Measuring the angle which is similar $\angle\beta_p$. Do mark as $\angle\beta_a$, $\angle\beta_d$.	9.2-12.4	6.2-15.7
4	Difference between bust level and sleeve width, cm	D_{1a} or D_{1d}	Measuring the difference of altitude coordinate between the bust line (an average of three key locators: front center - bust line, back center - bust line, lowest armhole - bust line) and the sleeve width (an average of four key locators: cap height - sleeve width, back fold - sleeve width, front fold -sleeve width, the lowest point of down sleeve cap - sleeve width)	-0.6-0.8	-0.4-1

Finish Table 4.3

5	Difference between waist level and it projection onto sleeve, cm	D_{2a} or D_{2d}	Measuring the difference of altitude coordinate between the waistline (an average of three key locators: front center - waistline, back center - waistline, profile seam - waistline) and locator of the projection of waistline to the sleeve Lwps (an average of four key locators: middle of upper sleeve - Lwps, back fold - Lwps, front fold - Lwps, middle of down sleeve - Lwps).	-0.8-2.6	-0.4-3.2
6	Distance between fold line and upper sleeve edge at sleeve width area, cm	X_{1a} or X_{1d}	Measuring the distance X_{1p} in Z direction. Do mark as X_{1a}, X_{1d}.	0.3-3.5	0.1-3.5
7	Distance between fold line and under sleeve edge at sleeve width area, cm	X_{1Pa} or X_{1Pd}	Measuring the distance X_{1Pp} in Z direction. Do mark as X_{1Pa}, X_{1Pd}.	0.1-2.1	0.3-2.8
8	Distance between fold line and upper sleeve edge at cuff area, cm	X_{2a} or X_{2d}	Measuring the distance X_{2p} in Z direction. Do mark as X_{2a}, X_{2d}.	0.5-3.6	0.5-3.7
9	Distance between fold line and under sleeve edge at lower arm at cuff area, cm	X_{2Pa} or X_{2Pd}	Measuring the distance X_{2Pp} after virtual simulation in Z direction. Do mark as X_{2Pa}, X_{2Pd}.	0.1-1.7	0.1-2.5
10	Difference of front fold and front edge upper sleeve, cm	$\lvert X_{1a}-X_{2a}\rvert$ or $\lvert X_{1d}-X_{2d}\rvert$	Calculating the absolute difference between X_{1a} and X_{2a} (or X_{1d} and X_{2d}) in Z direction	0-0.9	0-1
11	Difference of front fold and front edge down sleeve, cm	$\lvert X_{1Pa}-X_{2Pa}\rvert$ or $\lvert X_{1Pd}-X_{2Pd}\rvert$	Calculating the absolute difference between X_{1pa} and X_{2pa} (or X_{1pd} and X_{2pd}) in Z direction	0-1.5	0-1.3

After assembling the sleeve and the bodice into an armhole, some indexes such as $\angle\alpha_{1d}$, $\angle\alpha_{2d}$, $\angle\beta_d$ can be observed easily, whereas other indexes such as X_{1d}, X_{1pd}, X_{2d}, X_{2pd} could not be seen. Choosing the Clo3D software function "transparency surface", the coordinates of points could be accurately observed.

Tables 4.2 and 4.3 represented the range of both perfect and poor fit. All indexes were measured and calculated at 0.1° or 0.1 cm to ensure accuracy.

4.2.2. The relationship between Sp and Sa, Sd

All indexes from Tables 4.2 and 4.3 could be divided into two groups as stabilization (belonging to "stabilization" group by which desirable position of sleeve in 3D space can be obtained) and changeableness (belonging to "changeableness" group by which the pattern's structure could be preserved in real and virtual sleeves).

(1) The stabilization group includes three indexes β, D_1, D_2 to obtain high quality sleeve ($\Delta_r = 0$) in accordance with the arm morphology and jacket shape. These indexes should be approximately consistent with Sa and Sd. For example, ∠β represents the sleeve position after the assembly. If there is a significant deviation of this index before and after sewing simulation, it can be qualified as a poor fit. Similarly, the same case was applied for D_1, D_2.

(2) The changeableness group includes six indexes α_1, α_2, X_1, X_2, X_{1p}, X_{2p} ($\Delta_r \neq 0$). Some indexes of patterns could be changed under sewing operation and transforming from 2D into 3D objects.

The equation for calculating the relation among Sp, Sa, Sd is:

$$Iv = Ip \pm \Delta r \quad , \tag{4.1}$$

where I_v is the index of the virtual sleeve (consist of Sa and Sd), I_P is the index of patterns, Δr is the possible transforming range.

According to equation (4.1), the range Δ*r* can be identified as criteria of flat pattern transformation, which forms the basic principles about fit prediction for sleeve. By means of the system of equations like (4.1), the fifth principle was build.

The transforming range Δ*r* can be calculated via the equations (4.2) and (4.3).

$$\Delta r = \bar{x} \pm mr \quad , \tag{4.2}$$

$$mr = \pm \left[\frac{t^{\frac{1+pl}{2}}}{\sqrt{n}} \right] * SD \quad (4.3)$$
,

where $\overline{x}$ is the average value of index measured for perfect fit sleeve, m_r is the confidence interval, *pl* is the probability level, *t* is the Student-criteria, *n* is the number of objects, *SD* is the standard deviation.

4.3. Criteria obtainment and optimization

For the purpose of obtaining the criteria range of objective indexes for fit evaluation, all indexes were measured and analyzed. The experiment of criteria demonstrated the feasibility of fit prediction.

4.3.1. Criteria range obtainment

All sleeves with perfect fit participated in the analysis. The result shows in Table 4.4. According to the second principle mentioned, the same indexes connect Sp, Sa, and Sd.

Table 4.4 - Comprehensive criteria of perfect fit sleeves

Indexes symbol, unit	First part - the criteria range			Second part - the transformation range	
	Sp	Sa	Sd	Δr Sp-Sa	Δr Sp-Sd
First group "stabilization"					
∠β,°	12±0.2	10.9±0.4	11.5±0.4	1.1±0.6	0.5±0.7
D_1 , cm	0	-0.1±0.2	0.1±0.2	0.1±0.2	
D_2 , cm	0	0.1±0.4	0.4±0.4	0.1±0.4	0.4±0.4
Second group "changeableness"					
∠α_1,°	28.7±0.7	37.1±1.3	34.2±1.3	8.3±2,0	5.4±2.0
∠α_2,°	48.9±0.9	63.3±0.8	59.1±1.1	14.5±1.7	10.2±2,0
X_1, cm X_2, cm	3.4±0.4	1.9±0.3	2.2±0.3	1.5±0.6	1.2±0.6
$\lvert X_1-X_2 \rvert$, cm	0	0.3±0.1		0.3±0.1	
X_{1p}, cm X_{2p}, cm	3.4±0.4	0,9±0.2	1.1±0.2	2.5±0.5	2.3±0.6
$\lvert X_{1p}-X_{2p} \rvert$, cm	0	0.2±0.1		0.2±0.1	

As shown in Table 4.4, the outcomes were split into two parts (criteria range, transformation range) and two groups (stabilization, changeableness) for clarity of results. The first part consisted of three columns (Sp, Sa, and Sd), demonstrated the average values with 90% confidence interval and reflected the entire range of perfect fit. The second part includes two columns of Δr Sp-Sa and Δr Sp-Sd, representing the transforming range from Sp to Sa or Sd.

As shown in Table 4.4, the variation of indexes ∠β, D_1, and D_2 in the first group "stabilization" is relatively small. For example, ∠β were 12, 10.9, and 11.5 (Sp, Sa, and Sd), respectively. Those differences could be regarded as errors. D_1 and D_2 were also regarded.

The indexes in the second group "changeableness" were variable. It was used for the objective sleeve fit test by criteria and transform range comparing. If the value was out of range, it would be considered as misfit.

The second part of "transformation range" presented the result of Δr Sp-Sa ≤ Δr Sp-Sd, which indicated that the avatar's arm affects the sleeve, revealing the Sa's limitation for objective evaluation. In other words, the Sd was superior at index objective evaluation.

4.3.2. Criteria optimization by sensitive indexes screening

The perfect and poor fit sleeves were involved in the screening test. SPSS performed statistical analysis of independent t-test, the pretest revealed the normal distribution for all 22 indexes of Sa and Sd.

The $P < 0.1$ (two-sided) was considered statistically significant, with a bold mark and asterisk (in Table 4.5). Meanwhile, these significant indexes can be regarded as sensitive and reactive indexes to distinguish fit and misfit sleeves. The analysis shows that Sd has four sensitive indexes, and the Sa has only two. According to this result, Sd could express the majority sensitive distinctiveness during fit evaluation, which indicated Sd exposes more misfit defects than Sa.

Table 4.5 - T-test for perfect and worst fit

Index symbol	Sig. (2-tailed)/ P - values for the indexes	
	Sa	Sd
$\angle\alpha_1$	0.227	0.178
$\angle\alpha_2$	0.262	0.167
$\angle\beta$	0.587	**0.069***
D_1	0.123	0.37
D_2	0.155	0.251
X_1	0.105	**0.015***
X_2	0.259	**0.014***
$\lvert X_1-X_2\rvert$	0.959	0.72
X_{1p}	0.558	0.765
X_{2p}	**0.01***	**0.069***
$\lvert X_{1p}-X2_p\rvert$	**0.003***	0.137

*Notes: * means significant difference which is higher than the 0.1 level (2-tailed)*

Following the result of the t-test, the sleeve misfit has been influenced by comprehensive combination of pattern indexes, and some nuance of its alteration would affect the final fit. However, the nuance alteration was challenging to screen out by statistics. That was why other indexes do not express sensitivity.

From Table 4.5, the following prioritization as performance rank for the indexes in accordance with its sensitiveness was developed.

$$X_{2d} > X_{1d} > \angle\beta_d > X_{2pd} > \lvert X_{1pa} - X_{2pa}\rvert > X_{2pa} \quad , \tag{4.4}$$

According to equation (4.4), the row expresses the prioritization for indexes screening, which could be a part of sleeve fit prediction work flow. In this rank, four indexes from Sd were at the top because of the broader applicability. Two indexes from Sa were close behind because of the relatively screening significance.

The experimental results indicated that Sa priority on subjective evaluation (crease and wrinkles appearance), Sd priority on objective evaluation (variation of objective indexes value among Sp, Sa, Sd). Thus, there was no substitute for each other. The six screened indexes of Sa and Sd will participate in the subsequent analysis together.

4.3.3. Correlation and linear regression

The screened sensitive indexes of Table 4.5 were involved in correlation and linear regression analyses to construct the further fit prediction model. The analyses were assessed using the Pearson correlation (2-tailed) and univariate linear regression analyses. The details of the correlation result were listed in Table 4.6 (including seven Sp indexes of Table 4.2, six sensitive Sa and Sd indexes of Table 4.5).

Table4.6 - Pearson correlation coefficient (r-value) between Sp, Sa and Sd

Pattern Indexes	Virtual sleeve indexes					
	X_{2pa}	$\lvert X_{1pa}-X_{2pa}\rvert$	$\angle\beta_d$	X_{1d}	X_{2d}	X_{2pd}
$\angle\alpha_{1p}$	-0.075	-0.015	0.203	0.079	0.074	-0.176
$\angle\alpha_{2p}$	0.084	0.25	-0.094	-0.051	-0.042	0.123
$\angle\beta_p$	0.086	**-.510***	-0.009	0.274	0.333	-0.162
X_{1p}	**.795***	-0.039	-0.029	**.882***	**.906***	**.887***
X_{2p}	**.828***	-0.123	-0.045	**.869***	**.932***	**.882***
X_{1pp}	**.795***	-0.039	-0.029	**.882***	**.906***	**.887***
X_{2pp}	**.828***	-0.123	-0.045	**.869***	**.932***	**.882***

* Correlation is significant higher the 0.05 level (2-tailed).

As shown in Table 4.6, the pattern indexes X_{1p}, X_{2p}, X_{1pp}, X_{2pp} expressed significant correlation with virtual sleeve indexes X_{2pa}, X_{1d}, X_{2d}, X_{2pd}. The correlation coefficients expressed in bold font with an asterisk, which indicated significant values below 0.05 level. It can be found that X_{1p}, X_{1pp}, X_{2p}, and X_{2pp} have similar correlation coefficients （because X_{1pp}, X_{2pp} were projected from X_{1p}, X_{2p}） . Thus, the subsequent linear regression analysis indexes X_{1p} and X_{2p} for independent variables. It is important to note that the $\angle\beta_p$ expresses a significant correlation with $\lvert X_{1pa}-X_{2pa}\rvert$. This correlation significance was considered an accidental phenomenon, which does not participate in following linear regression analysis.

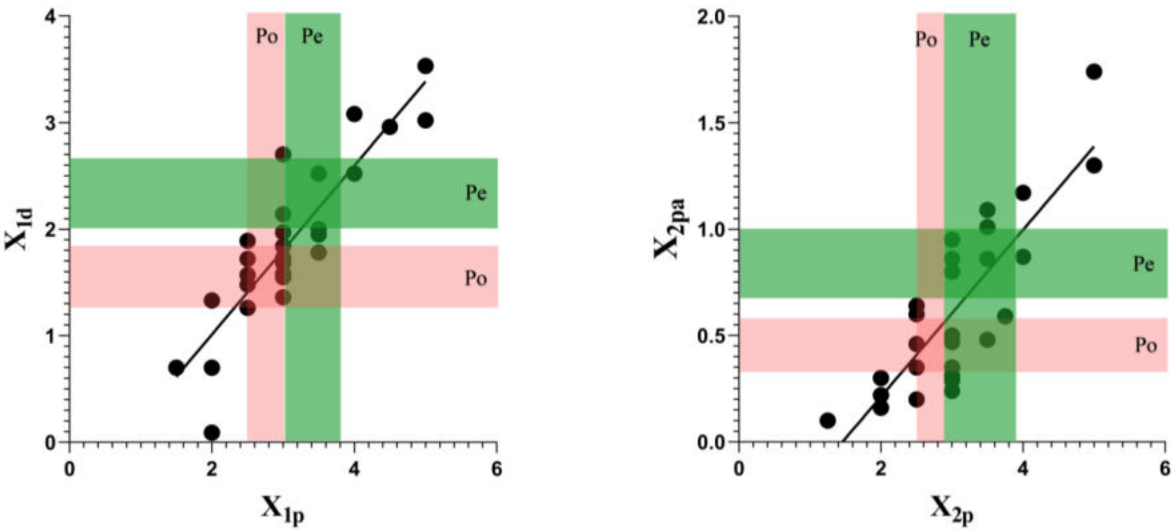
After correlation analysis, the strong positive correlations were distinguished between pattern indexes and virtual indexes in the front fold area. Next, linear regression analysis was conducted based on the relevant indexes of correlation analysis.

Table 4.7 - Linear regressions of excepted virtual sleeve indexes

Sp (independent variable X)	Sa and Sd (dependent variable Y)			
	X_{2pa}	X_{1d}	X_{2d}	X_{2pd}
X_{1p}	$X_{2pa} = 0.37X_{1p} - 0.5$	$X_{1d} = 0.79X_{1p} - 0.6$	$X_{2d} = 0.77X_{1p} - 0.7$	$X_{2pd} = 0.56X_{1p} - 0.8$
X_{2p}	$X_{2pa} = 0.39X_{2p} - 0.6$	$X_{1d} = 0.79X_{2p} - 0.6$	$X_{2d} = 0.81X_{2p} - 0.8$	$X_{2pd} = 0.57X_{2p} - 0.8$

Table 4.7 lists the fit prediction linear regressions for screened indexes of the simulated sleeve. Each regression shows a significant positive correlation. To visualize it, the linear regression equation Y (X_{1d}) = f (X_{1p}) and Y (X_{2pa}) = f (X_{2p}) were depicted in Fig. 4.5 as example.

The bars of Fig. 4.5 represent the range (Pe: "perfect fit", Po: “poor fit") which was compound with the linear regressions. If the values of X_{1p} and X_{2p} were known, the values of X_{1d} and X_{2pa} could be calculated. These results were the essential parts of fit prediction.



a *b*

Figure 4.5 - Linear regressions for prediction indexes from Sp to Sa and Sd: *a* - X_{1p} - X_{1d}, *b* - X_{2p} - X_{2pa}

4.4. Validation of fit prediction

In order to validate the applicability and the correctness of the results obtained, two new sleeve samples were involved. The details were shown in Table 4.8 and Fig. 4.6.

Table 4.8 - The validation indexes of selected patterns

Sample No.	Index								
	$\angle\alpha_{1p}$	$\angle\alpha_{2p}$	$\angle\beta_p$	X_{1p}	X_{1pp}	X_{2p}	X_{2pp}	$\lvert X_{1p}-X_{2p}\rvert$	$\lvert X_{1pp}-X_{2pp}\rvert$
1 [145]	29.1	50.3	11.8	3.5	3.5	3.5	3.5	0	0
2 [146]	31.6	52.2	10.2	2	2	2	2	0	0

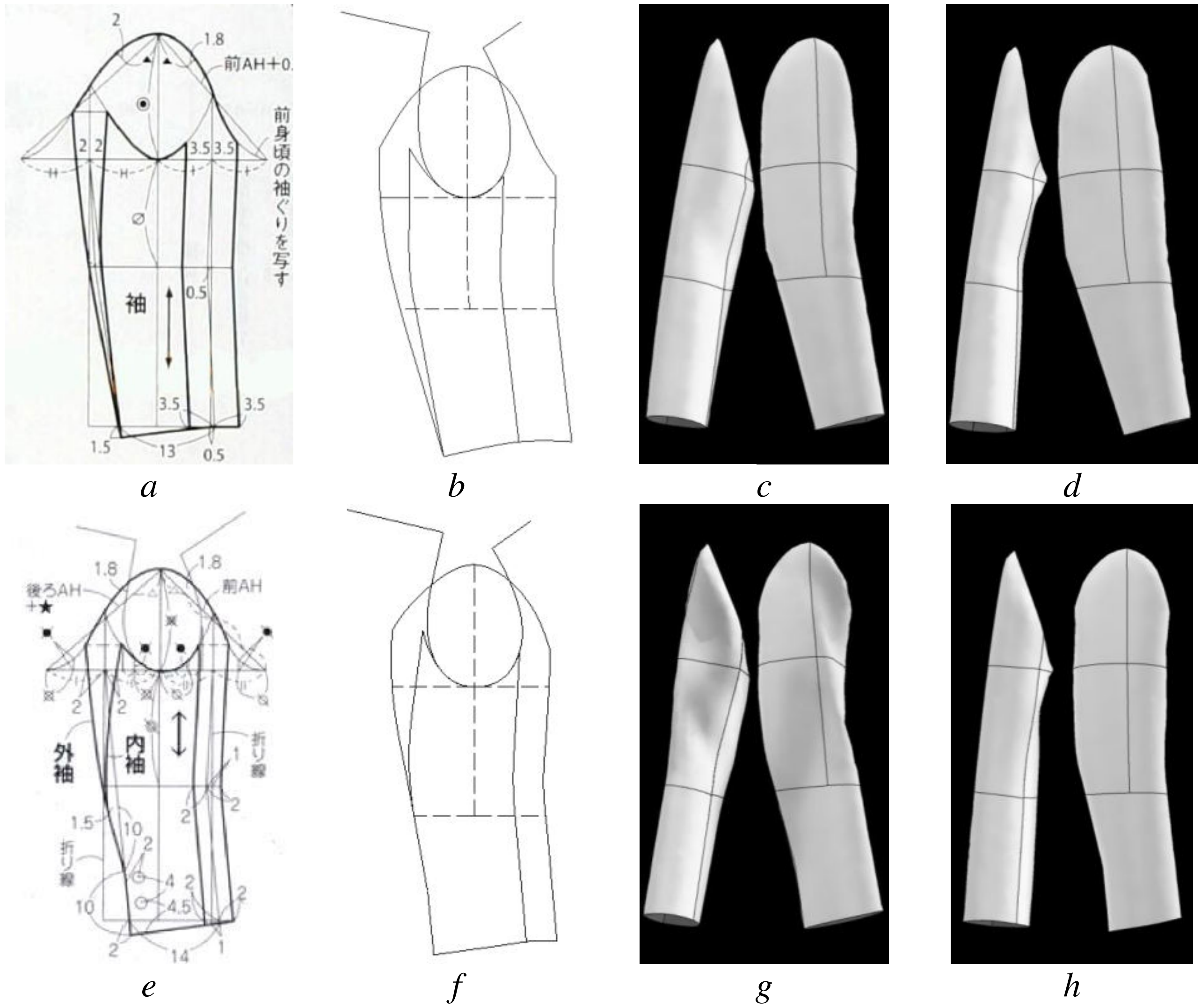


Figure 4.6 - The fashion magazine, Sp, Sa, Sd for fit validation: *a* - sample 1 of fashion magazine, *b* - sample 1 of Sp, *c* - sample 1 of Sa, *d* - sample 1 of Sd, *e* - sample 2 of fashion magazine, *f* - sample 2 of Sp, *g* - sample 2 of Sa, *h* - sample 2 of Sd

The validation procedure follows several steps. Firstly, the Sp were simulated to Sa and Sd by Clo3D (as Fig. 4.6 c,d,g,h). Due to several wrinkles appeared at Fig. 4.6,g,h. Sample 1 was regarded as the fit sleeve. Whereas, samples 2 was regarded as the misfit. As the first principle mentioned before, Sa has the advantage in subjective evaluation of wrinkles expression, and Sd has the advantage in the objective assessment of sensitive indexes detection. The comparison validation of Sa and Sd (as Fig. 4.6 c,d,g,h) demonstrated it. Secondly, according to Fig. 4.4 and Table 4.3, the index values of Sa and Sd were measured. Thirdly, the linear regression equations were used to calculate X_{2pa}, X_{1d}, X_{2d}, and X_{2pd} by means of X_{1p} or X_{2p}. Fourthly, Table 4.9 compared the predicted result, measured result, and theoretical criteria range for validation.

The validation result reflected the situation of fit and misfit in an objective aspect. The detailed data were shown in Table 4.9, which includes two groups of X_{1p} and X_{2p} (as Table 4.7). For Table 4.9, the abbreviations II, IO, OI, and OO consisted of symbols in (I) or out (O). The first symbol indicated that the equation's results were in or out of the criteria ranges. The second symbol indicated the measured values in or out of the criteria range.

Table 4.9 - The result of validation analysis for virtual sleeve

Grouping	Typing	Sample No.	The indexes of virtual sleeves			
			X_{2pa}	X_{1d}	X_{2d}	X_{2pd}
Group1. X_{1p} as independent variable of prediction equation	Predicted results by equations	1	0.8	2.2	2	1.2
		2	0.2	1	0.8	0.3
	Measured results	1	1.1	2.5	2.1	1.3
		2	0.2	0.7	0.5	0.8
	Differences between predicted and measured results (absolute value)	1	0.3	0.3	0.1	0.1
		2	0	0.3	0.3	0.5
	Comparison result of criteria range vs. predicted, and criteria range vs.measured	1	IO	II	II	II
		2	OO	OO	OO	OO
Group2. X_{2p} as independent variable of prediction equation	Predicted results by equations	1	0.8	2.2	2	1.2
		2	0.2	1	0.8	0.3
	Measured results	1	1.1	2.5	2.1	1.3
		2	0.2	0.7	0.5	0.8
	Differences between predicted and measured results (absolute value)	1	0.3	0.2	0.1	0.1
		2	0	0.3	0.3	0.5
	Comparison result of criteria range vs. predicted, and criteria range vs.measured	1	IO	II	II	II
		2	OO	OO	OO	OO

As shown in Table 4.9, the difference between predicted and measured results for sample 1 was minuscule, demonstrating the correctness and accuracy of the linear regression equation. In contrast, differences of sample 2 expressed the equation limitation for the misfit sleeve. In addition, it could be found that most values of sample 1 were located in the criteria range, and all values of sample 2 were out. The result proved the correctness of criteria range. All results of groups 1 and 2 were almost identical, which demonstrated the same capability X_{1p} and X_{2p}.

In summary, the objective and subjective validation results confirmed the correctness of predicted equations and criteria range.

Conclusion after chapter 4

1. The five principles were proposed, which could predict the whole sleeve behavior and several indexes influenced by the fit. Based on principles, the Sa and Sd was set, and the corresponding indexes were arranged.

2. The comprehensive criteria of perfect fit sleeves were obtained and optimized. Meanwhile, the correlations were also constructed to realize linear regression for fit prediction.

3. The obtained criteria and regression equations were validated by two new samples, which proved the correctness and applicability of the result.

CHAPTER 5. OBJECTIVE EVALUATION OF VIRTUAL SLEEVE THROUGH GRAYSCALE

The criteria and regression equations of the previous chapter indeed predict the sleeve behavior and several indexes before sewing. Nonetheless, there were limitations. Because the fit and misfit gap was too close, there was still a possibility that led to fit misjudgment in practical application, even for experienced patternmakers.

This chapter proposed a new grayscale algorithm for fit evaluation and defect identification of DTS, which opened a new avenue of objective fit evaluation from the image analysis aspect.

The results obtained in this chapter are published in two works [156, 160]

5.1. Methods and materials of research

5.1.1. Software of research

Clo3D software was used for sleeve simulation and image export. ET-CAD for patterns modification, ImageJ (NIH, USA) for image contrast enhancement and image grayscale measuring and initial quantification analysis, Excel and SPSS were used for statistical analysis of grayscale. Graph Pad was used for plotting.

5.1.2. Object of research

Some of the grayscale experiment objects inherited from Chapter 4, were as follows:

1. The DT size and patterns were followed the Chinese national standard, which was introduced in Table 1.7.

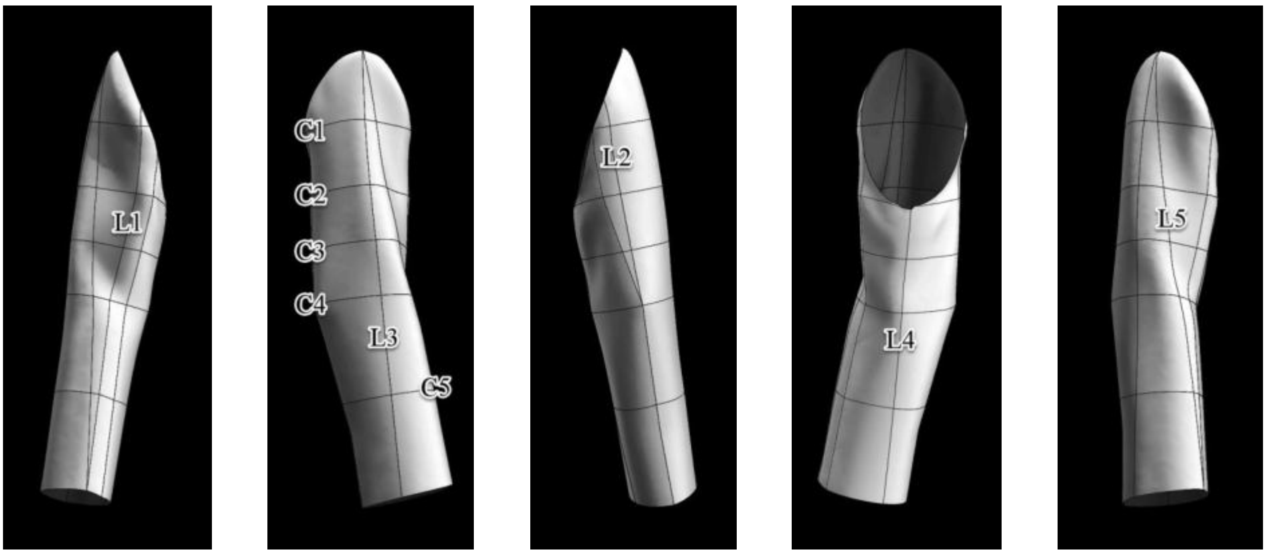
2. Due to the priority of Sa (avatar with full arm, as Fig.4.1) in surface creases appearance, all sleeves were simulated as Sa.

3. The subjective fit evaluation scale was the same as Table 4.1, which was perfect, appropriate, and poor.

4. Based on the scale, five experts selected 12 Pe sleeve and 12 Po for grayscale measuring, respectively.

The Sa removed all components except the right-hand sleeve for the sequence experiment. The sleeve was prepared in the virtual reality environment by consistent intensity and location of the light source, camera setting, and material color to improve accuracy.

Fig.5.1 shows five front, half profile, profile, back, and inside views. For grayscale measuring, the exported sleeve image of Clo3D has enhanced the contrast by ImageJ of equalizing histogram.



a *b* *c* *d* *e*

Figure 5.1 - Virtual sleeve with different views for grayscale evaluation: *a*- front, *b* - profile, *c* - back, *d* - inner, *e* - half profile

The distribution and position of wrinkles on the sleeve surface depend on many misfit reasons. For grayscale analysis, it was essential to create a uniform measurement index for different sleeve comparisons. Based on pattern sketching experience, the structural lines were drawn for wrinkle identification by grayscale. The main 10 lines of lengthwise (L) and crosswise (C) as indexes were marked in Fig. 5.1. The specificity was as follows:

L1 - Line along Front fold (FF),

L2 - Line along Back fold,

L3 - Vertical line from cap top point to bottom,

L4 - Vertical line from cap down to the bottom,

L5 - Sloping line from cap top point to the lowest point of front fold,

C1 - Horizontal line from the top of back fold,

C2 - Horizontal girth of SCW,

C3 - Horizontal girth between SCW to elbow width (1/2 location),

C4 - Horizontal girth of elbow width,

C5 - Horizontal girth between elbow width to bottom (1/2 location)

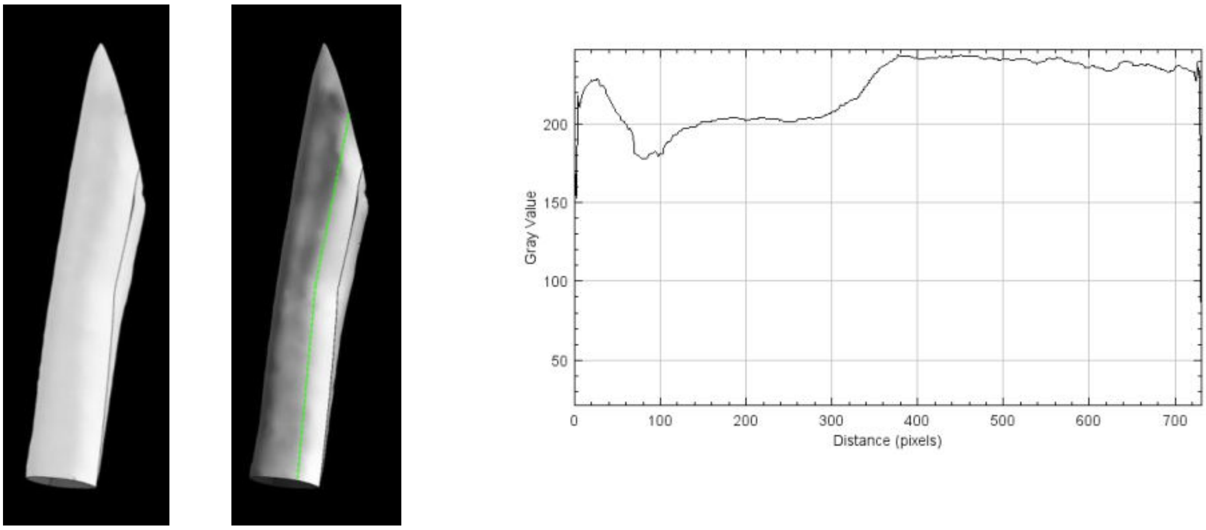
The 10 lines were taken into account the sleeve pattern feature and the morphological characteristics of the human arm. The shapes of sleeves can be divided into two parts in accordance with pattern designing. The first part was the fitting area located inside and near sleeve cap, and the second part was the designing area under sleeve cap width or armpit level. During the sleeve wearing, the fitting area became the critical area responsible for the misfit appearance, and the designing area was devoted to the sleeve style.

Two representatives FF (L1) and SCW (C2) lines were selected for subsequence experiments. The default light was choice (the light always was input from the image's right side) in order to minimize the effect of illumination (brightness, contrast).

5.2. Construction of initial grayscale database

The initial database was established to display the grayscale of sleeve images. Based on the proposed choice, 24 sleeves with 120 images were measured by ImageJ. The images contained intensity values from 0 (pure black) to 255 (pure white).

Fig. 5.2 shows the procedure of grayscale generating after the image was gradually converted to the grayscale chart step by step. With FF as an example.



a *b* *c*

Figure 5.2 - Steps of image treatment along FF: *a* - original virtual sleeve, *b* - virtual sleeve with FF after contrast enhancement, *c* - grayscale diagram

The detail of the procedure includes following steps:

(1) The sleeve image which was chosen for measuring (as Fig. 5.2,a).

(2) The line of the FF, which was located 3 cm from the front seam, and marked as green line (as Fig. 5.2,b).

(3) The image was converted into 8-bit grayscale and imported into the auto-algorithm, and contrast stretched to broaden the grayscale values from 0 to 255 (as Fig. 5.2,b).

(4) Grayscale values of the green line and corresponding diagram were obtained using the software ImageJ. After measuring, the grayscale diagram was automatically generated (as Fig. 5.2,c), in which axis X represented the distance (by pixel) of FF, and axis Y represented the grayscale values.

Fig. 5.2,c had a sharp change located at 25 to 100 pixels, which represented a wrinkle. The wrinkle length can be deduced according to the ratio between the sleeve and pixel distance. This diagram visualized the grayscale information along with FF. However, FF was only an example. In these 10 indexes (as Fig.5.1), a grayscale net could be built to describe the sleeve appearance from grayscale.

5.3. Fit criteria of grayscale

Based on the database of grayscale, the grayscale values of each diagram were calculated to obtain the average line and standard deviation. However, it is not enough to focus on the grayscale alone, but combining the subjective evaluation result is necessary to construct the fit criteria.

5.3.1. Criteria of fit evaluation

The grayscale results of the sleeve indexes were measured, collected, and sorted in combination with the previous subjective evaluation results. There were two categories of fit criteria belt - Pe and Po. Two types of Clo3D in-built fabric - Melton fabric (100% wool thickness 1.4 mm) and Muslin fabric (100% cotton, thickness is 0.3 mm) were taken in the experiment.

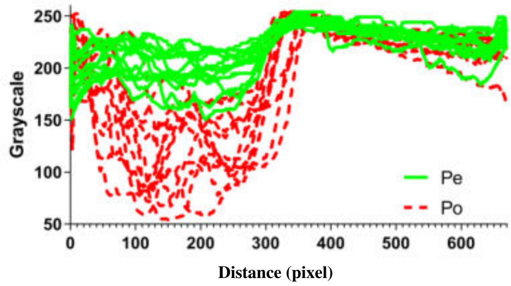
FF as an example, the procedure of fit criteria establishing contains the following steps:

1. Fig. 5.3,a shows the 24 grayscale diagrams (12 Pe, green; 12 Po, red) were overlapped plotting by GraphPad, the sleeves materials were Melton. Two grayscale belts can be roughly distinguished in the Figure.

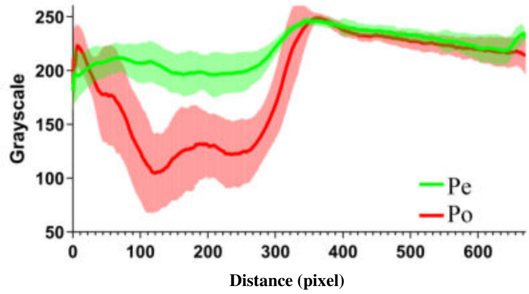
2. Based on overlapped plotting, Fig. 5.3,b shows the Melton grayscale criteria of Pe and Po through means and standard deviation, shown as lines and belts (Melton: Pe, green; Po, red).

3. Same as Fig. 5.3,b, Fig. 5.3,c shows the Muslin grayscale criteria of Pe and Po as lines and belts (Muslin: Pe, blue; Po, orange).

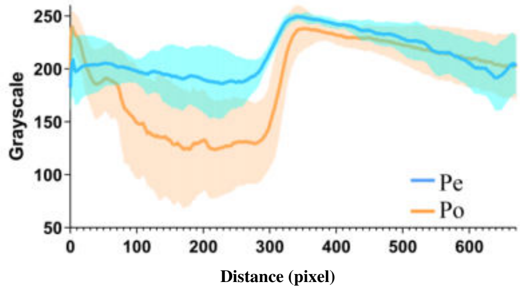
The belt and average line of Pe and Po were overlapped in the second half of sleeve (elbow-hem) (in Fig. 5.3,b,), which indicated few wrinkles expression in this part. However, the significant difference of grayscale was expressed in the first half (cap-elbow). The up and down fluctuation of the grayscale belt represented concave and convex of appearance wrinkle, which was the misfit indicator.



a



b



c

Figure 5.3 - Grayscale plots of FF: *a* - overlapped grayscale plot of Melton, *b* - grayscale criteria of Melton, *c* - grayscale criteria of Muslin

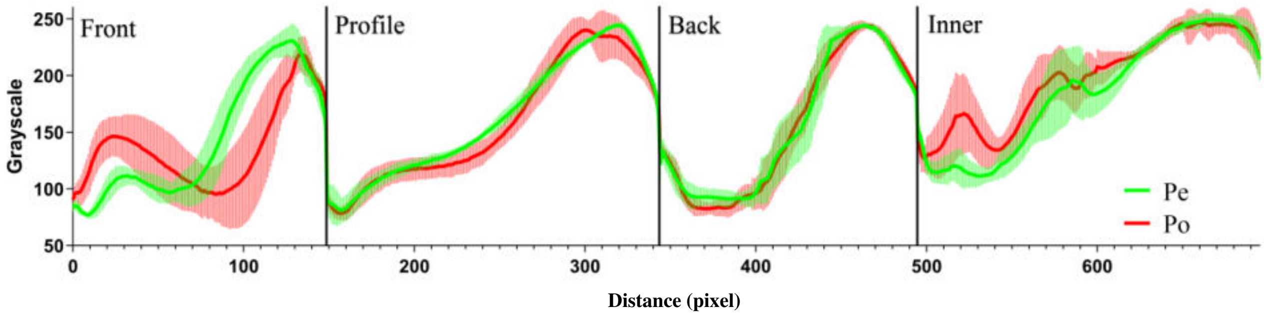
The comparison of Fig. 5.3,b and Fig. 5.3,c shows the following similarities and differences.

1. The trends of Melton and Muslin were similar, but the belt range of Melton was smaller than Muslin. Moreover, the trend of Melton was more prominent, which could be attributed to Melton being stiff than Muslin.

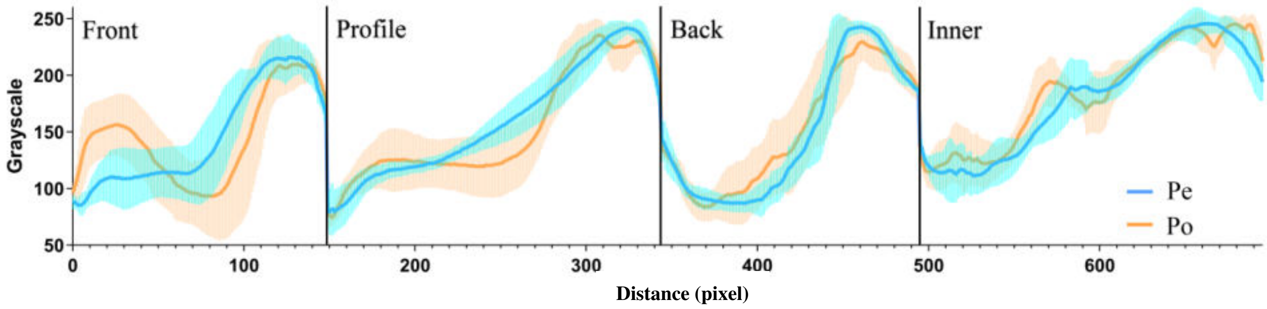
2. At the beginning, the first wave of Po intersected with Pe, which was caused by the shoulder divot at the sleeve cap.

3. There was an uplift at the end of Pe (both Melton and Muslin). It was not a fault, which was caused by the default light of Clo3D.

Similar to FF, Fig. 5.4 shows the grayscale criteria of SCW. The criteria were compounded by four front, profile, back, and inner views. Meanwhile, the grayscale criteria of each view expressed a low left-side to high right-side trend, which attributed to the default illumination as shown in Fig. 5.1. Similar to Fig. 5.3, the folds of Melton were more prominent than Muslin.



a



b

Figure 5.4 - Grayscale criteria of SCW: *a* - grayscale criteria of Melton, *b* - grayscale criteria of Muslin

The comparison between Pe and Po in four views shows that more differences existed in front and profile views, which indicated more misfit defect wrinkles as observed in these two views. For each view, the initial and final parts trend significantly change. In summary, the grayscale belt of Pe could be used as the fit criteria.

5.3.2. Fit criteria of grayscale validation and application

The reliability of validation was a crucial step concerning a new method. Three sleeves were randomly selected for validated the accuracy of grayscale criteria. The grayscale values of three samples were measured. Fig. 5.5 shows the grayscale plots. The upper and lower boundaries of fit belt were inherited from Fig. 5.3 and 5.4.

Compared to observation (Fig. 5.5), sample 1 was mainly within the fit belt. However, samples 2 and 3 were outside or across the belt. Thus, sample 1 was considered fit, samples 2 and 3 were considered misfit.

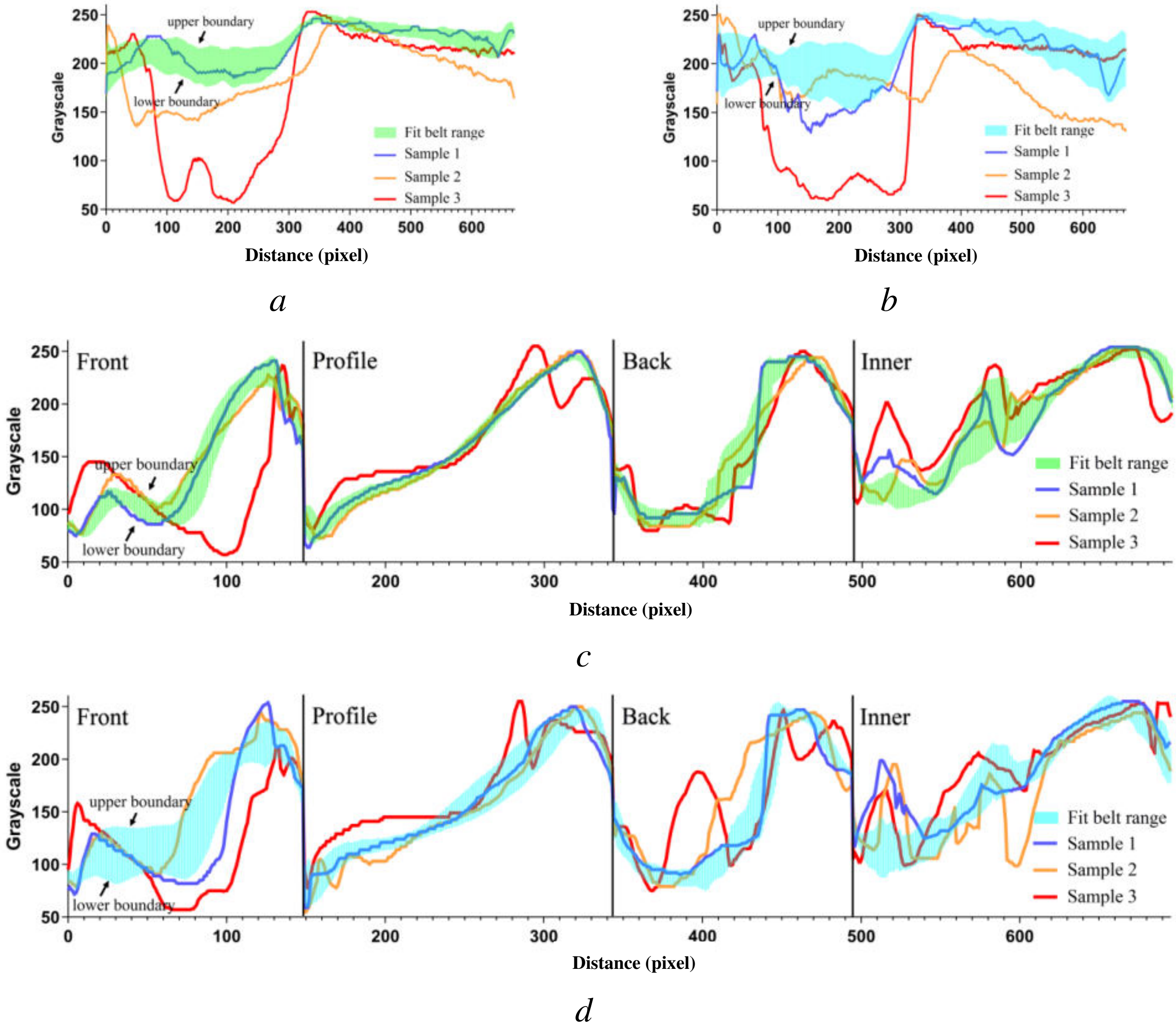


Figure 5.5 - Grayscale criteria validation: *a* - FF Melton, *b* - FF Muslin, *c* - SCW Melton, *d* - SCW Muslin

The definition of misfit could be converted into another form, which was deviation distance (Dev) as equation (5.1):

$$Dev = \sum_i |S_i - B_i|$$

$$|S_i - B_i| = \begin{cases} S_i - B_{it} & \text{if } S_i > B_{it} \\ 0 & \text{if } B_{it} > S_i > B_{il} \\ B_{il} - S_i & \text{if } S_i < B_{il} \end{cases} \quad (5.1)$$

,

where *Dev* is the sum grayscale offset between the sample and fit belt boundary, S_i is the i-th pixel of grayscale plot value, B_i is the i-th pixel value of proper boundaries of fit belt, B_{it} is the top boundary of fit belt, and B_{il} is the lower boundary of fit belt.

As shown in Fig. 5.5, the fit belt includes upper and lower boundaries. However, the grayscale plots of samples 2 and 3 are crossing the fit belt. Therefore, the If logic function was used to found the appropriate boundaries of the fit belt for correct deviation calculation.

The *Dev* of FF and SCW were not comparable because of the different pixel distances. For comparability, the standard deviation (Dev_{std}) was calculated as equation (5.2):

$$Dev_{std} = \frac{Dev}{N}, \tag{5.2}$$

where Dev_{std} is the standard deviation of each pixel (average), N is the number of total pixels.

The sleeve misfit can be quantified by equations (5.1) and (5.2). In the verification test, to facilitate the calculation, the pixels of samples were modified to be the same.

The grayscale criteria validation integrated subjective evaluation results, textile materials, fit belts, and samples' grayscale values.

The grayscale plot was considered as the object for objective evaluation. Virtual sleeve images were taken for subjective evaluation. This approach made the objective evaluation of grayscale more consistent with subjective results. Table 5.1 shows the deviation values of samples 1, 2, and 3.

Table 5.1 - Deviation between fit belt and samples

Index	Sample and subjective evaluation	Deviation for sleeves made of textile materials, unit: dimensionless			
		Melton		Muslin	
		Dev	Dev_{std}	*Dev*	Dev_{std}
L1	1 (fit)	77.85	0.12	2420.29	3.61
	2 (misfit)	13652.53	20.38	16157.46	24.12
	3 (misfit)	23777.47	35.49	24246.99	36.19
C2	1 (fit)	884.73	1.27	2222.15	3.20
	2 (misfit)	1086.89	1.56	4161.17	5.99
	3 (misfit)	10451.87	15.04	9601.00	13.81

Sample 1 with perfect fit has a small *Dev* and Dev_{std} (DD) value, while samples 2 and 3 with misfit have an enormous DD one. In addition, the sleeve fit level reflected the DD value of FF and SCW simultaneously, while the value of FF changed more dramatically than SCW in this validation test.

Moreover, the different stiffness of Melton and Muslin did affect the DD value. When distinguishing between fit and misfit, Melton showed more deviation.

The DD value can be used as a fit evaluation index to distinguish fit and misfit. Consequently, the sample size needs to be further expanded to obtain more objective and accurate results.

This grayscale study integrated subjective fit evaluation, virtual images, measurement indexes (10 lines), and grayscale diagrams. The grayscale criteria could effectively apply to evaluate the sleeve fit. In order to improve the efficiency of the design process, it is suggested that the proposed grayscale criteria should be used in the jacket design process after virtual simulation as an automatic fitting check tool.

5.4. Algorithm of defect identification of grayscale for sleeve

The previous study of fit criteria did an excellent job of fit evaluation by grayscale. By comparing the fit belt difference, the level of fit could be evaluated. However, the fit evaluation criteria were not enough, which various reasons for fit defects need to identify. In this sub-chapter, the pattern was modified with designed misfit defects. The corresponding grayscale plot could be used for defect identification.

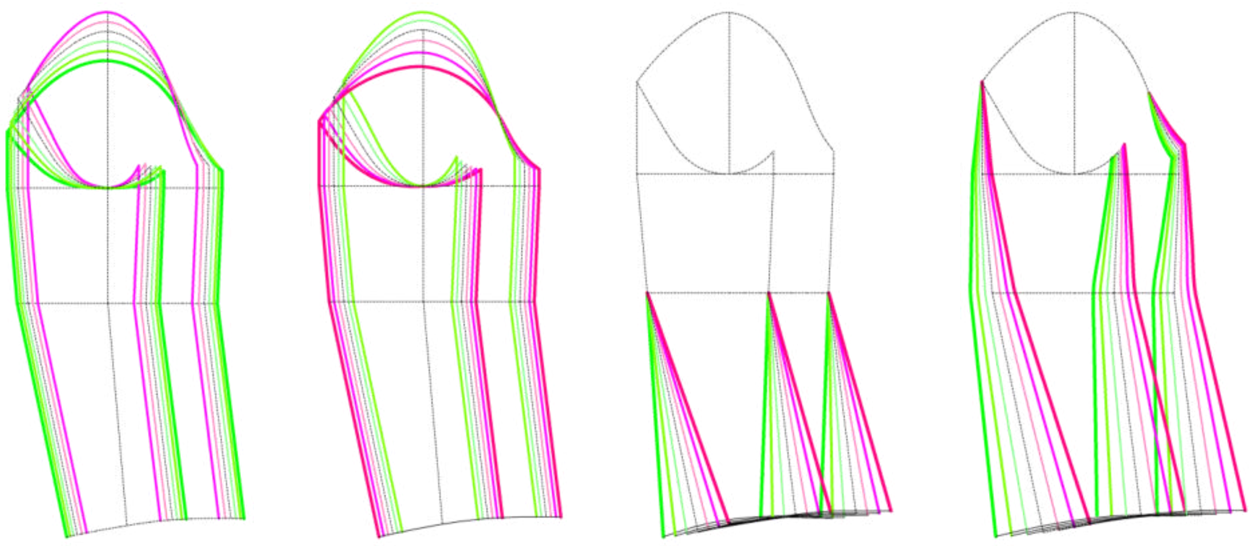
5.4.1. Training samples of pattern

Misfit defects could be caused by many factors relating to the pattern of armhole and sleeve, limitation of materials, body morphology, etc. Therefore, it makes practical sense to use modern CAD software to detect clothing fit defects in the virtual environment. The experimental scenario was constructed in this defect identification study by formalizing the pattern indexes, meanwhile, in combination with the grayscale result for CWJ TPS misfit defects identification.

In order to reproduce the sleeve fit defects, a perfect fit sleeve pattern was chosen from the previous grayscale fit criteria experiment, which was regarded as the control sleeve. Then the tested original drawings were modified by changing the design parameters responsible for the occurrence defects. Table 5.2 lists four modification parameters of SCH, SCW, elbow blend (Eb), and sleeve blend (Sb), with corresponding conditions.

Table 5.2 - Scheme of training sample for experiment

Construction parameters	Interval, step of parameter change	Conditions for deformation the sleeve pattern	Types of arm projections for analysis	Criteria for evaluating the quality
SCH, cm	[–3.... 2], ± 1	1. In parallel increasing and decreasing indexes of distance. 2. constant sleeve cap length which is 49 cm.	Front Profile Back Inner	1.Number and deepness of folds (Subjective evaluation) 2. Grayscale plot (Objective evaluation)
SCW, cm	[–4.....6], ±2			
Eb,°	[–9....9], ±3	1.In parallel increasing and decreasing indexes of angles		
Sb,°	[–6....6], ±2			



a *b* *c* *d*

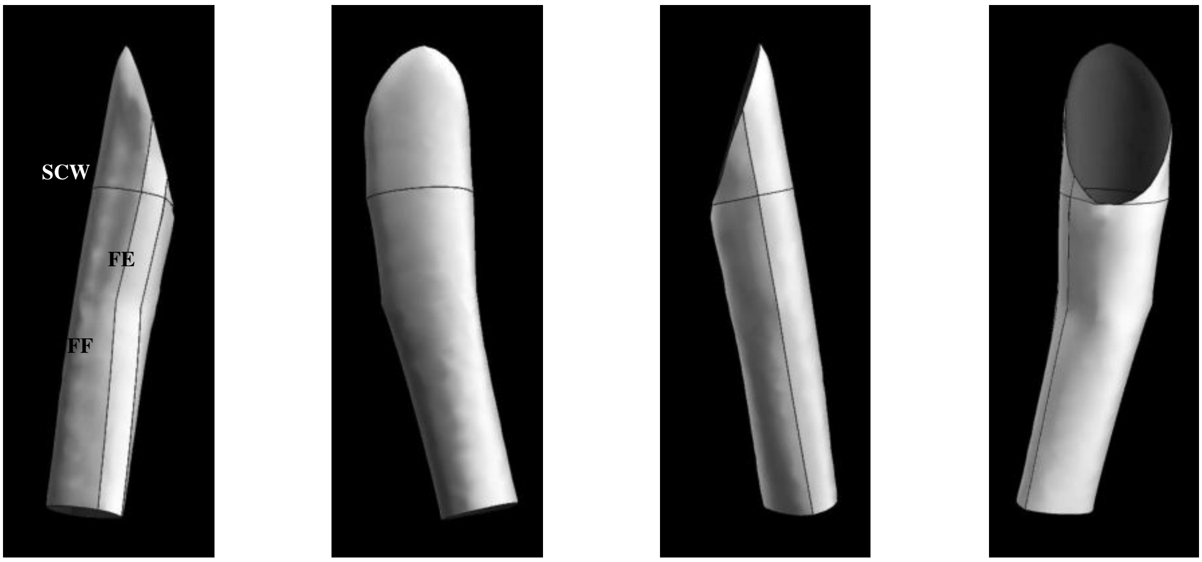
Figure 5.6 - Schemes of pattern deformation for designing defects: *a* - SCH, *b* - SCW, *c* - Eb , *c* - Sb

As shown in Table 5.2, the training sample was deformed along with four indexes parameters. Deformation conditions and intervals were set based on the experience of pattern making. Simulated each pattern as a sleeve, observed it from four images, and analyzed it through subjective and objective evaluation of grayscale.

As shown in Fig. 5.6, the pattern was gradually deformed by ET CAD software. The Increasing parameter is shown in purple, decreasing in green. It can be noticed that Eb and Sb have six deformations, while SCH and SCW have only five. Because of the limitation of the arm girth, some designed misfit was impossible.

5.4.2. Training samples of simulated sleeve

After pattern deformation, all patterns were simulated as Sa by Clo3D software for grayscale. The process and setting were inherited from the initial grayscale database construction of sub-chapter 5.2. the object of study has changed from the 24 perfect and poor fit patterns to the designed misfit patterns.



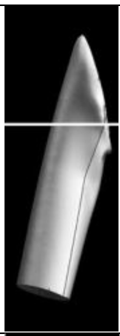
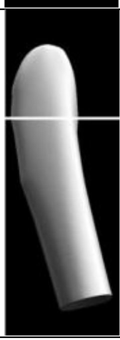
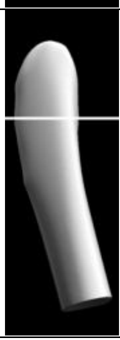
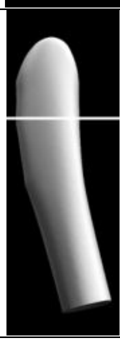
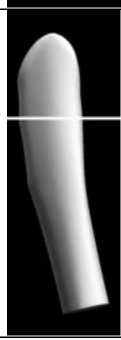
a *b* *c* *d*

Figure 5.7 - Schematic layout of the control sleeve with perfect fit: a - front, b - profile, c - back, d - inner

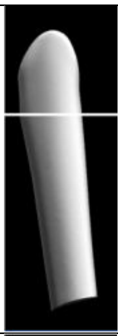
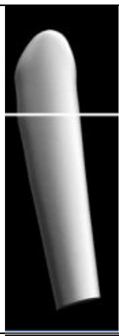
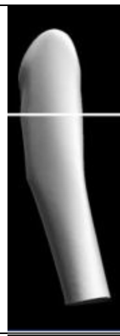
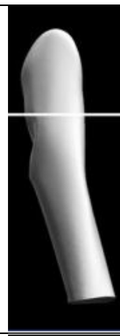
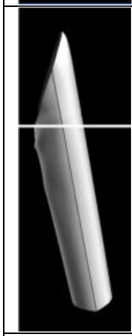
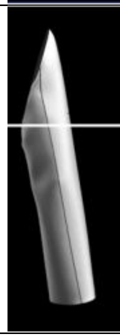
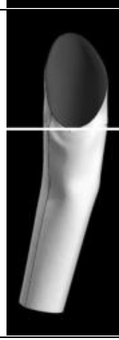
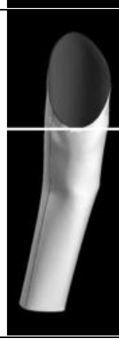
As shown in Fig. 5.7,a, two lines of FF and SCW were drawn for experimentation due to their representativeness (inherit the choice of criteria experiment of sub-chapter 5.1.2). FE represented front edge, which was used to distinguish with FF. Fig. 5.7 respectively show the image of sleeve samples with the perfect fit after contrast enhancement at the front, side, back, and inner views.

The training images of the virtual sleeves were generated according to the experimental scheme from Table 5.2 and Fig. 5.6. After simulation, Table 5.3 shows the images of the virtual sleeves, which show the location of the folds caused by changes in each design parameter.

Table 5.3 - Appearance of sleeve with designed misfit defects

Variable design parameter	Appearance of virtual arms						
1	2	3	4	5	6	7	8
SCH							/
							/
	-3 см	-2 см	-1 см	0	+1 см	+2 см	
SCW	/						

Finish Table 5.3

1	2	3	4	5	6	7	8
SCW	/						
		-4 см	-2 см	0	+2 см	+4 см	+6 см
EB							
							
	-9°	-6°	-3°	0	+3°	+6°	+9°
SB							
							
	-6°	-4°	-2°	0	+2°	+4°	+6°

Notes: “/” means that due to the limitation of the arm girth, the designed misfit is not possible.

As listed in Table 5.3, the simulated sleeve expressed the misfit appearance of changed parameter index. When SCH increased, the wrinkles mainly appeared on the elbow and sleeve cap, especially on the profile view. While, when SCH decreased, the wrinkles mainly appeared on the part of sleeve cap, which near the assembly line of sleeve - armhole at front view. The case of SCW was accompanied by opposite. When SCW increased, the wrinkles appeared near sleeve-armhole assembly line. While, when SCW decreased, elbow and sleeve cap expressed lots wrinkles.

When Eb increased, the wrinkles appeared on the upper part of sleeve at back view, the reason was the mismatch between sleeve pattern and arm posture at elbow part. When down part of sleeve was put forward too much, this kind of wrinkles appeared. However, when the sleeve moved backward, inconspicuous wrinkles appeared.

For Sb, moving the entire front cut forward or backward also deforms parts of the sleeve: the lower part under the armhole - when pulled back, the upper in the area of the elbow seam - when pulled back.

Thus, the generated training sample in the form of sleeves with different defects was the basis for further qualimetry.

5.4.3. Grayscale for defect identification

There was correspondence among wrinkles of the simulated sleeve, pattern parameter indexes deformation, and grayscale diagram. Thus, it is possible to build the relation between grayscale with parameter index, which can be used to sleeve defect identification.

Fig. 5.8 shows two grayscale lines of FF and SCW under the increasing or decreasing of parameter SCH deformation. the black line represented the grayscale of perfect fit sleeve, purple lines and belt represented the grayscale of increasing SCH, while green represented decreasing. The grayscale of FF and SCW changing were detailed in Fig. 5.8 a,c. By calculating the means and standard deviation, the grayscale deformation tendencies (belts) were shown in Fig.5.8,b,d.

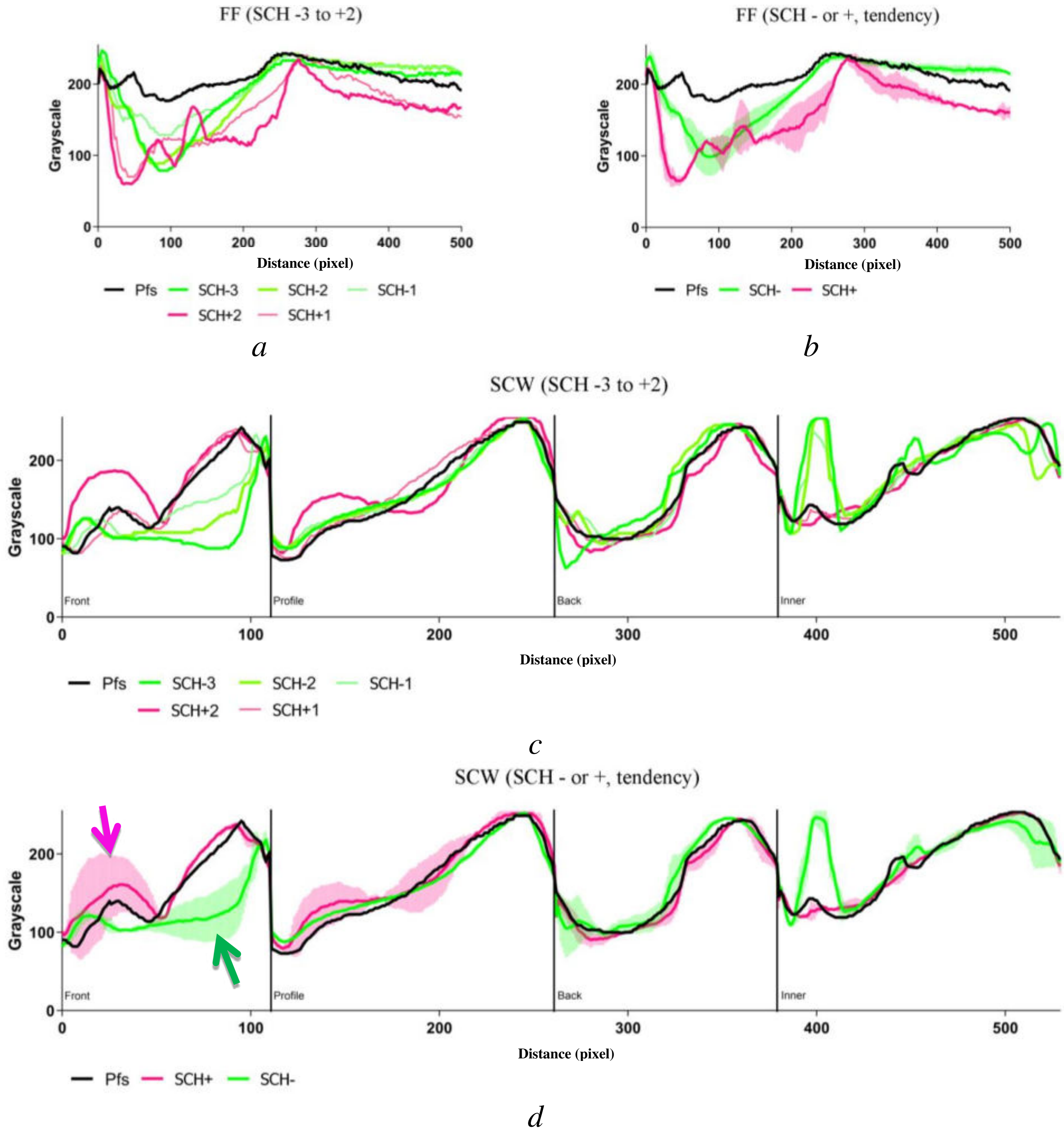


Figure 5.8 - Grayscale diagram of FF and SCW under the influence of SCH changing: *a* - detail of grouped diagram of FF, *b* - grayscale deformation tendency of FF, *c* - detail of grouped diagram of SCW, *d* - grayscale deformation tendency of SCW

Different grayscale tendencies reflected different pattern index deformation. Using the front part of SCW as an example (as Fig. 5.8,d), when SCH increases, the part of 0 to 50 pixels distance was bulge (purple arrow). On the contrary, when SCH decreases, the part of 50 to 100 was concave (green arrow). This result reflected the relation between pattern index deformation (SCH increase or decrease) and grayscale.

5.5. Subjective and objective evaluation of sleeve quality

Quantification of grayscale intensity differences for each experimental sleeve was performed by comparing it to a control sleeve that had a perfect fit. The equation was described as:

$$Go = \frac{\sum_i |P_i - D_i|}{n}, \tag{5.3}$$

where *Go* is the grayscale offset between the control sleeve (perfect fit) and experimental sleeves in each pixel, P_i is the i-th pixel of perfect fit sleeve value. D_i is the i-th pixel value of the deformed sleeve at different views, and was calculated by weighting. n is the number of pixels along FF or SCW lines, n = 500 for FF, n= 529 for SCW.

Equation (5.3) and Equation (5.1) were similar. The difference was: equation 5.1 for fit criteria, using fit belt and its' boundaries values; equation 5.3 for defect identification, using control sleeve and its' grayscale plot.

After measuring five mean difference values on the projections from the front (along SCW and FF), side (along SCW), back (along SCW), and inside (along SCW), the weighted difference between the control and experimental arms was calculated. The contribution of defects in the different projections to the overall impression of the sleeve was weighted as follows (%): defects in the front view were rated 50, side 30, back 15, inside 15. This weighted proportion was based on the consumer's experience with clothing observation when selecting and purchasing. Consumers tend to pay more attention to the front and the profile when facing a fitting mirror.

Table 5.4 - Indexes of objective (grayscale) and subjective (sensory) evaluations of experimental sleeves of training sample

Parameter index of pattern deformation, unit	Deformation interval	Objective evaluation grayscale offset value of experimental sleeve					Go	Subjective evaluation level of experimental sleeve				Aws
		Front		Profile	Back	Inner		Front	Profile	Back	Inner	
		F_{fF}	S_{wF}	S_{wP}	S_{wB}	S_{wI}						
SCH, cm	-3	27.3	53.7	10.9	16.4	25.9	27.3	Po	Pe	Ap	Po	1.75
	-2	30.0	40.7	11.0	11.3	21.7	23.8	Ap	Pe	Ap	Po	2.25
	-1	21.2	24.7	8.7	7.81	15.7	16.0	Ap	Pe	Ap	Po	2.25
	+1	45.5	9.7	7.7	3.6	4.3	16.9	Ap	Pe	Pe	Pe	2.5
	+2	57.3	28.6	21.0	13.4	8.1	30.2	Po	Po	Po	Ap	1.05
SCW, cm	-4	59.1	16.2	29.9	16.8	10.6	30.8	Po	Po	Po	Ap	1.05
	-2	50.5	10.9	20.4	21.0	7.0	25.0	Ap	Ap	Po	Ap	1.85
	+2	8.3	18.7	6.3	7.5	20.1	10.8	Pe	Pe	Ap	Po	2.75
	+4	28.1	45.7	11.6	10.4	28.1	24.9	Ap	Ap	Ap	Po	1.95
	+6	38.2	63.6	14.7	27.8	23.9	35.3	Po	Po	Po	Po	1
Eb,°	-9	31.7	9.6	5.0	5.9	13.2	13.4	Ap	Pe	Pe	Ap	2.45
	-6	18.9	10.6	5.3	5.7	15.6	10.5	Pe	Pe	Pe	Ap	2.95
	-3	11,0	8.0	2.7	5.1	11.9	6.9	Pe	Pe	Pe	Ap	2.95
	+3	22.7	8.6	3.7	5.8	11.3	10.3	Ap	Pe	Ap	Ap	2.3
	+6	27.1	16.5	20.1	30.2	10.7	22.0	Ap	Ap	Po	Ap	1.85
	+9	30.7	19.0	26.1	31.2	11.6	25.5	Ap	Po	Po	Po	1.5
Sb,°	-6	42.8	45.0	18.0	15.0	17.6	30.5	Po	Ap	Ap	Po	1.45
	-4	37.0	23.0	9.4	15.2	12.0	20.7	Ap	Pe	Ap	Ap	2.3
	-2	20.4	12.9	3.7	6.3	11.1	10.9	Ap	Pe	Pe	Ap	2.45
	+2	28.0	8.9	5.9	9.1	12.5	13.0	Pe	Ap	Ap	Ap	2.5
	+4	46.1	10.9	13.1	28.3	13.9	23.1	Ap	Po	Po	Ap	1.55
	+6	44.3	12.8	14.1	24.8	11.4	22.8	Po	Po	Po	Po	1

Notes: Grayscale measurement indexes of different views, F_{fF} represent front fold on front view, S_{wF} represent sleeve width on front view, S_{wP} represent sleeve width on profile view, S_{wB} represent sleeve width on back view, S_{wI} represent sleeve width on inner view.

The results of the calculations and measurements were shown in Table 5.4. The average of the weighted subjective score (Aws) obtained for the four projections and three score scales, which Pe represent three scores, Ap two scores, Po one score. The Go and Aws showed a negative relationship. The Go and Aws value of controlled perfect fit sleeve were 0 and 3, respectively. The larger Go value indicated the larger offset with the perfect fit sleeve, which means more defects. Meanwhile, the smaller Aws value indicated the poorly evaluated fit, which also means more defects.

After processing the result of Table 5.4, Fig. 5.9 shows diagrams of the differences between the projections of the control and experimental sleeves identified as Po, Ap, and Pe according to their grayscale offset.

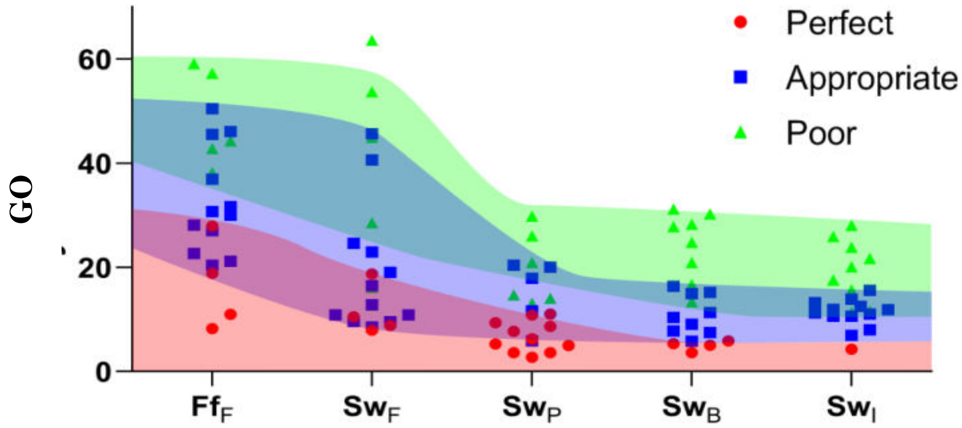


Figure 5.9 - Diagram of differences between the control sleeve and the experimental sleeves on the gray scale as a function of fit quality

As shown in Fig. 5.9, the diagrams overlap, especially at the front view, because of the certain conventionality of subjective evaluations. Therefore, the grayscale evaluation method was chosen as an alternative or addition.

In order to construct a linear regression to reveal the relationship between objective and subjective indicators, Table 5.5 shows the deformation interval of Table 5.4 sorted into the deformation level (DL).

Table 5.5 - The sorted deformation interval for linear regression

Parameter index of pattern deformation, unit	Deformation Interval of each index	DL
SCH	-3 cm	DL 3-
	-2 cm	DL 2-
	-1 cm	DL 1-
	+1 cm	DL 1+
	+2 cm	DL 2+
SCW	-4 cm	DL 2-
	-2 cm	DL 1-
	+2 cm	DL 1+
	+4 cm	DL 2+
	+6 cm	DL 3+

Finish Table 5.5

Eb	-9°	DL 3-
	-6°	DL 2-
	-3°	DL 1-
	+3°	DL 1+
	+6°	DL 2+
	+9°	DL 3+
Sb	-6°	DL 3-
	-4°	DL 2-
	-2°	DL 1-
	+2°	DL 1+
	+4°	DL 2+
	+6°	DL 3+

As shown in Table 5.5, the deformation interval of four indexes could be coordinated in DL by organizing and sorting, which makes it possible to construct the linear equation between the subjective evaluation and the grayscale offset.

The linear regression was employed to establish the relation between objective grayscale and subjective fit evaluation. The linear regression equation was described as:

$$Go_w = 43.1 - 11.4 \text{ Aws}, \quad (5.4)$$

where Go_w is the weighted grayscale offset, Aws is the arithmetic average score of the sensory analysis. The r^2 is 0.79.

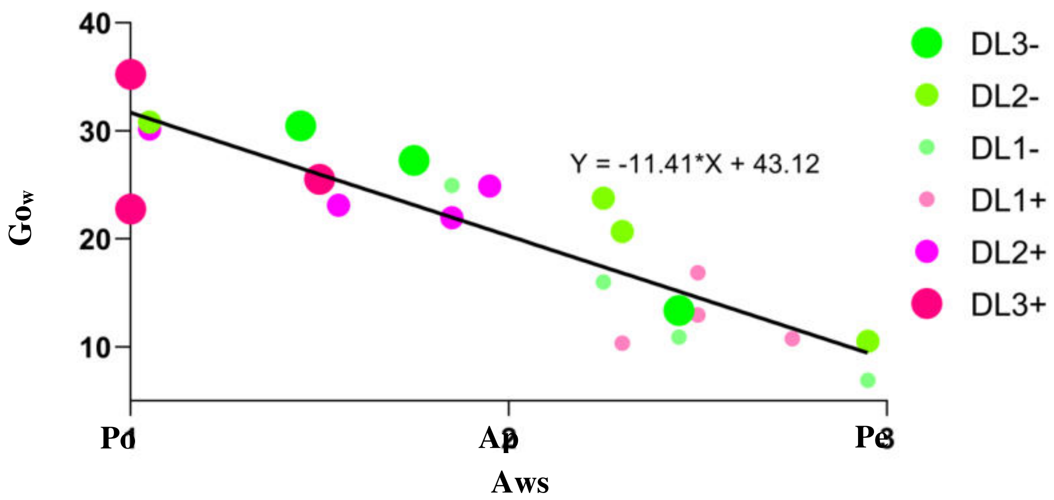


Figure 5.10 - Linear regression of Go_w and Aws

As shown in Fig. 5.10, the low Aws corresponds to high Go_w (and vice versa). Such combinations were predominantly on the left side (Po part) of the plot. Conversely, the right side (Pe part) of the graph contains scores for higher quality sleeves.

Thus, it was proved possible to use the sensory analysis results in parallel and quantify the differences between the control sleeve and the newly designed virtual sleeve. This result opens up the possibility for automatic quality assessment of DTS without involving experts.

Conclusion after chapter 5

1. The initial grayscale database of the experimental sleeves was established, which was constructed by grayscale measurement of image analysis.

2. The grayscale criteria for the sleeve fit evaluation were developed, which integrated with subjective fit evaluation, virtual images, measurement indexes, and grayscale diagrams. Meanwhile, the criteria validation experiment showed that the criteria effectively evaluated sleeve fit.

3. The grayscale algorithm for defect identification was established to help find the sleeve defects by grayscale.

4. The relationship between subjective and objective indicators was revealed. The linear regression equation linked the Go_w and Aws, which opens a possibility for automatic quality assessment of DTS without expert participation.

CHAPTER 6. EXPLORE THE CORRECTNESS AND GOODNESS OF FIT EVALUATION AND PREDICTION SYSTEM

This chapter aimed to evaluate the correctness of the obtained result, which involved three directions:

1. Ergonomic experiment consisted of ease combination, comfortable subjective evaluation, and pressure.

In this direction, the patterns with designed ease were sewed in the real jacket for wearing pressure evaluation. This direction revealed the relationship between wearing pressure, subjective evaluation, and ease allowance.

2. Possible application of DTS as an alternative to real sleeve.

In this direction, DTS and real sleeve were compared in three aspects of silhouette, surface appearance, and sleeve position. The aim was to analyze the feasibility of DTS as an alternative to real sleeve.

3. Series validation test

In this direction, a series of validation tests were conducted to prove the goodness of fit evaluation and prediction criteria for DTS.

6.1. Methods and materials of research

6.1.1. Instruments and software of research

The FlexForce (Tekscan Ltd, USA) sensor and accordance computer recording system was used for pressure evaluation. This sensor acquisition sensing area is 70 mm^2, the pressure acquisition range is 0 to 4.4 Newton, the measurement error is smaller than 3%. The sensor can measure the body's pressure with dynamic also. Fig. 6.1 shows the sensor and device for pressure evaluation.

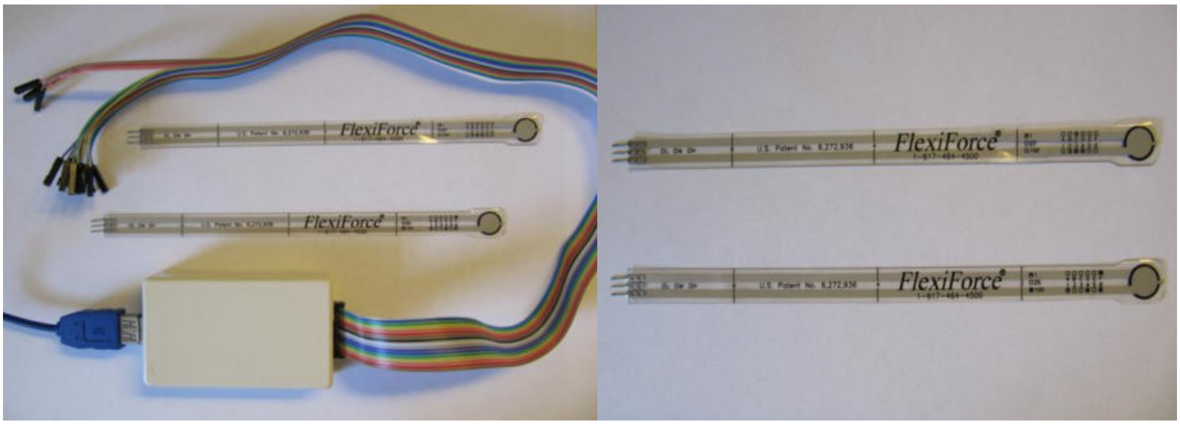


Figure 6.1 - The FlexForce sensor for measuring jacket pressure on the human body

For DTS as an alternative to real sleeve direction, Adobe illustrator was used to trace the silhouette of the sleeve and bodice. The Screen Protractor (Iconico Ltd, USA) was used for angles measurement.

For the series validation direction, since this direction was performed through the whole experiment, thus, all software used in the previous chapter would be present in this part.

6.1.2. Objects of research

The study objects of ergonomic direction were the classic women's jacket with design ease-allowance. The bodice was divided into several panels by central front, side seam, elbow seam, and several style seam such as princess seam. As the experiment focused on the sleeve part, no requirement was made for the collar part. The experimental jackets were made using three materials of Melton (material 1), Muslin (material 2), and Polyester blend (material 3).

The study objects of DTS alternative real sleeve direction included 16 images of two kinds of jackets. Those images were classified by four features: virtual-real, Sa-Sd, front view-profile view, Pe-Po.

The study object of series validation direction included two jacket patterns which out of previous pattern database, one should be Pe, and the other should be Po. This conjecture needs a series of experiments to verify.

6.2. Ergonomic of ease, pressure, and comfortable

Ergonomics is the science of designing and optimizing the relationship between human-object-environment For women's jackets, the ergonomic reflected on three aspects: ease combination, pressure, and wearing comfort. The experiment would explore the correctness and goodness of ease setting through these three aspect.

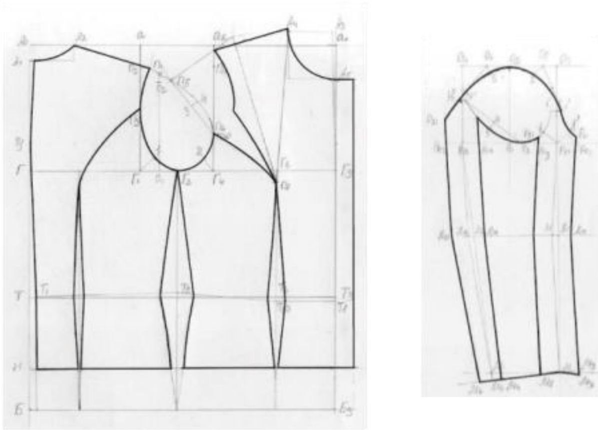
6.2.1. Ease of pattern parameter designing

Compared with other methods in Table 1.3, the COTSHL method was chosen because it is simplified and convenient at ease design. Thus, a fundamental jacket pattern was drawn for 164-92-100 female body size by COTSHL. Basis on this fundamental pattern, four designed ease combination patterns were also constructed. Table 6.1 shows the detail indexes of ease designed pattern, which named jacket 1 to Jacket 4 (J1 to J4) for distinguish.

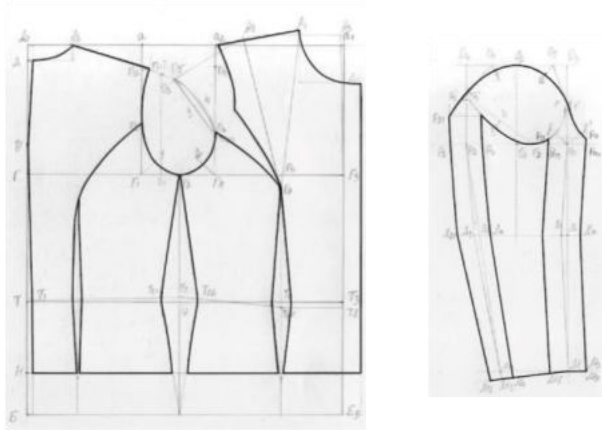
Table 6.1 - Detail of ease designed pattern

Ease Name	Abbr. Symbol	The value of the constructive increase ease of the jacket			
		J1	J2	J3	J4
Ease of half bust	E_{HB}	5,5	6,5	7,5	8,5
Ease of back width	E_{BW}	1,0	1,2	1,4	1,6
Ease of chest width	E_{CW}	0	0,5	0,8	1,0
Ease of waist girth half	E_{WGH}	3	4	5	6
Ease of hip girth half	E_{HGH}	4	5	5	6
Ease of back length	E_{BL}	0,7	0,7	0,7	0,7
Ease of snp-bp-waist line	E_{SBW}	1,0	1,0	1,0	1,0
Ease of back neck width	E_{BNC}	1,0	1,0	1,0	1,0
Ease of back neck height	E_{BSFS}	0,2	0,2	0,2	0,2
Ease of armhole depth	E_{AD}	2,7	3	3,5	4
Ease of arm girth across armpit point	E_{AGAP}	6,5	8	9	10
Ease of wrist girth	E_{WG}	9,5	9,5	9,5	9,5

As shown in Table 6.1, indexes E_{HB}, E_{BW}, E_{CW}, E_{AD}, E_{AGAP}, E_{WGH}, and E_{HGH} were designed as increasing ease for four jackets. Meanwhile, E_{SBW}, E_{BNC}, E_{BSFS}, and E_{WG} remain the same. Fig. 6.2 shows the flat patterns of four kinds ease combinations.



a



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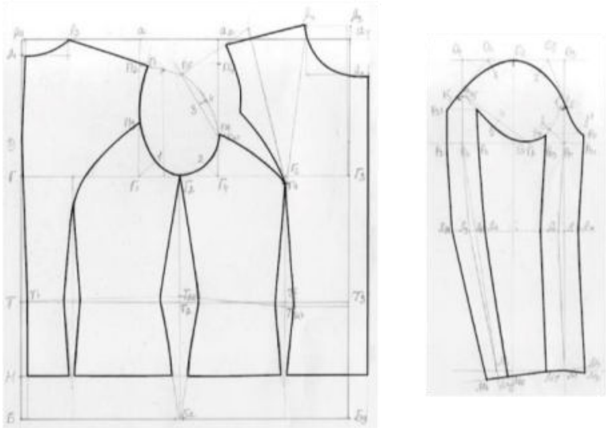
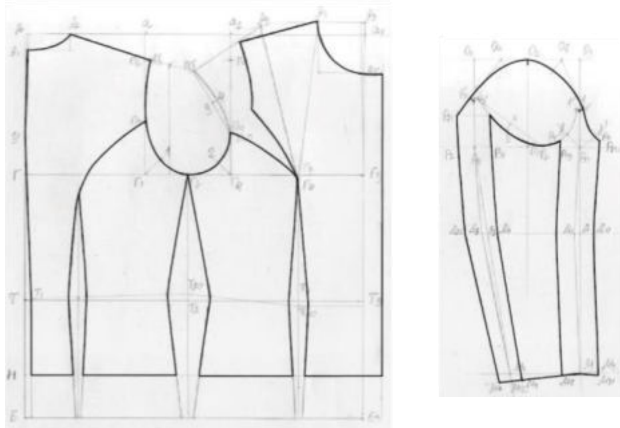


c



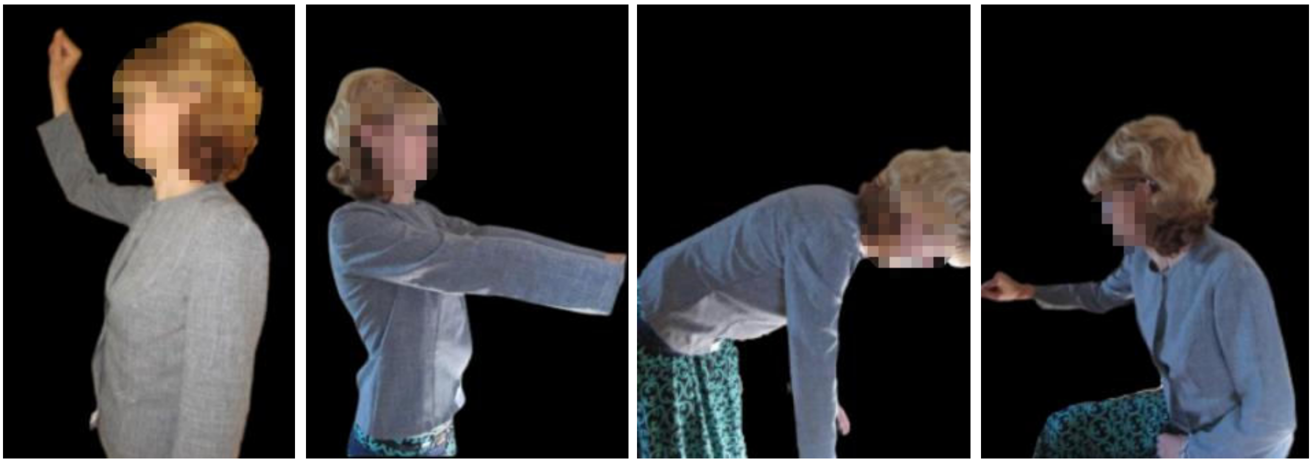
d

Figure 6.2 - The experimental women jacket pattern with designed ease-allowance combination: *a* - pattern of J1, *b* - pattern of J2, *c* - pattern of J3, *d* - pattern of J4

As shown in Fig. 6.2, design ease of pattern images was hard to notice due to the human eyes discern limitation. However, it would become obvious when the pattern was sewn into the real jacket.

6.2.2. Pressure evaluation

As one of the common physical properties, the pressure exists between clothing and the human body, which was important to reflect wearing comfort. A total of 12 sample jackets were made from three kinds of materials and four designed ease-allowance. Real women wear those samples in four typical postures for pressure investigation. The four postures were the large amplitude posture of daily life, which could help us measure the pressure limit.



a *b* *c* *d*

Figure 6.3 - Four large amplitude posture of daily life: *a* - arm raise, *b* - put forward, *c* - downward, *d* - open car door

As shown in Fig. 6.3, the four typical postures were：

1. Vertical arm raise for the bus.

2. Arm put forward at horizontal extension.

3. Body tilt downward, arm downward extension.

4. Open the door of the car.

FlexiForce Sensor was attached to the human body with adhesive tape and plaster. Fig. 6.4 and Table 6.2 show the detail of scheme and location of pressure sensor point (Ps), which corresponded with the gradually increased ease pattern of Table 6.1.

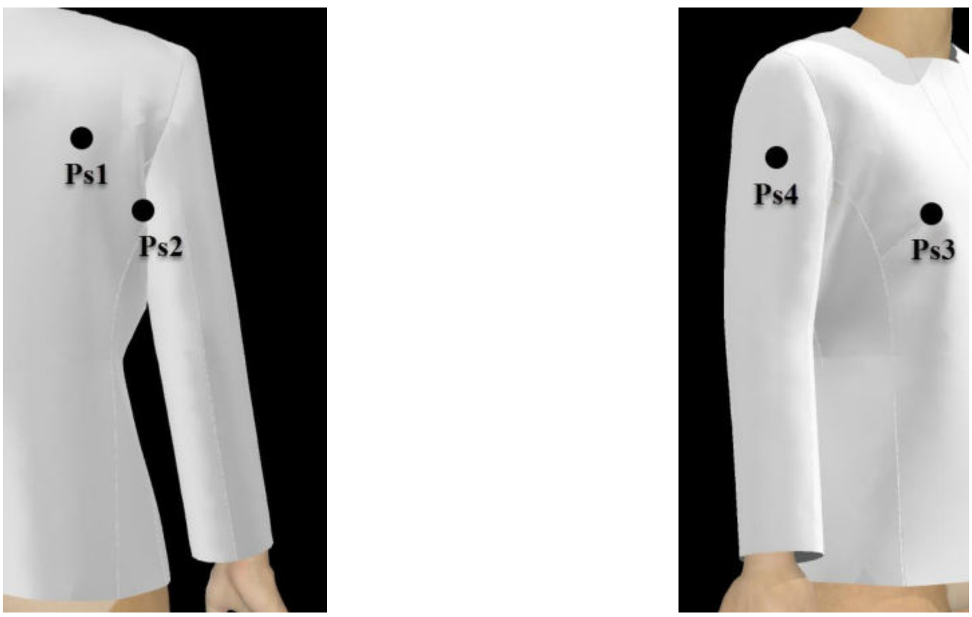


Figure 6.4 - Schematic picture of pressure measurement point

Table 6.2 - Scheme of pressure evaluation point location

No.	Correspondence with index of ease allowance	Scheme of sensor location
Ps1	E_{BW}	Point of the back, locating on the shoulder blade area
Ps2	E_{AD}	Point of back armhole, locating on the back armpit area, same height level of back armpit point
Ps3	E_{HB}	On breast point of the bust girth
Ps4	E_{AGAP}	On the shoulder girth

As shown in Fig. 6.4 and Table 6.2, these points were chosen because they were affected by the most significant pressure during human body movements. Therefore, the pressure evaluation point, human body posture, and designed ease-allowance were integrated into the pressure evaluation experiment. For example, the arms raise posture lets the Ps1 pressure maximize. Simultaneously, the designed pattern ease allows us to obtain the maximum Ps1 pressure under different E_{BW}.

Each point pressure value was evaluated by FlexForce and was measured between 14 and 22 times for accuracy. Meanwhile, processing the measurement results included the singular value exclusion, average calculation, and confidence interval determination [141, 142]. The detailed values of pressure evaluation were shown in Appendix J. Table 6.3 shows the scale for wearing comfortable evaluation.

Table 6.3 - Scale for subjective comfortable evaluation

Scale	Feeling	Scheme of evaluation
5	Very uncomfortable	Very tight, high pressure values by sensor evaluation, which restrain body' movement.
4	Uncomfortable	Tight, significant pressure value by sensor evaluation.
3	Best comfortable	Medium fit, moderate pressure values by sensor evaluation.
2	Comfortable	A little loose, lower pressure values by sensor evaluation.
1	Comfortable with loosely	Loose, sensor could not evaluate the pressure.

As shown in Table 6.3, the comfortable subjective evaluation was split into five scales, which from very uncomfortable to comfortable with loosely. Scale 5 and 4 represented tight and misfit, which accompanied the wearer's uncomfortable. Scale 3 was the best because it balanced comfort and fit. Scale 2 and 1 were also comfortable, but the loose style might have unnecessary wrinkles on the appearance.

6.2.3. The range of ease proving

Once all the values have been measured and evaluated, the relationship among ease (four kinds of ease combination, three material), wearing pressure (four posture, four sensor points), subjective comfortable (five scales) could be revealed. The relationship supported the opportunity for the desirable ease setting. Table 6.4 lists the subjective evaluation and pressure results with four kinds of ease combinations.

Table 6.4 - Subjective evaluations and pressure value result

No. of sample jacket	Pressure point	Feeling level and pressure value, kPa					
		Material 1		Material 2		Material 3	
		Feeling	Pressure	Feeling	Pressure	Feeling	Pressure
J1	Ps1	5	1,1	4	0,26	**3**	0,05
	Ps2	5	0,59	4	0,45	**3**	0,41
	Ps3	4	0,53	4	0,18	4	0,15
	Ps4	5	1,5	5	0,68	4	0,55
J2	Ps1	4	0,95	**3**	0,24	**3**	0,02
	Ps2	4	0,36	**3**	0,28	**3**	0,26
	Ps3	4	0,28	**3**	0,14	**2**	0,14
	Ps4	5	0,78	4	0,44	**3**	0,34
J3	Ps1	**3**	0,89	**3**	0,17	**2**	0
	Ps2	**3**	0,37	**2**	0,14	**2**	0,15
	Ps3	**3**	0,18	**2**	0,1	**1**	0,1
	Ps4	**3**	0,35	**2**	0,33	**1**	0,25
J4	Ps1	**2**	0,6	**2**	0,17	**1**	0
	Ps2	**2**	0,22	**2**	0,15	**1**	0,03
	Ps3	**2**	0,16	**2**	0,08	**1**	0,06
	Ps4	**2**	0,32	**1**	0,29	**1**	0,16

As shown in Table 6.4, J1 to J4 represented the ease-allowance increasing, Ps1 to Ps4 represented four evaluation points of pressure. The comfortable feeling scale 1-5 represented from tight uncomfortable to loosely comfortable.

As the ease-allowance increased, the pressure decreased significantly, and the subjective comfort scale changed simultaneously. The materials also affected the comfort. The best situation occurs in the combination of J3 with material 1, where all four sensor points were in three scale. Fig. 6.5 shows the relationship between ease-allowance and pressure in three materials.

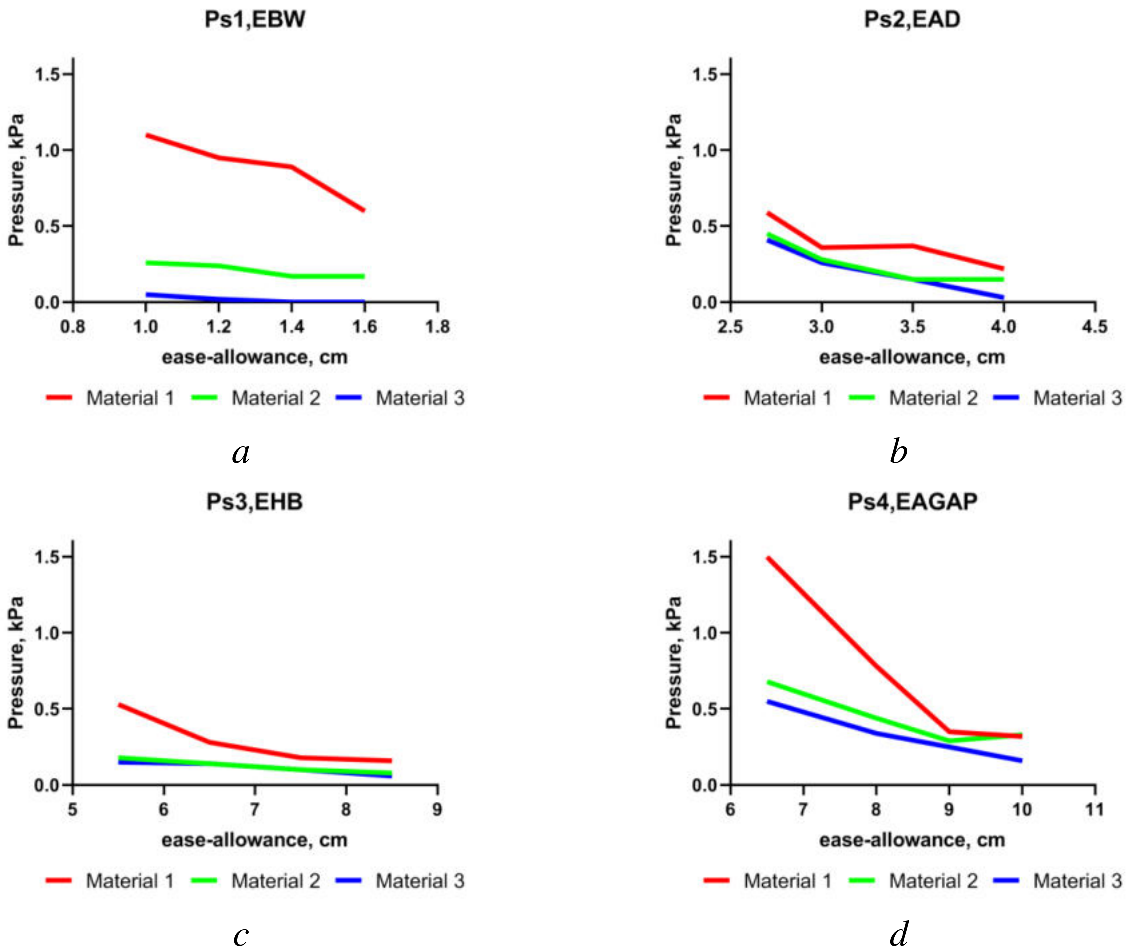


Figure 6.5 - The relationship between pressure (vertical axis, kPa) and ease-allowance (horizontal axis, cm): *a* - Ps1, E_{BW}, *b* - Ps2, E_{AD}, *c* - Ps3, E_{HB}, *d* - Ps4, E_{AGAP}

As shown in Fig. 6.5, the material and ease-allowance did affect the pressure. The pressure was negatively associated with ease-allowance. Meanwhile, the effect of materials was more complicated. The pressure of 1.1 kPa at Ps1, and 1.5 kPa at Ps4 (both material 1) were recorded as two maximums pressure values. Meanwhile, these two pressure values do not exceed the critical values of experience [153]. This result indicated that material 1 was more likely to appear larger pressure values than the remaining two materials, which need to be avoided when the small ease design.

The ease range with a comfortable scale (scale 1-3) could be obtained. Table 6.5 compared the ease of real jacket in comfortable scale (E_{RJC}) and ease of virtual simulated jacket with the perfect fit (E_{SJP}) in four indexes.

Table 6.5 - Ease comparison of real and simulation

Ease name	E_{RJC}, cm	E_{SJP}, cm
E_{BW}	1.0 - 1.6	0.79 - 2.71
E_{AD}	2.7 - 4.0	5.5 - 8
E_{HB}	6.5 -8.5	3.74 - 8.43
E_{AGAP}	9.0-10	3.52 - 9.84

As shown in Table 6.5, the majority range of E_{RJC} and E_{SJP} were overlapped, while E_{SJP} would have a slightly larger range. It should be noted that the index E_{AD} of E_{SJP} was more significant than E_{RJC}. Since the index E_{AD} was under the armpit, these loose wrinkles would hide when the arm in free nature dropped. Furthermore, the loose means the arm movement. Thus, this situation should be caused by pattern different pattern making methods.

The pressure-ease-feeling study of the sleeve efficiently remedied the deficiency of DTJ at pressure evaluation. The result contributed to the ergonomics of women's jackets.

6.3. Validation of DTJ as alternative to real

People have every reason to believe that DTJ can adequately replace sewing samples, significantly saving time and material costs in product development. For this reason, the virtual and real comparison validation was started between sleeve silhouette, appearance, and angle.

6.3.1. Virtual and real comparison validation on silhouette

In order to inspect the availability of DTJ, the study was conducted on the comparison of virtual (simulated sleeve) and real (sewing sleeve) to explore the similarities and differences between them. This part also aimed to propose a novel quantitative evaluation method for similarities and differences of jacket image silhouette, which integrated with the surface observation.

The whole practical comparison testing was operated by the following procedures:

1. Preparing and sewing

Two patterns were prepared, Pe and Po, simulated them into virtual jackets and sewn in real jackets. According to the result of the materials survey (as Appendix B), the Melton was adopted for real jacket sewing, which content is 50% wool and 50% acrylic blending. This blended fabric was made to improve the fabric's feel, performance, and durability. The thickness is 1.4 mm, the color is Olives green, and the weight is 490 g/m². This fabric has a dense set with a soft brushed surface. The virtual material was similar to the real Melton properties, which from the Clo3D in-built material library.

2. Requiring image for comparison

The total 16 images were acquired and classified by four features: virtual - real, with arm - without arm, front view - profile view, and perfect fit - poor fit. To be clear, the "with arm" means Sa (as Fig. 4.1,a) and real dress-form with the draping arm (cotton-filled for draping). To correspond, the "without arm" means Sd (as Fig. 4.1,b) and real dress-form without arm. For the sake of naming consistency, the name of the real dress-form named Sa and Sd also.

3. Silhouette requirement and comparison analysis.

Fig. 6.6 shows silhouette comparison, in which the silhouette was obtained by image projection. The green line represented virtual, the red real. In order to be accurate, the jacket silhouettes were overlapped and measured under the same scale for comparison.

4. Surface observation for wrinkles

The silhouette comparison was the objective method that only focused on the projected silhouette. The wrinkles comparison consisted of the previous evaluation of Table 2.4. Five experts were recruited for wrinkles comparison.

The Sd comparison of the perfect fit level was shown in Fig. 6.6,a. It can be found that except for the difference between the armpit (front) and cuff (profile), the rest of silhouette overlaps perfectly. Fig. 6.6,b represented Sd of poor fit level. The overlapped silhouette has several differences from the observation, especially on the profile view.

The Sa comparisons of perfect and poor fit were shown in Fig. 6.6,c,d. Due to the model's limitations, there were inevitably differences in arms posture between same sized avatar and real dress-form, which exhibited clearly at Sa of perfect fit (as Fig. 6.6,c, the smooth silhouette with differences). The Sa of poor fit showed distortion and discord silhouette with a significant difference.

The maximum distance of each silhouette comparison was marked on Fig. 6.6 and listed in Table 6.6.

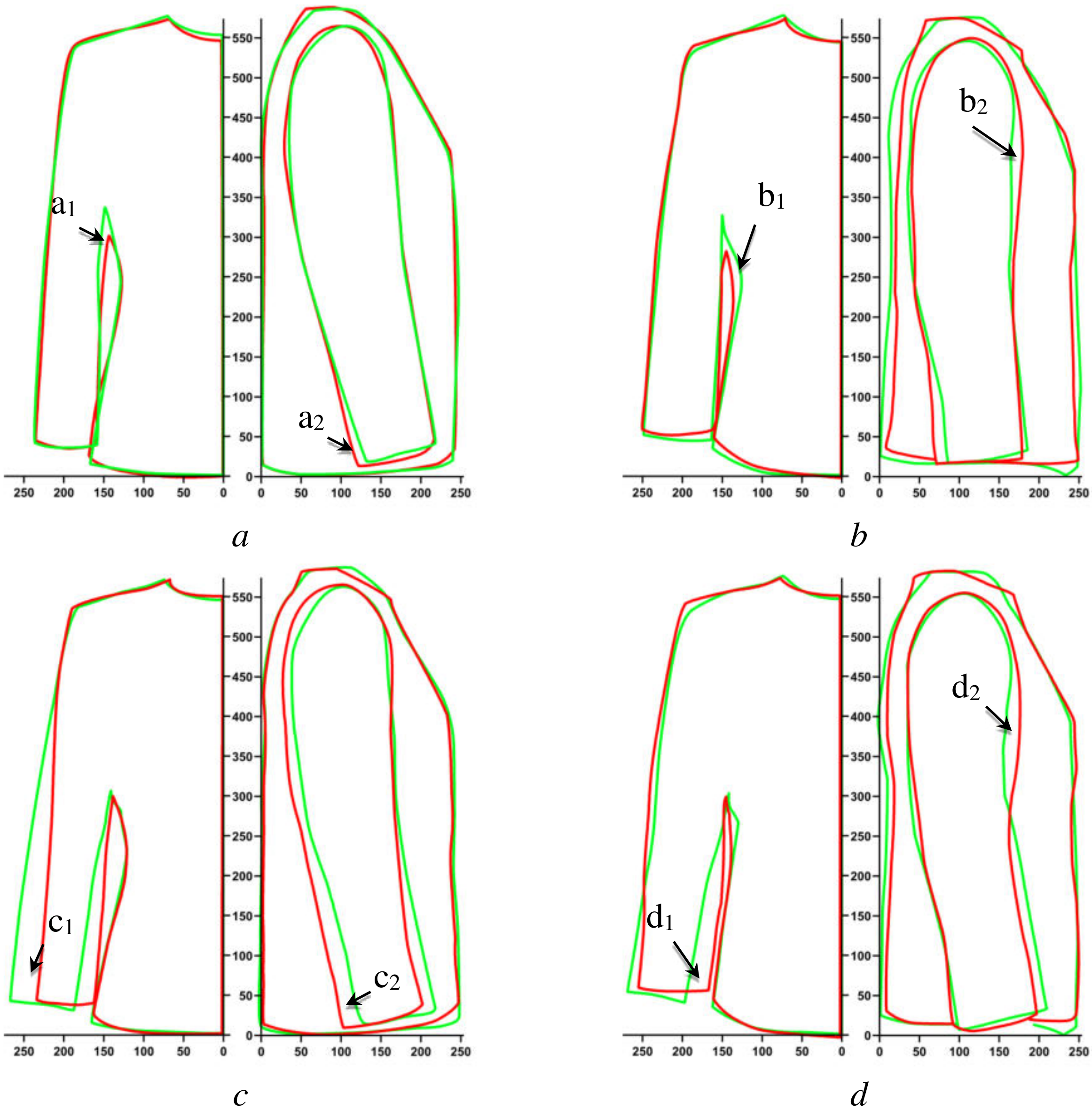


Figure 6.6 - Comparison of the obtained jacket silhouette: *a* - Sd of perfect fit, *b* - Sd of poor fit, *c* - Sa of perfect fit, *d* - Sa of poor fit, mm

Table 6.6 - The maximum difference on silhouette comparison

Dress-from type	Perfect			Poor		
	Front	Profile	Total	Front	Profile	Total
Sd, mm	a_1, 10	a_2, 12	22	b_1, 13	b_2, 15	28
Sa, mm	c_1, 35	c_2, 25	60	d_1, 28	d_2, 18	46

As shown in Table 6.6, the total poor fit of Sd shows more difference than perfect. However, Sa does not show the same situation because of the arm posture limitation.

a *b* *c*

Figure 6.7 - Worst fit jacket's surface observation and comparison for wrinkles: *a* - DTJ with default color, *b* - DTJ with same color of real, *c* - real jacket

The comparison of DTJ and real jacket on silhouette was a quantitative objective comparison, while the observation and comparison by experts was the supplement, which showed several interesting features (detail images were listed in Appendix K):

1. The virtual and real jackets showed the most similarity in terms of perfect fit and without arms (as Fig. 6.6,a).

2. The difference was not only expressed on silhouette but also on appearance. It was well known that the unbalanced force let wrinkles appear. The virtual and real jacket

appearance (as Fig. 6.7,b,c) indicated that the Clo3D was inadequate for wrinkles simulation. In other words, the built-in virtual physics engine of Clo3D could simulate the force or extension of material (e.g., wrinkles, folds). However, the real appearance was more complex, which the Clo3D physics simulation needed to be improved for more complex scenario.

3. The material color affected the wrinkles observation, the white material of Fig. 6.7,a expressed the wrinkles more clearly than Fig. 6.7,b. Meanwhile, the chromatic aberration and illumination also affected the comparison result.

6.3.2. Validation of virtual and real on sleeve posture (angels)

From the previous comparison of silhouette, the virtual and real was closest at Sd of perfect fit level (as Fig.6.6,a), Choosing it for further angles comparison.

Angles comparison was a part of the whole sleeve fit evaluation (connected with Fig.4.4). There were only three angles indexes available for virtual-real comparison. The angles schematic image was shown in Fig. 6.8, and the detailed results were expressed in Table 6.7.

a *b*

Figure 6.8 - Virtual-real comparison: *a* - DTS, *b* - real jacket sleeve

Table 6.7 - The results of virtual sleeve and real sleeve measuring

Type of sleeve	Index,°		
	∠α_1	∠α_2	∠β
Real jacket sleeve	34.6	56	11.9
DTS	33.6	58.5	11.9
Difference	1	2.5	0

As shown in Table 6.7, the three indexes values of DTS and real sleeves were close. The difference was found in ∠α_1, and ∠α_2, which were 2.5° and 1°, respectively. Those differences were regarded as measurement errors. The ∠β was the same, which indicated the accordant of sleeve sloping of posture. The angles comparison validation proved the effectiveness of virtual simulation. Simultaneously, it proved the consistency of Sd in perfect fit level again.

In summary, the DTJ can substitute the real jacket for fit evaluation. The best consistency was Sd with perfect fit level. However, the difference between DTS and real jacket sleeve still exist, limiting the virtual instead of real. The difference was mainly caused by inaccuracy and limitation of the simulation software, such as fabric property, detail avatar size modification, physical simulation engine (especially in the worst fit situation), etc. Therefore, we suggest that at least make one real sample for final pattern checking before production in the development jacket process.

6.4. Validation of system effectiveness

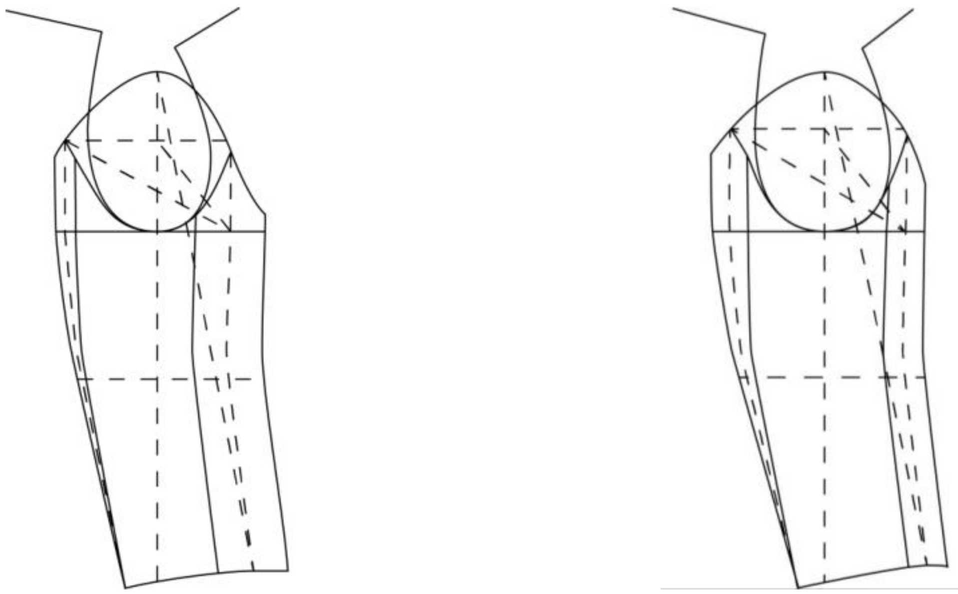
In order to explore the correctness and goodness of fit evaluation and prediction system of DTS, the validation experiment consists of three stages: experiment preparation, subjective fit evaluation, and comprehensive criteria validation.

6.4.1. Validation experiment preparation

The validation experiment preparation involved four parts, which were as follows:

1. Pattern collection: According to Chapter 2, two CWJ jacket patterns were

collected and named samples A and B. The two samples were out of the previous pattern database (as Fig. 6.9). The jacket size conformed to the typical body size of the Chinese (as Table 1.7). Meanwhile, measuring all parametrization indexes for graphoanalytic description.



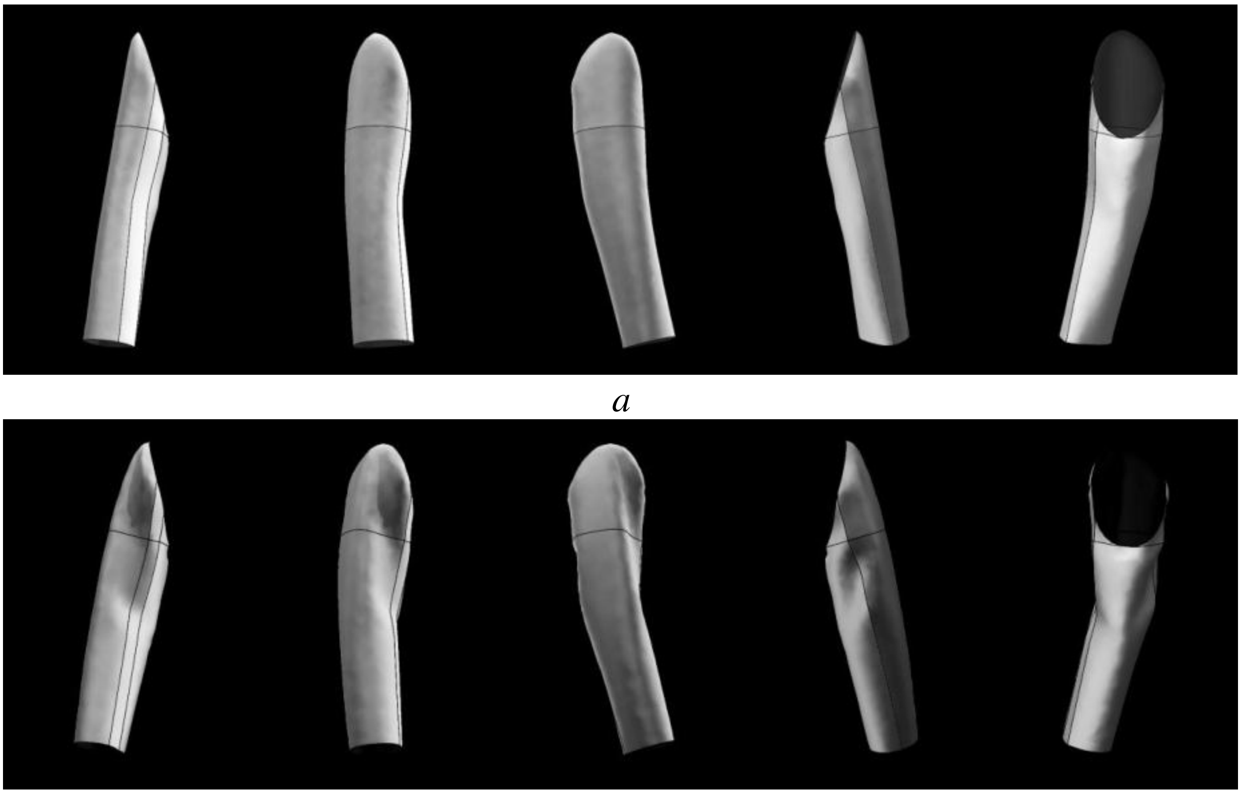
a *b*

Figure 6.9 - Sample of patterns for validation: *a* - sample A, *b* - sample B

2. Pattern setting: According to Chapter 3, feature points for 2D matrix fit criteria were set (four points on armhole, three points on sleeve cap curve, as Fig. 3.1), and feature points for 3D fit evaluation criteria were set (six points on armhole, six points on sleeve cap curve, as Fig. 3.3 and Table 3.3). According to Chapter 4, the indexes for whole sleeve fit evaluation criteria were set (nine indexes, Table 4.3). According to Chapter 5, marked two representative indexes on pattern (FF and SCW, as Fig. 5.1).

3. Dress form setting: According to Chapter 4, Sa and Sd participant in this validation (as Fig. 4.1).

4. Jacket sleeve simulation: The patterns were imported into Clo3D for simulation. After the simulation, other parts of jacket were deleted, which only the kept sleeve part. The sleeves were exported as pictures, and contrast was increased for subsequent subjective evaluation and grayscale measurement according to chapter 5. Fig. 6.10 shows the two required sleeve wear on Sa.



a

b

Figure 6.10 - Simulated sleeve samples for validation: *a* - sample A, *b* - sample B

6.4.2. Subjective fit evaluation

According to the method proposed in Chapter 2 for subjective fit evaluation, the five experts initially considered that sample A was a perfect fit and sample B was a poor fit. The specific result needs to be further verification subsequence.

6.4.3. Comprehensive criteria validation

According to Chapters 3-5, all sample A and B data were recruited for criteria validation. The red and bold font was marked in subsequence tables if the validated value was out of the criteria range. The comprehensive criteria validation involved six parts, which were as follows:

1. 2D matrix criteria validation: Comparing the obtained coordinate points values of samples A and B with the previously obtained criteria range (from Table 3.1), Table 6.8 shows the comparing result that sample A was within the range of all 14 indicators, and sample B has four outside. This result demonstrated the correctness of the criteria on 2D matrix.

Table 6.8 - Comparison of validation sample with criteria on 2D matrix

Feature point	Location in X-Y coordinates					
	X			Y		
	Criteria range	Sample A	Sample B	Criteria range	Sample A	Sample B
ABP	-7.16 ≤ i ≤ -6.14	-6.93	-7.03	8.09 ≤ i ≤10.07	9.74	9.89
AOB	-5.01≤ i ≤-3.21	-4.62	**-5.1**	1.14≤ i ≤2.23	1.84	**2.46**
AOF	2.57≤ i ≤4.86	3.63	4.68	0.59≤ i ≤2.29	1.49	1.7
AFP	5.67≤ i ≤6.84	5.68	6.61	6.99≤ i ≤8.26	7.32	7.75
SE	-10.37≤ i ≤-9.13	-9.23	**-9.48**	8.99≤ i ≤10.31	9.2	10.29
ST	-1.15≤ i ≤0.03	0	0	15.67≤ i ≤16.89	16.11	15.97
SF	7.40≤ i ≤8.48	7.42	8.12	7.04≤ i ≤9.02	8.06	**9.8**

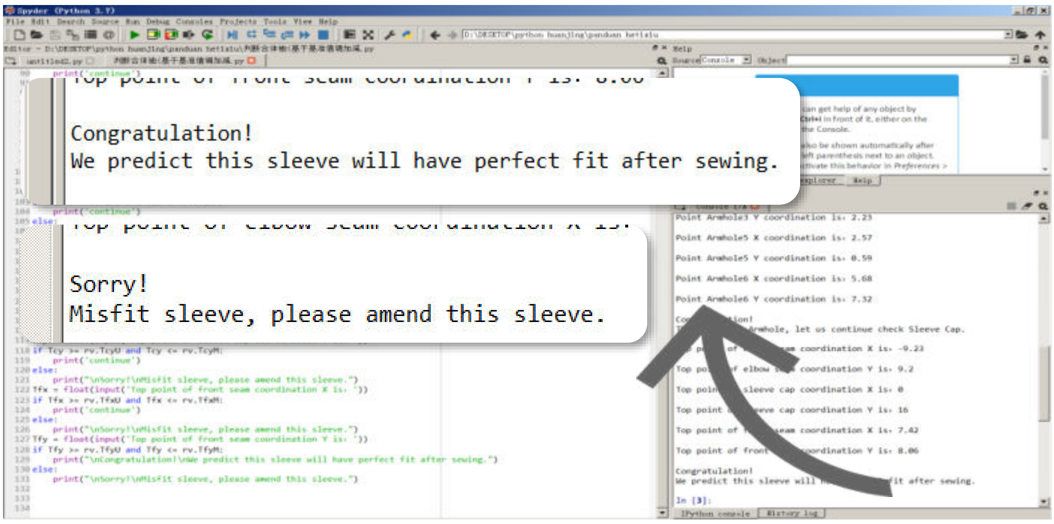
2. 3D feature point criteria validation: Comparing the obtained 3D feature points coordinate values of samples A and B with the previously obtained criteria range (from Table 3.4), Table 6.9 shows the comparing result of all 36 indicators.

Table 6.9 - Comparison of validation sample with criteria in 3D coordinate (x, y, z direction)

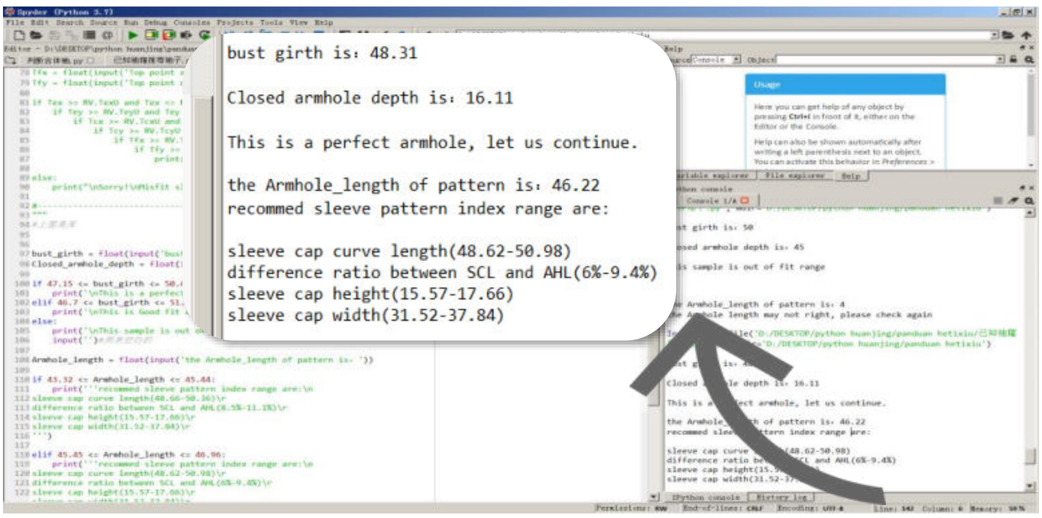
№	Nominal coordinates of points (in numerator - on the armhole line, in denominator - on the pellet line), cm								
	For front projection x			For frontal and profile projection y			For profile projection z		
	Criteria range	Sample A	Sample B	Criteria range	Sample A	Sample B	Criteria range	Sample A	Sample B
A_1 S_1	0,26...1.78 -1.73...0.04	0.33 -1.1	0.54 **0.51**	0.58…1.03 1...1.67	0.82 1.43	**1.32** **1.89**	0.26…0.99 -0,1..-0.81	0.63 -0.33	**0.09** -0.72
A_2 S_2	0,13...1.03 0.33…1.15	0.31 0.4	**0.08** 0.88	-6,54...-8.76 -6,22..-8.49	-6.65 -6.31	**-5.81** **-5.76**	-5,93..-.6.52 -6,94..-7.69	-5.93 -6.99	-6.12 -7.11
A_3 S_3	0,06...1.86 1.76…3.61	**-0.22** 3.1	**-0.88** 2.42	-13,11..-16.58 -12,43...-16.5	-14.23 -13.69	-13.24 -13.11	-0,79..-5.07 -2,78...-6.04	-4.12 -4.75	-2.45 **-6.12**
A_4 S_4	-2.61..+0.45 3.02…4.29	-0.92 4.11	-1.11 3.74	-15,08..-17.59 -14,61..-17.41	-15.52 -15.78	-14.88 -14.6	-0.64…0.74 -0,18...-2.23	0.63 **-0.22**	-0.33 **-2.35**
A_5 S_5	-1.16..+0.61 2.79…3.84	-0.05 2.79	-0.37 3.44	-12,05..-16.65 -11,81..-16.96	-13..43 -13.84	-13.11 -13.27	1.25…5.41 -0.85...3.71	4.55 3.39	4.23 2.45
A_6 S_6	0.12…0.9 1.54…2.44	0.22 1.74	0.47 2.22	-7,32..-9.47 -6,92..9.26	-8.36 **-7.41**	-6.68 **-7.72**	5.82…6.26 4.17…4.79	5.88 4.45	5.87 4.43

As shown in Table 6.9, there were three values of sample A out of range. There were two possible factors contributing to this phenomenon. First, the fabric is soft, although the adhesive tape and interlining were used to control the sleeve-armhole assembly deformation, however, deformation still exists. Second, the criteria range included confidence interval, therefore, small values near the criteria threshold might exclude. It could be found that these three data were close to the threshold (less than 0.5 cm would not cause identified misfit as experience). There were 11 values of sample B out of 3D criteria range. It was because sample B had already been regarded as misfit in 2D matrix criteria (Table 6.8).

3. Python module validation: The validation process followed the flow chart (Fig.3.9 and 3.10) to validate the effectiveness of the python model. The values of samples A and B were input into the judgment module separately. Fig. 6.11,a shows the correct judgement results, which indicated the correctness of the judgement module. Meanwhile, Fig.6.11,b shows the recommended sleeve range consisted of real values of sample A, which indicated the correctness of the recommendation module.



a



b

Figure 6.11 - Python module effective validation: *a* - result of judgement module, *b* - result of recommendation module

4. Whole sleeve fit prediction criteria validation: The whole sleeve fit prediction criteria consisted of two groups, which were group “stabilization” and “changeableness”. Comparing the obtained coordinate points values of samples A and B with the previously obtained criteria range (from Table 4.5).

Table 6.10 shows the comparing result that three values of sample A were out of range (less than 0.5 cm, close to the threshold), and sample B has 24 outside. This result demonstrated the correctness of the whole sleeve fit prediction criteria.

Table 6.10 - Comparison of validation sample with whole sleeve fit criteria

Indexes symbol	First part - the criteria range								
	Sp			Sa			Sd		
First group "stabilization"									
	SampleA	SampleB	Criteria range	SampleA	SampleB	Criteria range	SampleA	SampleB	Criteria range
∠β	**11.5**	**11.7**	(11.8-12.2)	11.3	**11.9**	(10.5-11.3)	11.9	**9.2**	(11.1-11.9)
D1, cm	0	0	0	0	**0.2**	(-0.3-0.1)	0.1	**0.5**	(-0.1-0.3)
D2, cm	0	0	0	-0.4	0.5	(-0.3-0.5)	0.2	0.8	(0-0.8)
Second group "changeableness"									
∠α1	28.9,	**30.3**	(28-29.4)	35.9	40.7	(35.8-38.4)	33	**32.3**	(32.9-35.5)
∠α2	**51**	**50.7**	(48-49.8)	63.3	67	(62.5-64.1)	59.5	**68.5**	(58-60.2)
X1, cm	3.5	**2**	(3-3.8)	1.6	**0.8**	(1.6-2.2)	2.1	**0.1**	(1.9-2.5)
X2, cm	3.5	**2**	(3-3.8)	1.9	**0.9**	(1.6-2.2)	2	**0.9**	(1.9-2.5)
|X1-X2|, cm	0	0	0	0.3	**0.1**	(0.2-0.4)	0.2	**0.8**	(0.2-0.4)
X1p, cm	3.5	**2**	(3-3.8)	0.8	**1.3**	(0.7-1.1)	**0.8**	**0.5**	(0.9-1.3)
X2p, cm	3.5	**2**	(3-3.8)	0.9	**0.1**	(0.7-1.1)	1.1	**0.4**	(0.9-1.3)
|X1p-X2p|, cm	0	0	0	0.1	**1.2**	(0.1-0.3)	0.3	0.1	(0.1-0.3)

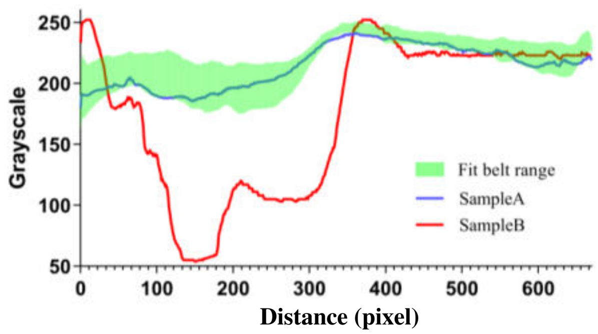
5. Linear regression validation of fit prediction for the whole sleeve: In order to verify the linear regression correctness in Table 4.7, the validation was carried out under the same procedure as described in Table 4.9.

Table 6.11 shows the result of samples A and B in linear regression prediction, measured result of simulation sleeve, the difference between prediction and measuring, and comparing with the criteria of Table 4.4. The comparison shows that all the predicted and measured results of sample A were in (“I”) the criteria range, while all results of sample B were out (“O”). This result proved the correctness of linear regression.

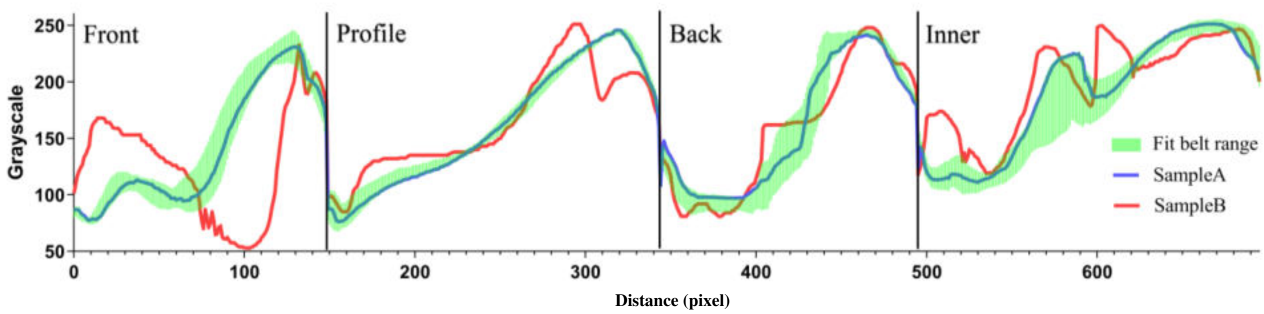
Table 6.11 - Validation samples with whole sleeve fit criteria

Sample name	The indexes of virtual sleeves															
	Predicted results by equations				Measured results				Differences between predicted and measured results (absolute value)				Comparison result of criteria range vs. predicted, and criteria range vs. measured			
	X_{2pa}	X_{1d}	X_{2d}	X_{2pd}	X_{2pa}	X_{1d}	X_{2d}	X_{2pd}	X_{2pa}	X_{1d}	X_{2d}	X_{2pd}	X_{2pa}	X_{1d}	X_{2d}	X_{2pd}
Group1. X_{1p} as independent variable of prediction equation																
A	0.8	2.2	2	1.2	0.9	2.1	2	1.1	0.1	0.1	0	0.1	II	II	II	II
B	0.3	1	0.8	0.3	0.1	0.1	0.9	0.4	0.2	0.9	0.1	0.1	OO	OO	OO	OO
Group2. X_{2p} as independent variable of prediction equation																
A	0.8	2.2	2	1.2	0.9	2.1	2	1.1	0.1	0.1	0	0.1	II	II	II	II
B	0.3	1	0.8	0.3	0.1	0.1	0.9	0.4	0.2	0.9	0.1	0.1	OO	OO	OO	OO

6. Grayscale fit criteria validation: In order to validate the correctness of grayscale criteria, the grayscale values of sample A and B were measured and compared with the previous fit criteria belt of Fig. 5.3,b and 5.4,a. Fig. 6.12 shows the validation comparing result (in Melton material). Sample A (blue line) were within the fit criteria belt (green belt). However, sample B (red line) were out or crossed the belt. This result revealed the correctness of fit criteria belt.



a



b

Figure 6.12 - Grayscale criteria validation: *a* - grayscale of FF, *b* - grayscale of SCW

7. Grayscale deviation validation: The grayscale deviation distance was another form to evaluate the fit of grayscale. Using equations 5.1 and 5.2, Table 6.12 shows the

grayscale deviation validation result of sample A and B with fit belt (in Melton material).

Table 6.12 - Grayscale deviation validation of samples with grayscale criteria belt

Index	Sample and subjective evaluation	Deviation for sleeves made of Melton, unit: dimensionless	
		Dev	*Devstd*
FF	SampleA	141.47	0.21
	SampleB	**25467.02**	**38.01**
SCW	SampleA	22.97	0.03
	SampleB	**11929.6**	**17.16**

As shown in Table 6.12, theoretically, the FF and SCW of sample A value should be zero because sample A was within the range of fit criteria belt. But the error was inevitable. However, the huge deviation values of sample B reflect it was a misfit sleeve.

Conclusion after chapter 6

1. Construction the relationship between wearing pressure, subjective evaluation, and ease allowance. The result validated the correct ease setting of DTJ and remedied the deficiency of DTJ at pressure evaluation.

2. The DTJ could perfectly alternative the real jacket for fit evaluation at the Sd with perfect fit. However, the substitute capability needs to be improved for more complex situations (e.g., misfit, Sa). DTS could replace the real sleeve for pattern checking before mass production in the present. However, it still at least made one real sample for pattern checking before production.

3. The system of fit evaluation and prediction underwent a series validation. The validation showed satisfying results. This fit evaluation and prediction system were recommended for women's sleeves and other parts.

CONCLUSIONS

FINAL RESULT OF RESEARCH

1. A new parametric pattern database of CWJ has been established on the basis of 29 indexes of 82 patterns. This database exactly described the pattern's geometric shape, ease-allowance range, and proportions relation of bodices and sleeves.

2. Two investigations of misfit defects distribution and materials composition for contemporary CWJ were performed, which is according to the internet resources of photos and relative descriptions. The result can help the patternmaker pay more attention to defects and choose proper quality materials.

3. The database of DTS with corresponding fit scales has been established. Each pattern was simulated as DTJ by Clo3D for fit evaluation. The grade scale reference and surface dividing method were adopted for a reliable subjective evaluation.

4. A matrix model of pattern for misfit detection was developed. Meanwhile, a new database and corresponding feature locators criteria of geometric mode for sleeve-armhole assembly fit evaluation have been developed. The results could help patternmakers recognize and amend the potential misfit defects. Based on these results, a database was derived to recommend the parametric pattern range of sleeve for the corresponding armhole. The automatic fit evaluation and prediction module for sleeve-armhole assembly were also developed to facilitate the result. With this module, enter the required parameters' values, and corresponding answers will automatically return.

5. The five principles were proposed, which could predict the whole sleeve fit and several related indexes. Following the principles, obtaining and optimizing the corresponding fit prediction criteria, revealing the correlation and linear regression relationship between pattern and DTS, and verifying the fit prediction result.

6. Two algorithms of image grayscale for fit evaluation have been developed, one for fit evaluation and the other for defect identification. The grayscale criteria for the sleeve fit evaluation were developed. The relationship between subjective and objective indicators was revealed by linear regression.

7. The correctness and goodness of the result were explored by three direction of ergonomic, DTS alternative real, and series validation. The result showed the satisfaction and feasibility, which could be predicted the sleeve fit before sewing.

8. It is recommended to utilize the results in the following aspects:

- in the educational process of higher and secondary educational institutions in the preparation of clothing designers or pattern makers, including added professional education;

- as theoretical content of women's jacket design, pattern making, simulation developing, and accordance fit prediction, especially for the sleeve part;

- to develop the Russia national technology initiative "FashionNet";

- to develop new modules or algorithms of CAD for fit evaluation and prediction.

RECOMMENDATIONS, PERSPECTIVES OF FUTURE RESEARCH

1. Compared with other garment parts, sleeves have their uniqueness, which was more affected by pattern block and tailoring. For this reason, the constructed DTJ needs to require a more consistent physical engine close to the real environment. Meanwhile, more details need to be considered, such as detail materials properties, lining and interlining, thread tension, detail body size modification, illumination, image contrast etc. However, the existing simulation software could not meet the demand for virtual simulation. For the above aspects, virtual reality simulation technology will be iteratively updated in the future.

2. In the present research, to avoid the potential impact of wearing the garment in multiple layers, the simulation and fit evaluation were based on scenarios where the women's jackets were worn naked avatar or Dummy: without underwear, without a shirt, and in a static standing position. In the future, additional scenarios (wearing underwear or a shirt, active posture) will be included to make the DTJ system more closely with the daily situation.

3. The database and modules obtained from this study will be further trained and tested to refine the computer-aided automated CWJ fit prediction system. These results can be extended as the protocol to the remaining parts of women's jacket or other clothing categories, which will also be implemented in future work.

LIST OF ABERRATIONS

Δr	-	Possible transforming range
ABP	-	Most back point of armhole
AFP	-	Most front point of armhole
AG	-	Arm girth
AHD	-	Armhole depth (pattern measurement)
AHD_B	-	Armhole depth (body measurement)
AHL	-	Armhole length
AHW	-	Armhole width
AL	-	Arm length
Ap	-	Appropriate fit
ASG	-	Armscye girth (body measurement)
Aws	-	Average of weighted subjective score
BCH	-	Cap height of body
BG	-	Bust girth
B_i	-	The i-th pixel value of proper boundaries of fit belt
B_{il}	-	Lower boundary of fit belt
B_{it}	-	Top boundary of fit belt
BL	-	Back length
bnp	-	Back neck point
BW	-	Back width
BW_p	-	Bust width of pattern
C	-	Crosswise
CAD	-	Computer-aided design
CG	-	Chest girth
CW	-	Chest width
CWJ	-	Classic women's jacket
d	-	Absolute error margin
DD	-	Dev and Dev_{std}
Dev	-	deviation distance
Dev_{std}	-	standard deviation of grayscale
D_i	-	The i-th pixel value of the deformed sleeve at different views
DL	-	Deformation level
DT	-	Digital twins
DTJ	-	Digital twins of jacket
DTS	-	Digital twins of sleeve
E_{AD}	-	Ease of armhole depth
E_{AG}	-	Ease of arm girth
E_{AGAP}	-	Ease of arm girth across armpit point
Eb	-	Elbow blend
E_{BG}	-	Ease of bust girth
E_{BL}	-	Ease of back length
E_{BNC}	-	Ease of back neck width

E_{BSFS}	-	Ease of back neck height
E_{BW}	-	Ease of back width
E_{CW}	-	Ease of chest width
E_{EG}	-	Ease of elbow girth
EG	-	Elbow girth
E_{HB}	-	Ease of half bust
E_{HGH}	-	Ease of half hip girth
EL	-	Elbow length
E_{RJC}	-	Ease of real jacket in comfortable scale
E_{SBW}	-	Ease allowance to the distance of SNP-BP-waist line
ESD	-	Elbow seam distance
E_{SJP}	-	Ease of virtual simulated jacket with the perfect fit
E_{WG}	-	Ease of wrist girth
E_{WGH}	-	Ease of half waist girth
FE	-	Front edge
FF	-	Front fold
F_{fF}	-	Front fold on front view
FSD	-	Front seam distance
Go	-	Grayscale offset value
Go_w	-	Weighted grayscale offset value
I_P	-	Index of patterns
I_v	-	Index of the virtual sleeve
L	-	Lengthwise
l1	-	Distance between down sleeve cap curve and SCW - elbow seam across
l2	-	Distance between down sleeve cap curve and SCW - front seam across
m_{r}	-	Confidence interval
n	-	Numbers
N	-	Number of total pixels
NG	-	Neck girth
P Sleeve Δ	-	Percentage of sleeve Δ
Pe	-	Perfect fit
P_i	-	The i-th pixel of perfect fit sleeve value
pl	-	Probability level
Po	-	Poor fit
Ps	-	Pressure sensor point
Sa	-	Sleeve of avatar (sleeve simulate on full arm avatar)
SE	-	Top point of sleeve elbow seam
Sb	-	Sleeve blend
SCH	-	Sleeve cap height
SCL	-	Sleeve cap curvy length
SCW	-	Sleeve cap width
Sd	-	Sleeve of dummy (sleeve simulate on arm partly removed avatar)
SD	-	Standard deviation

SF	-	Top point of sleeve front seam
SHW	-	Shoulder width
S_i	-	The i-th pixel of grayscale plot value
SL	-	Shoulder line
Sleeve Δ	-	Distance between sleeve cap curve and armhole length
snp	-	Side neck point
Sp	-	Sleeve pattern
sp	-	Shoulder point
Ss	-	Sleeve sloping
ST	-	Top point of sleeve cap
S_{wB}	-	Sleeve width on back view
S_{wF}	-	Sleeve width on front view
S_{wI}	-	Sleeve width on inner view
S_{wP}	-	Sleeve width on profile view
t	-	Student-criteria
TPS	-	Two pieces sleeve
WBF	-	Width of bodice pattern at bust level
WG	-	Wrist girth
$\overline{x}$	-	Average value
Z	-	Standard normal variate

LIST OF TABLES

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APPENDIX A

Survey of contemporary classic jacket defect distribution

(1) The example of defect wrinkles

Fig. A.1 shows the example of misfit defect identification with arrows. During this process, the side with more defects (left or right) was selected.

Figure A.1 - Example of misfit defects identification

(2) Detail of each jacket defect destitution

Fig. A.2 shows the surface of the garment is segmented into 19 areas from A-R.

The Table A.1 shows the detail of each jacket defect destitution, “1” represents this area exist wrinkles, “blank” represent this area do not identify wrinkles. “A-R” represent each divide area, “T” represents total defects on the bodice of three views, “U” represents the total defect on the sleeve of three views.

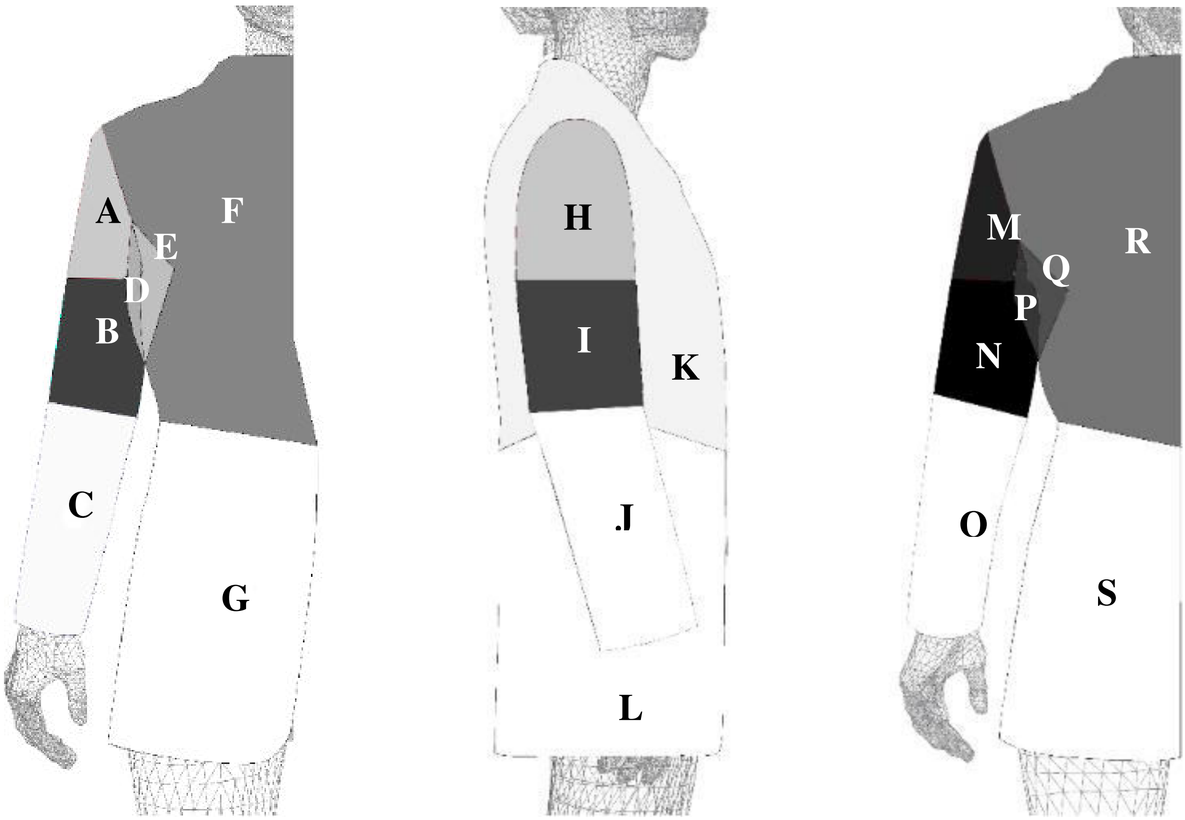


Figure A.2 - Example of jacket surface segment

Table A.1 - Detail of each jacket defect destitution

No.	Sample name	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	**T**	**U**
1	8 By1		1							1								1			3	2
2	Alexandermcqueen 1		1				1			1		1			1			1	1		7	3
3	Alexandermcqueen 2		1							1					1			1			4	3
4	Alexandermcqueen 3		1	1						1								1			4	3
5	Alexandermcqueen 4						1							1			1	1			4	2
6	Alexandermcqueen 5						1														1	0
7	Alexandermcqueen 6		1				1							1							3	2
8	Alexandermcqueen 7	1	1		1	1				1				1	1		1				8	7
9	Alexandermcqueen 8					1								1				1			3	1
10	Alexandermcqueen 9	1	1						1	1				1	1						6	6
11	Alexandermcqueen 10				1	1			1					1			1				5	4
12	Balenciaga 1								1					1	1				1		4	3
13	Balmain 1				1	1												1	1		4	1
14	Balmain 2		1											1					1		3	2
15	Balmain 3	1												1							2	2
16	Balmain 4						1		1	1					1			1	1		6	3
17	Balmain 5									1					1						2	2
18	Baum Und 1									1					1						2	2
19	Bcbg Max Azria 1		1							1					1		1		1		5	4
20	Benetton 1						1												1		2	0
21	Bottegaveneta 1		1				1			1					1						4	3
22	Burberry 1					1								1			1				3	2

23	Burberry 2		1				1			1					1				1		5	3
24	Burberry 3		1			1			1	1				1	1		1				7	6
25	Burberry 4	1	1						1	1				1	1		1				7	7
26	Burberry 5		1						1					1	1				1		5	4
27	Burberry 6													1							1	1
28	Burberry 7						1			1					1		1		1		5	3
29	Carolina Herrera 1						1							1			1	1			4	2
30	Chiu Chui 1						1							1	1		1		1		5	3
31	D&G 1						1								1				1		3	1
32	D&G 2		1				1			1					1				1		5	3
33	D&G 3		1							1					1		1	1			5	4
34	D&G 4								1	1				1	1		1				5	5
35	D&G5						1								1		1		1		4	2
36	Dazzle 1		1							1				1	1		1				5	5
37	Dior 1													1			1				2	2
38	Dior 2		1				1			1				1	1				1		6	4
39	Donna Karan 1					1				1				1	1						4	3
40	E Becky 1		1							1				1	1						4	4
41	E&P 1						1		1					1	1		1				5	4
42	Eachway 1													1	1				1		3	2
43	Eland 1						1							1	1			1			4	2
44	Eland 2		1				1			1				1	1			1			6	4
45	Ellassay 1		1							1					1			1	1		5	3
46	Ellassay 2		1				1			1					1			1	1		6	3
47	Ellassay 3		1						1	1					1			1			5	4
48	Ellassay 4		1			1	1			1				1	1		1	1	1		9	5
49	Ellassay 5	1	1			1				1				1	1		1				7	6
50	Ellassay 1																				0	0
51	Ellassay 2		1						1	1				1	1			1			6	5
52	Ellassay 3		1							1				1	1						4	4
53	Emiliopucci 1	1					1											1			3	1
54	Emiliopucci 2		1		1					1				1	1						5	5
55	Emiliopucci 4													1			1				2	2
56	Emiliopucci3		1						1					1	1						4	4
57	Emporio Armani 1		1							1				1	1		1				5	5
58	Emporio Armani 2		1				1											1	1		4	1
59	Emporio Armani 3		1							1				1	1				1		5	4
60	Emporio Armani 4		1												1			1			3	2
61	Emporio Armani 5									1				1			1				3	3
62	Emporio Armani 6									1											1	1
63	Emporio Armani 7		1		1					1					1						4	4
64	Emporio Armani 8		1							1				1	1			1			5	4
65	Emporio Armani 9		1														1				2	2
66	Emporio Armani 10									1					1		1	1	1		5	3
67	Emporio Armani 11																				0	0
68	Emporio Armani 12														1				1		2	1
69	Emporio Armani 13														1		1				2	2
70	Emporio Armani 14				1												1	1			3	2
71	Emporio Armani 15																1		1		2	1

72	Emporio Armani 16													1							1	1
73	Emporio Armani 17													1							1	1
74	Emu 1				1									1	1			1			4	3
75	Emu 2		1				1			1				1	1				1		6	4
76	Ep Yaying 1				1		1							1	1		1		1		6	4
77	Ep Yaying 2																				0	0
78	Ep Yaying 3						1											1	1		3	0
79	Ep Yaying 4				1		1										1				3	2
80	Ep Yaying 5	1					1		1	1				1	1				1		7	5
81	Ep Yaying 6						1								1			1	1		4	1
82	Escada 1														1		1	1			3	2
83	Escada 2					1				1									1		3	1
84	Escada 3					1			1					1	1						4	3
85	Escada 4	1	1			1				1				1	1		1	1	1		9	6
86	Escada 5		1						1					1							3	3
87	Escada 6		1			1	1			1				1	1						6	4
88	Escada 7	1	1						1					1	1			1			6	5
89	Escada 8		1				1			1							1	1			5	3
90	Escada 9				1										1		1				3	3
91	Escada10		1		1				1					1			1				5	5
92	Eva Ouxiu 1						1					1					1		1		4	1
93	Eva Ouxiu 2						1			1				1			1				4	3
94	Fairy Fiar 1					1								1	1			1			4	2
95	Fendi 1		1							1								1			3	2
96	Fendi 2		1												1		1	1			4	3
97	Ferragamo 1	1	1		1	1			1	1				1	1			1	1		10	7
98	G2000 1									1				1	1						3	3
99	G2000 2									1					1		1	1			4	3
100	Ga 1	1	1				1		1						1			1	1		7	4
101	Ga 2		1							1					1		1				4	4
102	Galliano 1									1				1	1		1				4	4
103	Giffen Good 1	1					1			1				1	1		1	1			7	5
104	Giffen Good 2	1							1					1			1				4	4
105	Giffen Good 3		1											1	1		1				4	4
106	Giorgio Armani 1		1				1		1					1	1		1				6	5
107	Giorgio Armani 2		1							1					1		1	1			5	4
108	Giorgio Armani 3					1									1						2	1
109	Giorgio Armani 4		1									1					1				3	2
110	Giorgio Armani 5	1	1						1									1			4	3
111	Giorgio Armani 6		1				1			1				1	1		1		1		7	5
112	Giorgio Armani 7									1							1				2	2
113	Giorgio Armani 8									1					1						2	2
114	Girdear 1				1					1					1		1				4	4
115	Girdear 2								1					1	1						3	3
116	Givenchy 1					1												1	1		3	0
117	Givenchy 2													1	1			1			3	2
118	Givenchy 3	1			1													1			3	2
119	Givenchy 4	1	1		1				1	1											5	5

120	Givenchy 5				1					1				1	1		1				5	5
121	Givenchy 6													1			1				2	2
122	Gloria 1					1	1			1				1			1	1	1		7	3
123	G-Star 1		1							1					1						3	3
124	Gucci 1					1	1		1	1				1	1			1			7	4
125	Gucci 2													1			1				2	2
126	Gucci 3	1					1														2	1
127	Gucci 4																	1	1		2	0
128	Gucci 5				1		1										1	1	1		5	2
129	Gucci 6	1																1			2	1
130	Gucci 7					1				1											2	1
131	Gucci 8				1				1					1				1			4	3
132	Gucci 9		1			1	1			1					1		1	1			7	4
133	Gucci 10																				0	0
134	Gucci 11			1	1				1	1				1	1		1				7	7
135	Gucci 12																				0	0
136	Gucci 13																1				1	1
137	Gucci 14						1							1	1		1		1		5	3
138	Gucci 15																	1			1	0
139	Guess Marciano 1													1				1	1		3	1
140	Honrn 1					1												1			2	0
141	Hopeshow 1		1							1				1			1				4	4
142	Hopeshow 2		1				1			1					1			1	1		6	3
143	Hopeshow 3		1						1	1				1	1		1	1			7	6
144	Hopeshow 4		1		1					1				1	1						5	5
145	Hugoboss 1				1												1	1			3	2
146	Hugoboss 2																				0	0
147	Hugoboss 3		1				1								1			1	1		5	2
148	Hugoboss 4																				0	0
149	Hugoboss 5		1							1					1		1	1			5	4
150	Hugoboss 6		1												1			1			3	2
151	Hugoboss 7													1				1			2	1
152	Hugoboss8																				0	0
153	J. Crew 1				1									1	1		1				4	4
154	Jia Fen 1																1				1	1
155	Jia Fen 2		1																1		2	1
156	Joseph 1		1		1		1			1				1	1		1	1	1		9	6
157	Joseph 2														1		1				2	2
158	Juzui 1						1							1				1			3	1
159	Juzui 2									1				1	1			1	1		5	3
160	Kabuyi 1		1						1					1	1		1				5	5
161	Kenzo 1						1		1					1			1				4	3
162	Koton 1				1													1			2	1
163	Koton 2		1	1													1				3	3
164	La Chapelle 1		1							1				1	1		1				5	5
165	Lan Di 1						1										1	1	1		4	1
166	Lan Di 2		1				1			1					1		1	1			6	4
167	Lan Di 3						1		1					1	1		1	1			6	4
168	Lan Di 4													1	1		1				3	3

169	Lan Di 5													1	1						2	2
170	Lan Di 6									1				1	1			1			4	3
171	Lan Di 7					1								1	1			1			4	2
172	Lan Di 8		1				1							1	1			1			5	3
173	Lan Di 9						1							1	1		1				4	3
174	Lan Di 10				1									1	1				1		4	3
175	Lan Di 11	1								1				1	1		1		1		6	5
176	Lang Zi 1		1				1			1				1	1			1			6	4
177	Lang Zi 2				1									1	1		1				4	4
178	Lang Zi 3				1										1		1	1			4	3
179	Lang Zi 4					1	1			1				1	1			1	1		7	3
180	Lang Zi 5		1							1				1	1				1		5	4
181	Lang Zi 6		1				1			1				1	1			1			6	4
182	Lang Zi 7				1									1							2	2
183	Lang Zi 8					1								1			1		1		4	2
184	Lang Zi 9						1										1		1		3	1
185	Lang Zi 10													1			1				2	2
186	Lang Zi 11													1				1	1		3	1
187	Lang Zi 12				1									1	1			1	1		5	3
188	Lang Zi 13		1				1			1				1	1		1	1			7	5
189	Lily 1		1		1	1				1								1			5	3
190	Lily 2		1		1					1					1		1	1			6	5
191	Lily 3		1																		1	1
192	Louisvuitton 1		1															1			2	1
193	Louisvuitton 2																1				1	1
194	Louisvuitton 3																				0	0
195	Louisvuitton 4		1				1		1					1			1		1		6	4
196	Louisvuitton 5		1														1				2	2
197	Maje 1		1				1			1					1		1				5	4
198	Marisfrolg 1													1	1			1			3	2
199	Marisfrolg 2		1				1			1				1	1		1		1		7	5
200	Max Mara 1		1		1					1							1				4	4
201	Max Mara 2	1				1	1		1					1	1			1	1		8	4
202	Miumiu 1		1		1					1								1			4	3
203	Moissac 1				1	1									1		1	1			5	3
204	Moschino 1				1										1		1				3	3
205	Moschino 2				1	1				1					1			1			5	3
206	Next 1		1							1				1	1		1	1			6	5
207	Next 2	1	1							1				1			1	1			6	5
208	Next 3		1			1								1	1			1			5	3
209	Next 4		1							1				1	1			1			5	4
210	Next 5																	1			1	0
211	Next 6		1														1				2	2
212	Next 7						1		1					1	1		1				5	4
213	Next 8		1			1	1			1				1	1		1		1		8	5
214	Nina Ricci 1		1				1			1							1	1			5	3
215	Ochirly 1		1			1				1					1		1	1	1		7	4
216	Ochirly 2		1			1				1					1		1				5	4

217	Ochirly 3		1							1				1	1			1			5	4
218	Ochirly 4	1	1				1			1				1				1			6	4
219	Ochirly 5				1												1				2	2
220	Omnialuo 1				1	1								1			1	1			5	3
221	Omnialuo 2	1	1							1				1	1		1				6	6
222	Philipp Plein 1				1									1	1			1	1		5	3
223	Pinko 1		1							1					1						3	3
224	Pinko 2		1						1					1	1			1			5	4
225	Pinko 3		1				1			1					1		1	1	1		7	4
226	Ports 1				1												1		1		3	2
227	Ports 2	1	1							1				1	1			1	1		7	5
228	Ports 3		1				1			1				1	1			1	1		7	4
229	Ralphlauren 1									1				1	1						3	3
230	Ralphlauren 2	1												1					1		3	2
231	Ralphlauren 3									1				1	1						3	3
232	Ralphlauren 4		1							1					1		1	1			5	4
233	Ralphlauren 5													1			1	1	1		4	2
234	Ralphlauren 6	1	1							1					1		1				5	5
235	Ralphlauren 7	1	1				1			1		1		1	1		1	1	1		10	6
236	Reiss 1				1	1											1	1			4	2
237	Reiss 2						1								1		1	1	1		5	2
238	Rick Owens 1						1												1		2	0
239	Roberto Cavalli 1						1								1		1		1		4	2
240	Roberto Cavalli 2				1					1				1	1		1		1		6	5
241	Roeyshouse 1		1			1				1				1	1			1	1		7	4
242	Roeyshouse 2				1										1			1			3	2
243	Roeyshouse 3						1								1		1	1	1		5	2
244	Roeyshouse 4		1		1									1	1			1			5	4
245	Roeyshouse 5						1							1				1			3	1
246	Romon 1		1							1					1		1	1			5	4
247	Romon 2		1							1				1	1		1				5	5
248	Romon 3		1							1							1	1			4	3
249	Romon 4		1		1					1					1				1		5	4
250	Romon 5														1		1		1		3	2
251	Romon 6					1									1		1		1		4	2
252	Romon 7	1	1				1			1					1		1	1			7	5
253	s Deer 1																1	1			2	1
254	s Deer 2				1												1		1		3	2
255	Samsoe & Samsoe 1		1							1					1				1		4	3
256	Sandro 1		1		1	1				1				1	1		1	1			8	6
257	Se Fon 1	1	1		1	1				1		1		1	1		1		1		10	7
258	Season Wind 1		1				1			1				1	1			1	1		7	4
259	Senkni 1						1							1	1		1		1		5	3
260	Senkni 2	1	1							1				1	1		1	1			7	6
261	Senkni 3		1											1							2	2
262	Sheng Yuzhu 1		1							1					1						3	3
263	Shiatzy Chen 1						1								1		1				3	2
264	Show Long 1		1							1				1	1		1				5	5
265	Show Long 2					1	1			1				1	1				1		6	3

266	Sisley 1						1							1			1				3	2
267	Som 1				1									1			1		1		4	3
268	Sunview 1	1	1		1		1		1	1				1	1		1	1	1		11	8
269	Teenieweenie 1	1					1			1				1	1				1		6	4
270	Teenieweenie 2		1							1				1	1		1		1		6	5
271	Thom Browne 1		1							1				1	1				1		5	4
272	Thom Browne 2					1									1		1	1			4	2
273	Thom Browne 3				1										1		1	1			4	3
274	Thom Browne 4		1															1			2	1
275	Thom Browne 5		1		1										1			1			4	3
276	Three Color 1	1	1				1		1	1		1		1	1		1	1	1		11	7
277	Three Color 2		1				1			1				1	1		1				6	5
278	Tomford 1		1											1			1				3	3
279	Trussardi 1	1	1				1		1					1	1		1				7	6
280	Uniqlo 1		1							1					1				1		4	3
281	V Grass 1		1		1					1					1		1	1			6	5
282	Valentino 1		1			1								1			1				4	3
283	Vero Moda 1	1				1								1	1				1		5	3
284	Whistles 1													1							1	1
285	White Collar 1		1											1	1						3	3
286	Xii Basket 1		1		1					1				1	1		1		1		7	6
287	Xii Basket 2						1		1					1			1		1		5	3
288	Xuege 1						1										1		1		3	1
289	Yiner 1	1	1				1			1				1					1		6	4
290	Yiner 2		1		1					1				1	1		1				6	6
291	Yiner 3		1							1				1	1				1		5	4
292	Yiner 4	1					1			1				1	1		1				6	5
293	Yiner 5	1	1		1		1		1	1				1	1			1	1		10	7
294	Yiner 6														1			1	1		3	1
295	Yiner 7					1								1			1				3	2
296	Yiner 8		1							1				1	1			1			5	4
297	Youngor 1				1												1	1			3	2
298	Youngor 2				1	1								1	1		1				5	4
299	Youngor 3	1				1			1					1	1		1		1		7	5
300	Youngor 4		1												1			1	1		4	2
301	Z Dorzi 1		1				1			1				1	1				1		6	4
302	Zara 1				1	1				1					1		1	1			6	4

APPENDIX B

Survey of contemporary jacket shell material composition

Table B.1 - Detail of each jacket shell material composition

No.	Sample name	Material composition
1	8 By1	63% Wool, 25% Silk, 12% Polyamide
2	Alexandermcqueen 1	100% silk
3	Alexandermcqueen 2	86% Wool, 14% Silk
4	Alexandermcqueen 3	100% silk
5	Alexandermcqueen 4	100% wool
6	Alexandermcqueen 5	77%wool,23%silk
7	Alexandermcqueen 6	54% silk and 46% wool
8	Alexandermcqueen 7	100% silk
9	Alexandermcqueen 8	63% Wool, 25% Silk, 12% Polyamide
10	Alexandermcqueen 9	66% cotton, 34% wool
11	Alexandermcqueen 10	100% wool
12	Balenciaga 1	100% wool
13	Balmain 1	100% wool
14	Balmain 2	100% wool
15	Balmain 3	100% virgin wool
16	Balmain 4	100% Mulberry silk
17	Balmain 5	100% wool
18	Baum Und 1	100% wool
19	Bcbg Max Azria 1	98% cotton, 2% elastane (thick velvet)
20	Benetton 1	70% Polyester 9% Silk 9% Acrylic 7% Metallic Polyester 5% Polyamide
21	Bottegaveneta 1	100% wool
22	Burberry 1	98%WOOL 2%ELASTANE
23	Burberry 2	98%fleece wool,2%elastane
24	Burberry 3	66% Viscose, 32% Cupro, 2% Elastane
25	Burberry 4	60% cotton and 40% linen
26	Burberry 5	60% cotton and 40% wool
27	Burberry 6	40% viscose, 26% wool, 21% linen, 13% polyamide.
28	Burberry 7	100% wool
29	Carolina Herrera 1	100% Mulberry silk
30	Chiu Chui 1	polyester96.00%Spandex4.00%
31	D&G 1	72% Polyester, 18% Viscose, 10% Metallic Fiber
32	D&G 2	100% wool
33	D&G 3	45% wool, 28% Tussah silk, 18% cotton, 9% Mulberry silk
34	D&G 4	100% wool
35	D&G5	100% wool
36	Dazzle 1	100% wool
37	Dior 1	98% Wool 2% Viscose
38	Dior 2	71% cotton and 29% polyester
39	Donna Karan 1	100% virgin wool
40	E Becky 1	polyester92%Spandex8%
41	E&P 1	82% polyester 12% silk 3% metallized fiber 3% polyamide
42	Eachway 1	polyester78.1%Viscose16.3%Spandex5.6%
43	Eland 1	73% Polyester, 17% Silk, 10% Polyamide
44	Eland 2	83% cotton, 13% polyester and 4% elastane
45	Ellassay 1	Wool50.6%Viscose28.1%polyester17.9%Spandex3.4%
46	Ellassay 2	Wool97.7%Viscose2.3%
47	Ellassay 3	polyester78.2%Viscose19.3%Spandex2.5%
48	Ellassay 4	Wool81.8%polyester17.6%Spandex0.6%
49	Ellassay 5	polyester64.9%Viscose33.6%Spandex1.5%

50	Ellassay 1	96% Polyester，3% wool，1% tencel(viscose)
51	Ellassay 2	98% Virgin Wool, 2% Elastane
52	Ellassay 3	99% Virgin Wool 1% Elastane
53	Emiliopucci 1	98% Virgin Wool, 2% Elastane
54	Emiliopucci 2	97% viscose and 3% elastane
55	Emiliopucci 4	75% viscose, 25% mohair
56	Emiliopucci3	97% viscose and 3% elastane
57	Emporio Armani 1	100% wool
58	Emporio Armani 2	100% silk
59	Emporio Armani 3	100% cotton
60	Emporio Armani 4	72% cotton, 26% modal and 2% elastane
61	Emporio Armani 5	87% Polyester 9% Wool 4% Viscose
62	Emporio Armani 6	53% POLYESTER 43% WOOL 4% ELASTANE
63	Emporio Armani 7	54% Wool 43% Polyester 3% Elastane
64	Emporio Armani 8	100% virgin wool
65	Emporio Armani 9	100% virgin wool
66	Emporio Armani 10	100% virgin wool
67	Emporio Armani 11	5% Spandex 95% Virgin wool
68	Emporio Armani 12	100% modal
69	Emporio Armani 13	63% Acrylic, 21% Wool, 16% Polyester
70	Emporio Armani 14	95.5%Wool 2.5%polyester 2.5%Elastane
71	Emporio Armani 15	100% modal
72	Emporio Armani 16	57% Acetate 1% Spandex 2% Nylon 40% Polyester
73	Emporio Armani 17	100% polyester
74	Emu 1	polyester77.7%Viscose16.6%Spandex5.7%
75	Emu 2	polyester86.5%Viscose13.5%
76	Ep Yaying 1	polyester100%
77	Ep Yaying 2	49.5%Wool37.6%acrylic8.7%polyester2.8%Other
78	Ep Yaying 3	63.4% tri-acetate36.6%polyester
79	Ep Yaying 4	75.1%Flax24.9%polyester
80	Ep Yaying 5	polyester75.7%Flax11.3%Viscose10.5%Spandex2.5%
81	Ep Yaying 6	tri-acetate66.7%polyester33.3%
82	Escada 1	95%Wool 5%polyester
83	Escada 2	92% polyester, 8% polyurethane
84	Escada 3	98% virgin wool, 2% elastane
85	Escada 4	100% Virgin wool
86	Escada 5	95%VISCOSE 5%ELASTANE
87	Escada 6	47% Wool 45% Polyester 5% Nylon 3%
88	Escada 7	100% silk
89	Escada 8	50%Wool 50%Polyester
90	Escada 9	95%Wool 5%Viscose
91	Escada10	100% cotton
92	Eva Ouxiu 1	100% viscose
93	Eva Ouxiu 2	98% virgin wool 2% elastane
94	Fairy Fiar 1	polyester100%
95	Fendi 1	89% Polyester, 11% Polyurethane
96	Fendi 2	50% Acetate, 50% Viscose
97	Ferragamo 1	40% Wool, 29% Polyester, 28% Viscose, 3% Elastane
98	G2000 1	51% wool and 49% silk
99	G2000 2	100% wool
100	Ga 1	51% wool, 49% silk
101	Ga 2	96% Virgin Wool, 4% Elastane
102	Galliano 1	Wool, polyester
103	Giffen Good 1	Viscose61%Polyamide）32.2%Spandex6.8%
104	Giffen Good 2	polyester98%Spandex2%
105	Giffen Good 3	polyester79.8%Viscose18.7%Spandex1.5%
106	Giorgio Armani 1	100% wool
107	Giorgio Armani 2	98% virgin wool 2% elastane

108	Giorgio Armani 3	100% silk
109	Giorgio Armani 4	98% virgin wool 2% elastane
110	Giorgio Armani 5	57% Polyester, 40% Cotton, 3% Elastane
111	Giorgio Armani 6	48%Wool 47%polyester 5%other
112	Giorgio Armani 7	50% cotton 49% viscose 1% elastane
113	Giorgio Armani 8	100% silk
114	Girdear 1	67% viscose 28% polyamide 5% elastane
115	Girdear 2	96% virgin wool, 4% elastane
116	Givenchy 1	84% Acetate, 16% Viscose
117	Givenchy 2	50% Viscose, 47% Acetate, 3% Elastane
118	Givenchy 3	70% Acetate, 30% Viscose (Crepe)
119	Givenchy 4	100% wool
120	Givenchy 5	70% Acetate, 30% Viscose
121	Givenchy 6	91% Viscose, 7% Polyamide, 2% Elastane
122	Gloria 1	100% polyester
123	G-Star 1	73% viscose 23% silk 4% elastane
124	Gucci 1	100% Virgin Wool
125	Gucci 2	99% Wool 1% Viscose
126	Gucci 3	99% Virgin Wool, 1% Elastane
127	Gucci 4	54% Viscose, 46% Acetate
128	Gucci 5	58% Cotton, 42% Polyester
129	Gucci 6	63% Acetate, 37% Viscose
130	Gucci 7	63% Wool, 25% Silk, 12% Polyamide
131	Gucci 8	100% polyester
132	Gucci 9	72% cotton 26% virgin wool 2% polyamide
133	Gucci 10	wool tweed
134	Gucci 11	56% Cotton, 40% Viscose, 4% Elastane
135	Gucci 12	wool
136	Gucci 13	100% wool
137	Gucci 14	36% Polyester, 32% Virgin wool, 31% Polyamid, 1% Elastane
138	Gucci 15	63% Wool, 25% Silk, 12% Polyamide
139	Guess Marciano 1	71% triacetate, 29% polyester
140	Honrn 1	tri-acetate65.2%polyester34.8%
141	Hopeshow 1	60% tri-acetate; 40% polyester
142	Hopeshow 2	83% Viscose-Rayon, 13% Virgin wool, 4% Elastane-Spandex
143	Hopeshow 3	96% Virgin wool, 4% Elastane
144	Hopeshow 4	53%Polyester 43%Wool 4%Elastane
145	Hugoboss 1	96% Virgin wool, 4% Elastane
146	Hugoboss 2	45% polyester, 27% acrylic, 15% wool, 13% cotton
147	Hugoboss 3	66% viscose; 34% polyester
148	Hugoboss 4	100% wool
149	Hugoboss 5	50% Polyester, 43% Virgin wool, 4% Elastane, 3% Cotton
150	Hugoboss 6	64% Polyester, 34% Viscose, 2% Elastane
151	Hugoboss 7	100% Flax
152	Hugoboss8	100% wool tweed
153	J. Crew 1	97%Polyammide 3%Elastane
154	Jia Fen 1	66.4%Wool，33.6%polyester
155	Jia Fen 2	64%Wool24%polyester9%Polyamide3%Other
156	Joseph 1	69% Polyester, 30% Viscose, 1% Elastane
157	Joseph 2	45% Cotton 31% Polyester 15% Acrylic 9% Wool
158	Juzui 1	67%Viscose 28%Polyamide 28%Polyammide 5%Elastane
159	Juzui 2	61% Polyester, 26% Viscose, 7% Cotton, 6% Elastane,
160	Kabuyi 1	64%polyester33%Viscose3%Spandex
161	Kenzo 1	68% Polyester, 29% Viscose, 3% Elastane
162	Koton 1	80% Polyester, 14% Viscose, 6% Elastane
163	Koton 2	64%polyester,34%viscose2%elastane
164	La Chapelle 1	polyester97.1%Spandex2.9%
165	Lan Di 1	Viscose55.4%polyester36.4%Polyamide8.2%

166	Lan Di 2	polyester94.4%Spandex5.6%
167	Lan Di 3	polyester78.7%Viscose21.3%
168	Lan Di 4	polyester100%
169	Lan Di 5	polyester59.4%Cotton30.4%Viscose8.1%Polyamide2.1%
170	Lan Di 6	polyester61.2%Viscose38.8%
171	Lan Di 7	tri-acetate70.2%polyester29.8%
172	Lan Di 8	acetate70.9%polyester29.1%
173	Lan Di 9	acetate65.4%polyester34.6%
174	Lan Di 10	polyester92.5%Spandex4.3%Other3.2%
175	Lan Di 11	Silk91.3%Spandex8.7%
176	Lang Zi 1	polyester92.7%Spandex7.3%
177	Lang Zi 2	polyester100%
178	Lang Zi 3	polyester80%Viscose18%Spandex2%
179	Lang Zi 4	Cotton59.3%polyester35.4%Spandex5.3%
180	Lang Zi 5	polyester69%Viscose29%Spandex2%
181	Lang Zi 6	polyester100%
182	Lang Zi 7	polyester100%
183	Lang Zi 8	polyester95.8%Spandex4.2%
184	Lang Zi 9	tri-acetate62.2%polyester37.8%
185	Lang Zi 10	Wool96.1%Spandex3.9%
186	Lang Zi 11	polyester61.0%acetate39%
187	Lang Zi 12	polyester100%
188	Lang Zi 13	polyester83.9%Viscose13.1%Spandex3.0%
189	Lily 1	53.5%linen 45.4%Wool 1.3%elastane
190	Lily 2	98% Cotton 2% Elastane
191	Lily 3	68% polyester, 29% viscose, 3% elastane
192	Louisvuitton 1	49% Cotton, 29% Wool, 20% Polyester, 2% Other fibers
193	Louisvuitton 2	100% virgin wool
194	Louisvuitton 3	100% virgin wool
195	Louisvuitton 4	44% rayon, 43% polyester, 11% cotton twill, 2% spandex
196	Louisvuitton 5	100% wool
197	Maje 1	recycled wool, viscose, polyamide
198	Marisfrolg 1	100% wool
199	Marisfrolg 2	98% cotton, 2% elastane
200	Max Mara 1	52% Cotton 45% Polyamide 3% Elastane.
201	Max Mara 2	62% Acetate, 35% Polyamide, 3% Elastane
202	Miumiu 1	viscose, nylon, wool, cotton, cashmere
203	Moissac 1	64.1% tri-acetate; 35.9% polyester
204	Moschino 1	70.0%polyester 28.6%Wool 1.4%elastane
205	Moschino 2	73.2% tri-acetate; 26.8% polyester
206	Next 1	40.9%loycell 37.7%polyester 11.5%Wool 9.9%Cotton
207	Next 2	70% Viscose, 30% Wool
208	Next 3	56.7%viscose 41.6%polyester 1.7%elastane
209	Next 4	viscose, nylon, elastane.
210	Next 5	65% wool, 35% silk
211	Next 6	100% wool
212	Next 7	64% Viscose 26% Polyester 8% Acrylic 2%
213	Next 8	100% cotton
214	Nina Ricci 1	polyester, viscose, elastane.
215	Ochirly 1	94.5%polyester,4.5%viscose
216	Ochirly 2	68.3%polyester 30.2%viscose 1.5%elastane
217	Ochirly 3	66.8%polyester 33.2%viscose
218	Ochirly 4	100% polyester
219	Ochirly 5	51%polyester 49%Wool
220	Omnialuo 1	polyester74.7%Viscose18%Spandex7.3%
221	Omnialuo 2	polyester55%Viscose24%Wool17%Spandex4%
222	Philipp Plein 1	73.3% tri-acetate; 26.7% polyester
223	Pinko 1	98.4%Cotton 1.6%elastane

224	Pinko 2	68% polyester, 29% viscose, 3% elastane
225	Pinko 3	63.4%polyester 34.8%viscose 1.8%elastane
226	Ports 1	100% polyester
227	Ports 2	65% Cotton, 34% Polyester, 1% Elastane
228	Ports 3	84.6%polyamide 11.3%elastane 4.1%polyester
229	Ralphlauren 1	96% WOOL 4% ELASTANE
230	Ralphlauren 2	95% Wool; 5% polyamide
231	Ralphlauren 3	47% Recycled wool, 47% Polyester, 3% Acrylic, 3% Nylon
232	Ralphlauren 4	70%Polyester 28%Viscose 2%Elastane
233	Ralphlauren 5	95%Polyester 5%Elastane
234	Ralphlauren 6	100% polyester
235	Ralphlauren 7	97% Cotton, 3% Elastane
236	Reiss 1	100% polyester
237	Reiss 2	91.6%polyamide 8.4%elastane
238	Rick Owens 1	63% Polyester, 32% Rayon, 5% Spandex
239	Roberto Cavalli 1	100% polyester
240	Roberto Cavalli 2	66.8%Polyester,30.8%viscose,2.4%elasten
241	Roeyshouse 1	polyester70.3%Cotton29.7%
242	Roeyshouse 2	polyester96.2%Spandex3.8%
243	Roeyshouse 3	acetate64.4%polyester34.8%Viscose0.8%
244	Roeyshouse 4	Wool82.9%Viscose17.1%
245	Roeyshouse 5	Wool95.8%Spandex4.2%
246	Romon 1	83%Polyester 15%Viscose 2%Elastane
247	Romon 2	80%Polyester 20%Viscose
248	Romon 3	96%Polyester 4%Elastane
249	Romon 4	100% polyester
250	Romon 5	80% Polyester, 20% Wool
251	Romon 6	51% Cotton, 45% Polyester, 4% Elastane
252	Romon 7	65% Polyester, 33% Viscose, 2% Elastane
253	s Deer 1	polyester100%
254	s Deer 2	polyester100%
255	Samsoe & Samsoe 1	64% Polyester, 34% Viscose, 2% Elastane
256	Sandro 1	63%polyester,32%viscose5%elastane
257	Se Fon 1	polyester65.6%Viscose33.2%Spandex1.2%
258	Season Wind 1	polyester76.3%Viscose21.8%Spandex1.9%
259	Senkni 1	polyester69.4%Viscose29.3%Spandex1.3%
260	Senkni 2	polyester81%Viscose18%Spandex1%
261	Senkni 3	polyester100%
262	Sheng Yuzhu 1	Wool100%
263	Shiatzy Chen 1	98% Polyester, 2% Viscose
264	Show Long 1	polyester79%Viscose13.6%Spandex1.5%Other5.9%
265	Show Long 2	polyester94.5%Spandex5.5%
266	Sisley 1	100% polyester
267	Som 1	polyester75%Viscose18%Spandex7%
268	Sunview 1	Cotton68%Flax30%Spandex2%
269	Teenieweenie 1	76.6%polyester, 19.5%viscose, 3.9%elastane
270	Teenieweenie 2	87.1%Cotton,12.9%loycell
271	Thom Browne 1	63.3%polyester,32.6%viscose4.1%elastane
272	Thom Browne 2	65%Polyester 33%Viscose 2%Elastane
273	Thom Browne 3	64%Viscose 34%Polyester
274	Thom Browne 4	54% Wool 43% Polyester 3% Elastane
275	Thom Browne 5	90.1%polyester9.9%elastane
276	Three Color 1	Wool100%
277	Three Color 2	polyester72%Viscose20%Spandex8%
278	Tomford 1	92% Polyester, 8% Elastane
279	Trussardi 1	54% Viscose, 46% Polyester
280	Uniqlo 1	72.9%Wool 27.1%polyester
281	V Grass 1	polyester94.7%Spandex5.3%

282	Valentino 1	polyester78% Viscose18%Spandex4%
283	Vero Moda 1	polyester71% Viscose21%Spandex8%
284	Whistles 1	87.5%polyester6.7%Acrylic2.8%Wool3.0%Other
285	White Collar 1	Wool50.4%polyester46.8%Other2.8%
286	Xii Basket 1	Viscose68.1%Polyamide28.2%Spandex3.7%
287	Xii Basket 2	polyester66.1%Viscose31.1%Spandex2.8%
288	Xuege 1	68.7%polyester27.7%Viscose3.6%Spandex
289	Yiner 1	tri-acetate70.1%polyester29.9%
290	Yiner 2	Cotton46.9%Wool44%Other9.1%
291	Yiner 3	Wool64%Silk33%Spandex3%
292	Yiner 4	polyester96.8%Spandex3.2%
293	Yiner 5	Viscose63.2%Polyamide36.8%
294	Yiner 6	Wool53.3%polyester29.7%Polyamide12.8%Silk3.5%Other0.7%
295	Yiner 7	polyester64.9%Viscose31.7%Spandex3.4%
296	Yiner 8	polyester60%Viscose24%Wool13%Spandex3%
297	Youngor 1	50.0%Acrylic50.0%polyester
298	Youngor 2	100.0%polyester
299	Youngor 3	68.1%polyester30.0%Viscose1.9%Spandex
300	Youngor 4	polyester77.5%Viscose16.9%Spandex5.6%
301	Z Dorzi 1	polyester98%Spandex2%
302	Zara 1	76% Polyester, 19% Viscose, 5% Elastane

APPENDIX C

Database of parameterization of training pattern sample

Table C.1, C.2, and C.3 shows the database of 82 pattern samples in 29 parameterization indexes.

Table C.1 - Pattern block parameterization of training samples (bodice)

Pattern №	Ease of width of pattern on bust level(bust =84cm),cm	Ease of width of back (back=31cm),cm	Ease of width of armhole (armhole=19cm),cm	Ease of width of front (front=34cm),cm	Armhole depth & ease of armhole depth(shoulder pad0.5) (depth of arm section =10cm),cm		Armhole length,cm	Configuration of armhole line,°		Distance between back and front shoulder point,cm
	Whole	Back	Profile	Front	AHD	Ease		Back	Front	
	1	2	3	4	5	6	7	8	9	10
1	12.6	2.76	5.78	4.04	16	5.5	45.95	11.25°	31.32°	2.09
2	16.56	4.38	7.78	4.38	16.4	5.9	48.43	12.42°	33.76°	2.22
3	13.44	2.96	5.98	4.48	16.8	6.3	47.42	16.37°	34.75°	1.8
4	16.7	3.2	9.72	3.76	17.1	6.6	50.04	13.77°	29.31°	1.45
5	12.36	3.16	5.1	4.1	15.9	5.4	45.29	12.06°	34.08°	1.87
6	16.74	3.68	9.78	3.28	16.7	6.2	49.17	15.23°	30.36°	1.51
7	13.34	3.7	6.26	3.38	16.2	5.7	46.43	13.67°	31.52°	1.87
8	15.98	4.38	8.52	3.08	17.4	6.9	49.83	11.58°	30.50°	1.79
9	15.86	3.06	9.46	3.34	16.5	6	48.66	16.15°	30.98°	1.76
10	16.36	3.24	9.18	3.96	16.6	6.1	48.86	16.68°	31.93°	1.45
11	15.44	3.4	8.58	3.44	16.5	6	48.28	15.57°	28.65°	1.87
12	16	3.02	9.96	3.04	16.7	6.2	49.14	10.79°	29.14°	1.87
13	17.02	4.34	8.78	3.9	16.9	6.4	49.3	14.40°	30.99°	1.76
14	13.76	3.54	6.92	3.3	16.7	6.2	47.74	14.16°	30.74°	1.87
15	18	3.8	10.68	3.5	17.2	6.7	50.88	13.28°	31.14°	1.76
16	16.86	4.14	9.38	3.34	16.4	5.9	48.85	14.48°	30.09°	1.87
17	14.8	3.6	6.84	4.36	15.6	5.1	45.74	14.03°	32.40°	1.91
18	10.3	3.78	3.48	3.02	18	7.5	47.43	13.94°	32.31°	1.61
19	18.2	5.38	8.34	4.48	17.8	7.3	49.91	14.94°	26.77°	2.28
20	16.56	4.3	9.62	2.62	19.7	9.2	54.35	14.09°	30.30°	2.02
21	10.52	2.74	3.8	4	17.1	6.6	45.99	15.56°	26.06°	1.65
22	19.12	4.8	9.48	4.84	15.8	5.3	48.2	12.68°	29.72°	1.42
23	11.3	2.56	6.28	2.48	18	7.5	49.36	10.08°	25.82°	1.54
24	12.44	3.4	4.6	4.46	16.6	6.1	46.11	10.69°	33.64°	1.42
25	14.5	5.42	4.52	4.56	17.7	7.2	47.85	14.46°	29.17°	2.28
26	13.56	3.3	5.32	4.94	18.2	7.7	49.53	14.80°	31.03°	2.1
27	9.4	2.66	3	3.72	15.7	5.2	43.32	18.62°	33.05°	1.12

28	11.64	3.12	4.64	3.88	16.7	6.2	46.02	10.89°	24.39°	2.06
29	14.16	3.56	6.2	4.42	17.3	6.8	48.07	13.43°	32.92°	2.6
30	13.72	1.94	9.24	2.54	16.7	6.2	49.01	10.23°	28.85°	1.86
31	13.64	3.26	5.88	4.5	17.1	6.6	48	17.30°	30.08°	2.46
32	14.86	4.22	6.1	4.54	15.8	5.3	45.67	13.04°	28.37°	2.26
33	14.58	5.12	5.76	3.7	15.9	5.4	45.34	9.70°	30.58°	2.26
34	12.22	3.6	4.68	3.96	15.8	5.3	44.91	14.21°	32.57°	1.36
35	16.24	4.06	7.92	4.28	15.8	5.3	47.18	7.70°	32.80°	3.14
36	14.66	5.88	6.02	2.76	17.3	6.8	46.58	16.90°	38.08°	2.42
37	14.78	3.76	7.22	3.82	15.4	4.9	45.55	12.67°	32.14°	1.7
38	18.88	5	9.38	4.52	14.8	4.3	46.1	12.74°	29.36°	2.15
39	11.92	1.42	7.88	2.64	15.9	5.4	46.4	13.51°	25.59°	1.86
40	12.82	2.92	6.02	3.88	16.4	5.9	46.8	12.62°	35.74°	2.27
41	11.22	4.24	3.56	3.4	16.3	5.8	45.2	8.47°	28.47°	2.06
42	12.72	4.12	5.32	3.26	17.4	6.9	47.42	13.62°	30.52°	1.91
43	13.5	4.16	5.46	3.88	18	7.5	49.16	12.26°	30.77°	2.14
44	11.06	4	3.34	3.74	16.3	5.8	44.67	8.48°	32.73°	2.06
45	12.96	3.06	6.08	3.8	16.4	5.9	46.78	12.91°	32.91°	1.51
46	13.1	3.18	5.72	4.18	15.9	5.4	45.41	13.43°	33.68°	2.15
47	10.82	3.4	3.28	4.14	16.3	5.8	44.54	10.92°	32.89°	2.26
48	9.76	1.84	4.06	3.86	16.2	5.7	44.67	11.03°	28.62°	1.77
49	13.42	3.08	6.02	4.3	15.8	5.3	45.49	11.51°	34.16°	2.15
50	16.32	3.06	9.24	4.02	15.4	4.9	47.61	10.15°	26.38°	1.94
51	14.52	2.06	8.22	4.24	15.4	4.9	46.56	10.93°	23.52°	1.43
52	12.24	2.02	6.2	4.02	16.1	5.6	46.58	12.85°	34.90°	2.21
53	10.16	3.04	2.58	4.52	16	5.5	43.72	16.87°	34.14°	1.89
54	11.7	3.26	3.88	4.56	15.8	5.3	44.14	17.80°	33.43°	2.17
55	9.54	2.14	3.96	3.44	16.8	6.3	45.82	14.27°	25.63°	1.74
56	14.32	3.06	7.8	3.46	15.5	5	46.45	12.24°	30.48°	2.1
57	14.22	2.92	6.82	4.48	15.7	5.2	46.43	12.08°	33.79°	1.74
58	11.28	1.64	6.32	3.34	16.2	5.7	46.63	11.12°	31.69°	1.65
59	13.72	3.8	5.76	4.16	16.2	5.7	46.21	12.37°	28.70°	1.54
60	12.86	4.1	3.76	4.98	16.4	5.9	45.25	13.91°	28.96°	1.87
61	15.62	4.2	7	4.44	16.1	5.6	47.14	11.89°	32.19°	1.71
62	7.48	2.9	2.5	2.1	17.1	6.6	45.18	12.07°	27.78°	2.06
63	16.28	3.66	8.24	4.38	16.4	5.9	47.92	11.22°	31.67°	1.54
64	12.22	2.44	6.94	2.86	16.9	6.4	48.17	9.25°	26.83°	1.74
65	10.5	2.64	3.88	3.98	16.2	5.7	44.59	10.95°	28.53°	1.77
66	10.46	3.98	2.82	3.68	16.7	6.2	45.21	14.80°	32.16°	2.22
67	12.92	4.14	4.22	4.56	16.8	6.3	46.22	9.28°	28.19°	1.71
68	12.16	2.98	5.08	4.1	17.4	6.9	47.37	10.65°	32.79°	1.71
69	11.94	2.42	5.14	4.38	16.1	5.6	45.61	8.34°	29.89°	2.25
70	14.96	2.62	8.94	3.4	15.9	5.4	47.63	9.88°	21.83°	1.35

71	13.84	3.4	6.02	4.4	16.2	5.7	46.62	4.97°	24.58°	1.35
72	9.28	3.06	2.98	3.24	17.3	6.8	45.81	13.04°	33.54°	1.71
73	10.28	0.94	9.28	0.08	15.3	4.8	46.54	7.17°	27.41°	2.08
74	12.22	1.58	6.64	4	15.8	5.3	46.24	10.22°	33.70°	2.13
75	15.2	3.26	7.34	4.58	15.9	5.4	46.62	12.62°	30.61°	1.71
76	12.7	1.96	8.04	2.7	17.5	7	49.53	10.99°	28.93°	1.62
77	13.24	3.58	5.6	4.04	16	5.5	45.49	9.46°	31.97°	2.22
78	12.2	3.02	5.62	3.56	16.1	5.6	46.12	12.54°	29.49°	1.07
79	12.22	3.52	4.76	3.96	16.1	5.6	44.72	14.00°	31.86°	1.9
80	12.86	4.28	4.74	3.82	15.8	5.3	44.56	17.87°	31.52°	1.51
81	12.9	1.62	6.68	4.6	15.8	5.3	46.59	15.96°	35.68°	2.27
82	12.96	3.66	5.42	3.88	15.8	5.3	44.86	14.48°	32.50°	2.15

Table C.2 - Pattern block parameterization of training samples (sleeve)

Pattern №	Ease to arm girth	Ease to elbow girth	Ease to wrist girth	Distances in between the elbow seam at arm; elbow; wrist level			Distances in between the front seam at arm; elbow; wrist level			Sleeve cap height
	arm	elbow	wrist	arm	elbow	wrist	arm	elbow	wrist	
	1	2	3	4	5	6	7	8	9	10
1	6.2	8.86	13.32	5.19	0.33	0.00	4.00	4.00	4.00	15.89
2	8.12	10.08	11.96	3.80	0.00	0.00	10.00	10.00	10.00	16.66
3	8.2	10	13.6	6.27	3.00	2.00	7.20	7.20	7.20	16.55
4	10.84	12.82	14.4	3.44	2.02	0.00	7.00	7.00	7.00	17.11
5	4.78	/	13.28	/	/	/	/	/	/	15.69
6	10.26	12.38	14.2	4.67	3.00	2.00	7.00	7.00	7.00	16.79
7	7.78	9.86	12.2	0.00	0.00	0.00	4.00	4.00	4.00	16.10
8	10.32	12.3	13.82	0.00	0.00	0.00	10.00	10.00	10.00	17.26
9	9.98	12.08	13.86	0.00	0.00	0.00	4.00	4.00	4.00	16.56
10	10	12.08	13.6	0.00	0.00	0.00	8.00	8.00	8.00	16.70
11	9.54	11.5	13.28	0.00	0.00	0.00	5.00	5.00	5.00	16.52
12	9.9	11.92	13.56	0.00	0.00	0.00	7.00	7.00	7.00	16.94
13	8.74	10.84	12.64	0.00	0.00	0.00	5.00	5.00	5.00	16.98
14	8.72	10.76	12.68	0.00	0.00	0.00	6.00	6.00	6.00	16.55
15	11.44	13.5	14.66	0.00	0.00	0.00	5.00	5.00	5.00	17.40
16	10.28	12.26	13.82	3.77	2.02	0.00	5.00	5.00	5.00	16.52
17	7.6	10.16	13.78	0.00	0.00	0.00	7.00	7.00	7.00	15.67
18	4.52	7.02	9.62	0.00	0.00	0.00	5.00	5.00	5.00	17.06
19	10.08	11.98	13.74	3.54	2.10	0.00	9.00	9.00	9.00	17.43
20	10.78	12.82	12.28	0.00	0.00	0.00	8.00	8.00	8.00	19.17
21	7.04	9.34	11.48	3.77	1.69	0.00	8.00	8.00	8.00	16.56
22	10.1	12.08	13.78	0.00	0.00	0.00	6.00	6.00	6.00	16.16
23	6.72	8.8	10.16	0.00	0.00	0.00	8.11	7.00	6.00	17.66
24	7.22	9.34	11.64	0.00	0.00	0.00	6.00	6.00	6.00	16.16
25	6.64	8.84	12.76	/	/	/	/	/	/	17.01
26	7.86	10.22	12.1	0.00	0.00	0.00	6.00	6.00	6.00	17.59

27	4.72	7.04	9.64	0.00	0.00	0.00	10.08	8.00	7.00	15.08
28	6.62	9.72	15.48	0.00	0.00	0.00	9.06	8.00	7.00	16.38
29	8.46	9.92	12.01	/	/	/	/	/	/	16.92
30	8.4	10	9.12	0.00	0.00	0.00	8.00	8.00	8.00	16.96
31	7.76	10.02	12.02	0.00	0.00	0.00	8.00	8.00	8.00	16.91
32	6.62	9.24	13.16	0.00	0.00	0.00	8.00	8.00	8.00	15.81
33	8.84	10.48	10.1	0.00	0.00	0.00	5.00	5.00	5.00	15.81
34	6.67	/	11.13	/	/	/	/	/	/	15.60
35	9.64	11.16	11.18	0.00	0.00	0.00	6.00	6.00	6.00	16.00
36	8.6	9.8	13.02	0.00	0.00	0.00	6.00	6.00	6.00	16.54
37	6.96	8.56	11.42	0.00	0.00	0.00	5.00	5.00	5.00	15.51
38	7.02	8.56	9.48	0.00	0.00	0.00	5.00	5.00	5.00	15.57
39	6.32	9.38	14.08	3.78	0.95	0.00	6.00	6.00	6.00	16.12
40	8.22	9.86	10.1	3.00	2.36	0.00	5.00	5.00	5.00	16.09
41	6.38	8.58	10.9	0.00	0.00	0.00	6.00	6.00	6.00	15.97
42	6.63	/	13.91	/	/	/	/	/	/	16.92
43	9.12	10.94	11.22	0.00	0.00	0.00	7.00	7.00	7.00	17.53
44	5.62	8.72	12.42	2.49	0.90	0.00	6.00	6.00	6.00	15.97
45	8.66	10.12	9.1	0.00	0.00	0.00	6.00	6.00	6.00	16.13
46	8.08	9.7	9.1	0.00	0.00	0.00	5.00	5.00	5.00	15.57
47	4.34	7.34	13.08	0.00	0.00	0.00	7.00	7.00	7.00	15.81
48	3.64	6.02	9.22	0.00	0.00	0.00	6.00	6.00	6.00	15.90
49	8.2	9.92	10.1	0.00	0.00	0.00	5.00	5.00	5.00	15.57
50	10.2	11.4	10.18	2.84	2.00	0.00	6.00	6.00	6.00	16.02
51	8.2	9.8	10.1	4.29	4.00	2.00	4.00	4.00	4.00	15.97
52	8.88	10.48	11.1	3.62	1.60	0.00	5.00	5.00	5.00	15.95
53	4.74	6.98	10.1	0.00	0.00	0.00	4.00	4.00	4.00	15.38
54	6.22	8.42	10.76	0.00	0.00	0.00	5.00	5.00	5.00	15.26
55	6.7	8.54	11.08	0.00	0.00	0.00	7.00	7.00	7.00	16.59
56	8.78	10.48	11.1	0.00	0.00	0.00	5.00	5.00	5.00	15.59
57	9.78	11.08	11.22	2.52	1.00	0.00	5.00	5.00	5.00	15.74
58	7.36	9.06	9.1	0.00	0.00	0.00	6.00	6.00	6.00	16.14
59	6.32	8.26	9.64	0.00	0.00	0.00	6.00	6.00	6.00	16.11
60	5.92	8.08	10.54	0.00	0.00	0.00	6.00	6.00	6.00	15.88
61	7.72	10.42	14.24	2.42	1.31	0.00	7.00	7.00	7.00	16.04
62	5.74	/	10.74	/	/	/	/	/	/	16.45
63	8.9	11.28	14.18	4.24	3.00	0.00	6.00	6.00	6.00	16.53
64	9.16	11.2	13.06	0.00	0.00	0.00	7.00	7.00	7.00	17.01
65	5.62	8.22	12.38	3.27	1.40	0.00	5.00	5.00	5.00	15.90
66	7.78	9.4	8.96	3.50	2.00	0.00	5.00	5.00	5.00	15.94
67	6.8	9.22	12.18	3.38	3.00	3.00	3.00	3.00	3.00	16.46
68	7.66	9.8	11.84	2.26	2.00	2.00	5.00	5.00	5.00	16.87
69	5.6	7.82	10.42	0.00	0.00	0.00	4.00	4.00	4.00	15.91
70	9.02	11.02	12.88	0.00	0.00	0.00	6.00	6.00	6.00	16.34
71	7.6	9.72	11.8	0.00	0.00	0.00	4.00	4.00	4.00	16.36
72	6.26	8.44	10.8	0.00	0.00	0.00	6.00	6.00	6.00	16.46
73	6.74	8.86	11.14	2.31	2.00	2.00	3.00	3.00	2.00	16.06
74	6.64	9.94	18.72	4.39	3.70	3.00	5.00	5.00	5.00	15.87
75	6.84	9.46	13.2	5.71	2.00	0.00	6.00	6.00	6.00	16.04
76	9.44	11.52	13.16	5.06	1.91	0.00	6.00	6.00	6.00	17.47

77	8.34	10.8	12.36	0.00	0.00	0.00	6.00	6.00	6.00	14.31
78	7.5	10.74	10.98	0.00	0.00	0.00	10.13	8.00	6.00	16.02
79	6.94	9.26	11.4	0.00	0.00	0.00	6.00	6.00	6.00	15.67
80	4.94	7.28	9.8	0.00	0.00	0.00	4.00	4.00	4.00	15.54
81	7.46	9.44	11.1	4.33	3.00	2.00	6.00	6.00	6.00	15.62
82	6.58	8.82	11.02	3.34	1.75	0.00	5.00	5.00	5.00	15.57

Notes: “/” means the value of this indexes was difficult to measure due to the TPS special split seam.

Table C.3 - Pattern block parameterization of training samples (bodice+ sleeve)

Pattern №	Sleeve Δ	curve length of upper sleeve	Sleeve Cap curve distance B	Sleeve Cap curve distance C	down part sleeve cap curv	Whole length of sleeve cap curv	Sleeve elbow seam and back width of bodice distance	Sleeve cap height with armhole depth	Sleeve sloping
	1	2	3	4	5	6	7	8	9
1	3.06	33.72	1.80	1.80	15.29	49.01	2.54	0.00	1.07
2	3.19	37.08	1.80	1.80	14.54	51.62	2.26	0.10	0.76
3	3.77	37.02	1.80	1.80	14.17	51.19	3.26	-1.90	0.71
4	4.09	35.90	1.80	1.80	18.23	54.13	2.67	2.30	0.64
5	2.37	/	1.80	1.80	/	47.66	/	2.10	/
6	3.84	37.29	1.80	1.80	15.73	53.01	2.67	-1.00	0.63
7	3.91	29.35	1.80	1.80	20.99	50.34	3.07	-0.20	0.56
8	3.72	34.83	1.80	1.80	18.73	53.55	3.74	-1.50	0.77
9	4.10	30.07	1.80	1.80	22.70	52.76	3.32	0.00	0.56
10	3.88	33.01	1.80	1.80	19.73	52.74	3.10	0.40	0.71
11	3.96	30.83	1.80	1.80	21.41	52.24	3.47	-0.40	0.65
12	3.68	32.71	1.80	1.80	20.11	52.82	2.64	-0.20	0.64
13	3.07	30.76	1.70	1.70	21.61	52.37	2.80	-1.10	0.61
14	3.75	31.21	1.70	1.70	20.28	51.49	3.42	0.20	0.68
15	3.98	32.56	1.80	1.80	22.30	54.86	2.82	1.40	0.54
16	4.17	34.68	1.80	1.80	18.34	53.02	2.93	-1.60	0.58
17	3.91	32.05	1.80	1.80	17.60	49.65	2.79	1.50	0.63
18	1.50	29.16	1.50	1.50	19.77	48.93	2.55	0.40	0.51
19	3.81	38.26	2.00	1.90	15.46	53.72	3.14	0.30	0.68
20	2.58	36.05	2.00	2.00	20.88	56.93	2.20	0.80	0.59
21	3.90	35.15	1.80	1.80	14.75	49.89	3.72	-1.50	0.63
22	3.67	30.56	1.80	1.80	21.31	51.87	3.07	-1.30	0.58
23	2.47	33.51	1.90	1.90	18.32	51.83	2.46	-0.60	2.26
24	3.86	30.40	1.90	1.90	19.57	49.97	2.93	1.30	0.59
25	2.68	/	2.00	2.00	/	50.53	/	0.10	/
26	2.89	31.75	1.80	1.80	20.67	52.42	3.15	-2.10	0.59
27	3.10	31.19	1.80	1.80	15.23	46.42	2.41	-2.10	2.86
28	3.58	32.71	1.90	1.90	16.89	49.60	3.29	1.70	2.22
29	3.35	/	1.80	1.80	/	51.42	/	0.10	/
30	2.93	32.80	1.80	1.80	19.14	51.94	2.22	0.70	1.29
31	3.14	32.42	1.80	1.80	18.72	51.14	3.69	-1.40	0.67
32	3.23	31.20	1.80	1.80	17.71	48.90	2.88	2.00	0.64
33	5.07	29.16	2.00	1.70	21.25	50.41	3.24	-0.90	0.49

34	4.33	/	2.00	2.00	/	49.24	/	1.80	/
35	4.72	31.31	2.00	2.00	20.59	51.90	3.39	0.90	0.60
36	4.37	30.13	1.80	2.20	20.82	50.95	4.47	-1.30	0.56
37	3.49	28.80	1.80	1.80	20.23	49.04	2.07	0.20	0.32
38	2.93	28.39	1.90	1.80	20.64	49.03	1.82	-0.50	0.58
39	2.80	33.50	1.80	1.80	15.70	49.20	2.25	-0.90	-0.48
40	3.90	32.51	2.00	1.80	18.20	50.70	3.08	0.30	0.54
41	3.66	29.85	1.80	1.80	19.01	48.86	3.45	-1.60	0.59
42	3.47	24.27	1.60	1.60	26.62	50.89	/	-0.10	/
43	3.96	32.68	2.00	1.80	20.45	53.12	3.24	0.30	0.60
44	3.56	32.23	1.80	1.80	16.00	48.23	3.50	-0.40	0.59
45	4.28	30.28	2.00	2.00	20.78	51.06	3.65	0.20	0.56
46	4.37	29.11	1.90	1.80	20.68	49.78	4.05	2.40	0.57
47	2.32	29.91	1.50	1.50	16.95	46.86	2.82	1.30	0.70
48	2.31	29.26	1.90	1.80	17.72	46.98	2.44	0.60	0.63
49	4.32	29.09	1.90	1.80	20.72	49.81	3.88	0.20	0.58
50	4.44	33.62	2.00	1.80	18.43	52.05	2.91	0.60	0.62
51	4.04	32.53	1.80	1.80	18.07	50.60	2.45	2.40	0.50
52	4.40	32.76	2.00	1.80	18.21	50.98	3.74	1.40	0.60
53	3.12	27.17	1.80	1.80	19.67	46.84	3.12	-0.60	0.57
54	3.77	28.23	2.00	1.80	19.68	47.91	3.86	-1.70	0.60
55	4.07	31.05	2.00	2.00	18.84	49.89	3.19	1.50	1.39
56	4.17	29.27	2.00	1.80	21.34	50.62	2.75	-0.20	0.55
57	5.13	32.41	2.00	2.00	19.15	51.56	3.32	-0.70	-0.54
58	3.64	29.85	2.30	1.90	20.42	50.27	3.53	0.50	0.59
59	2.79	30.42	1.50	1.50	18.58	49.00	2.31	0.50	0.59
60	3.11	29.71	1.50	1.80	18.65	48.36	3.03	2.80	0.60
61	3.03	33.16	1.50	1.50	17.01	50.17	2.62	0.30	-0.10
62	3.44	/	1.60	1.60	/	48.62	/	-0.50	/
63	3.96	35.03	2.00	1.80	16.85	51.88	2.19	-0.30	0.56
64	4.34	32.44	2.00	2.00	20.07	52.51	2.87	-0.10	0.62
65	3.78	32.20	2.00	2.00	16.17	48.37	3.14	1.00	0.58
66	4.58	32.39	2.00	1.80	17.40	49.79	3.33	-1.80	0.49
67	3.70	30.91	1.80	1.80	19.01	49.92	3.04	1.00	0.47
68	3.54	31.81	1.80	1.80	19.10	50.91	3.02	-0.10	0.50
69	3.01	27.67	1.80	1.80	20.95	48.62	2.45	0.50	0.52
70	3.60	30.31	1.80	1.50	20.92	51.23	2.53	-0.40	0.55
71	4.09	28.55	2.00	1.90	22.16	50.71	3.03	2.50	0.48
72	3.48	29.96	2.00	1.80	19.33	49.29	3.63	0.40	0.57
73	3.00	29.13	1.80	1.80	20.41	49.54	1.40	0.90	1.11
74	3.13	33.47	1.90	1.80	15.90	49.37	2.45	1.10	1.10
75	3.01	35.50	1.80	1.80	14.13	49.63	2.09	1.70	0.55
76	3.81	37.02	2.00	2.00	16.33	53.34	2.54	-0.40	0.57
77	2.04	28.34	1.50	1.50	19.18	47.53	2.87	-1.10	0.55
78	3.53	32.64	1.80	1.80	17.01	49.65	2.89	-1.40	2.88
79	3.99	29.87	1.80	1.80	18.84	48.71	3.47	0.70	0.56
80	2.61	27.61	1.60	1.60	19.56	47.17	2.27	-0.10	0.51
81	3.12	34.60	2.00	1.80	15.12	49.71	2.22	0.70	0.59
82	3.80	32.57	2.00	1.80	16.09	48.66	3.32	1.80	0.58

Notes: “/” means the value of this indexes was difficult to measure due to the TPS special split seam.

APPENDIX D

Reliable subjective evaluation grade for each sample

Table D.1 - Reliable subjective evaluation grade for each sample (original five grade of perfect, good, appropriate, fair, poor)

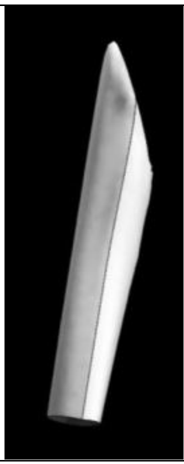
Sample number	Fit grade	Sample number	Fit grade
1	Poor	42	Odd
2	Perfect	43	Perfect
3	Good	44	Good
4	Perfect	45	Good
5	Odd	46	Perfect
6	Perfect	47	Appropriate
7	Fair	48	Appropriate
8	Perfect	49	Appropriate
9	Appropriate	50	Fair
10	Perfect	51	Poor
11	Good	52	Good
12	Fair	53	Appropriate
13	Good	54	Good
14	Perfect	55	Appropriate
15	Good	56	Perfect
16	Perfect	57	Appropriate
17	Poor	58	Perfect
18	Good	59	Perfect
19	Appropriate	60	Poor
20	Good	61	Appropriate
21	Appropriate	62	Odd
22	Fair	63	Good
23	Perfect	64	Appropriate
24	Perfect	65	Appropriate
25	Odd	66	Good
26	Appropriate	67	Appropriate
27	Good	68	Good
28	Appropriate	69	Perfect
29	Odd	70	Good
30	Perfect	71	Fair
31	Good	72	Fair
32	Appropriate	73	Fair
33	Perfect	74	Perfect
34	Odd	75	Good

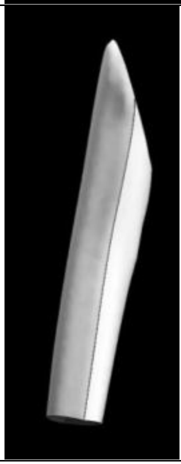
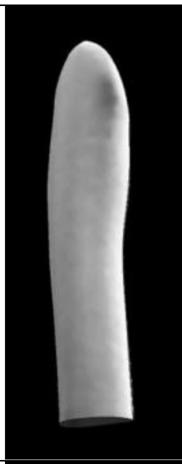
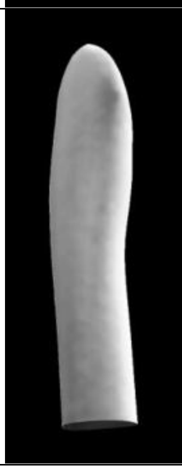
35	Good	76	Perfect
36	Poor	77	Good
37	Appropriate	78	Good
38	Good	79	Perfect
39	Good	80	Good
40	Good	81	Good
41	Appropriate	82	Perfect

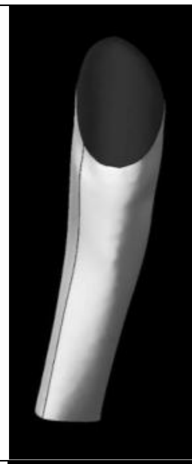
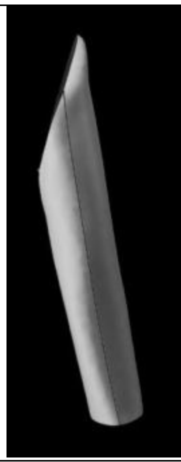
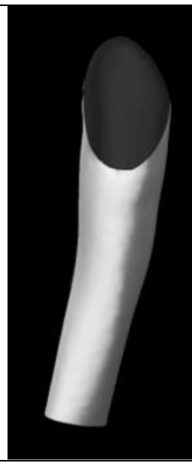
APPENDIX E

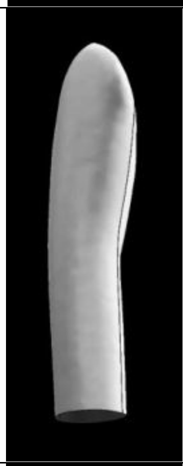
Misfit tolerance threshold of designed pattern

Table E.1 - Detection of misfit tolerance threshold of designed pattern

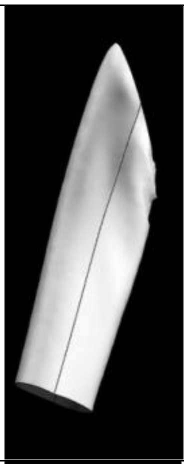
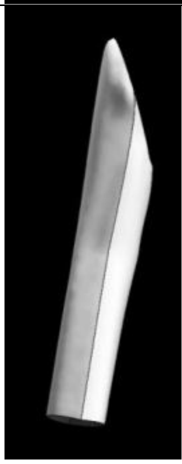
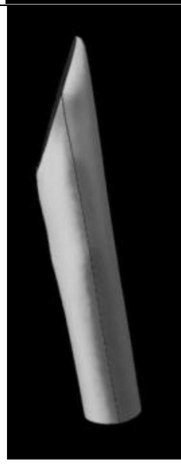
Deforming	Front	1/2 Front	Profile	Back	Inner
Closed sleeve cap					
BSD deformation					
BSD 2cm					
BSD 4cm					

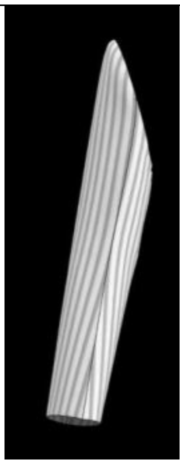
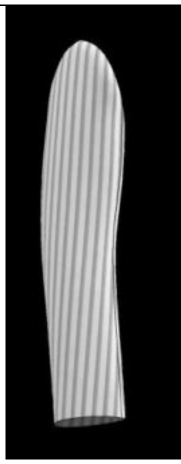
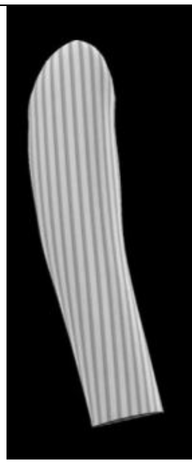
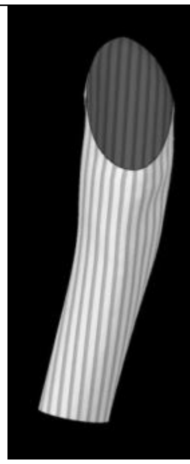
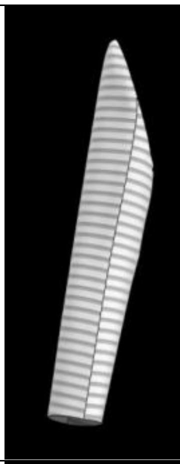
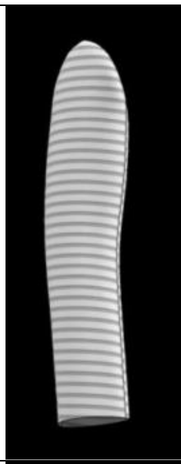
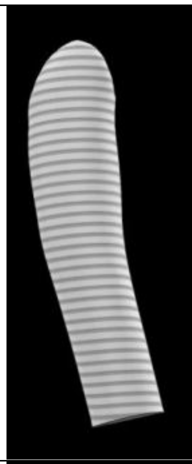
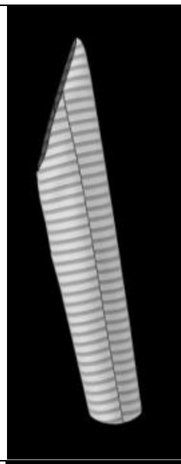
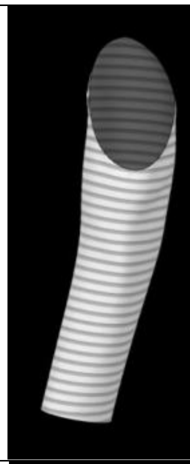
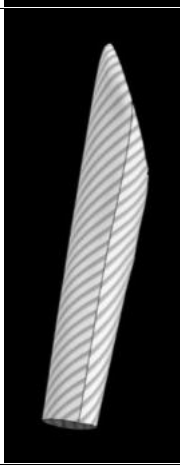
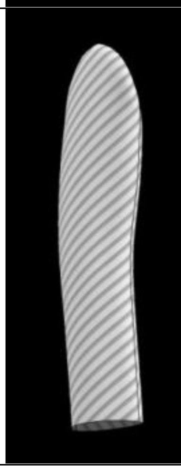
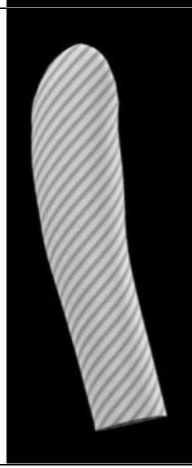
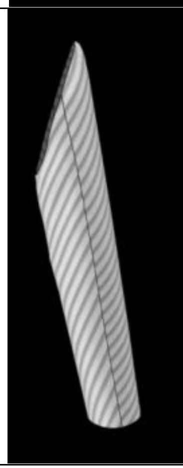
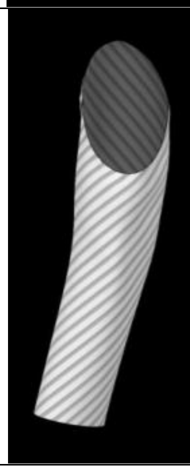
BSD 6cm					
BSD 8cm					
FSD deformation					
FSD 2cm					
FSD 4cm					

FSD 6cm					
FSD 8cm					
SCH deformation					
SCH +0.5cm					
SCH +1cm					

SCH +2cm					
SCH -0.5cm					
SCH -1cm					
SCH -2cm					

SCH -3cm					
SCW deformation					
SCW +1cm					
SCW +2cm					
SCW +4cm					

SCW +6cm					
SCW -1cm					
SCW -2cm					
SCW -4cm					
Fabric grainline deformation					

Grainline straight					
Grainline crosswise					
Grainline bias					

APPENDIX F

Database of training samples feature point coordinates

Table F.1, F.2 show the coordinates on armhole (before assembly), Table F.3, F.4 show the coordinates on sleeve cap (after assembly),

Table F.1 - Feature point coordinates (A1 - A3), cm

number of jacket sample	Coordinates of points								
	A1			A2			A3		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-1.395	0.707	0.603	-0.372	-7.456	-6.413	-0.065	-14.264	-3.587
2	-1.079	0.787	0.991	-0.834	-6.926	-6.187	-1.508	-14.206	-4.898
3	-1.508	0.605	0.744	-0.776	-7.075	-6.115	-0.565	-14.84	-4.112
4	-1.437	0.614	0.755	-0.205	-8.512	-6.132	-1.121	-15.529	-4.445
5	/	/	/	/	/	/	/	/	/
6	-1.075	0.866	0.769	-0.596	-6.724	-5.955	-1.856	-15.392	-4.131
7	-1.31	0.726	0.609	-0.557	-7.807	-6.214	-1.197	-14.953	-3.362
8	-1.273	0.831	0.772	-0.634	-7.811	-6.076	-1.387	-15.818	-4.025
9	-1.197	0.763	0.861	-0.726	-6.925	-5.965	-1.3	-15.017	-4.295
10	-1.506	0.733	0.576	-0.603	-7.54	-6.285	-1.732	-15.008	-4.725
11	-1.359	0.714	0.695	-0.692	-7.363	-6.213	-1.574	-15.557	-4.126
12	-3.748	-0.129	0.872	-2.326	-10.184	-5.5	-5.268	-20.49	-3.824
13	-1.174	0.91	0.761	-0.832	-7.493	-6.21	-1.617	-15.039	-4.705
14	-1.226	0.736	0.539	-0.488	-7.765	-6.25	-0.963	-14.787	-3.999
15	-0.962	0.812	0.682	-0.329	-8.196	-6.239	-1.689	-15.887	-4.443
16	-1.235	0.795	0.869	-0.781	-7.578	-6.257	-1.607	-14.617	-4.932
17	-1.422	0.634	0.758	-0.647	-7.246	-6.226	-1.211	-13.991	-4.331
18	-1.292	0.922	0.662	-0.449	-8.113	-6.361	-0.228	-16.514	-0.787
19	-2.339	0.309	0.982	-1.609	-7.718	-5.867	-2.631	-17.499	-2.536
20	-1.551	0.701	0.981	-1.012	-7.462	-6.105	-1.866	-18.692	-1.919
21	-0.853	0.932	0.662	-0.387	-6.082	-6.177	-0.214	-14.93	-2.611
22	-1.573	0.815	0.714	-0.984	-7.081	-5.983	-1.464	-13.302	-5.915
23	-0.256	1.029	0.482	-0.637	-6.981	-6.375	-0.533	-16.112	-3.206
24	-1.559	0.785	0.696	-0.63	-7.558	-6.233	-0.734	-15.295	-2.353
25	/	/	/	/	/	/	/	/	/
26	-1.876	0.506	1.141	-0.918	-8.522	-6.441	-0.282	-16.595	-2.703
27	-1.273	1.124	0.282	-0.294	-8.29	-6.121	0.069	-13.302	-3.366
28	-0.594	0.968	0.765	-0.437	-7.379	-6.316	-0.573	-14.082	-3.915
29	/	/	/	/	/	/	/	/	/
30	-0.374	1.02	0.527	-0.259	-6.952	-6.363	-1.351	-15.757	-3.616
31	-1.867	0.635	0.761	-0.977	-6.827	-6.06	-0.725	-16.009	-3.22
32	-1.48	0.653	0.456	-0.925	-7.29	-6.355	-1.515	-14.07	-4.272
33	-1.218	0.737	0.773	-1.005	-7.07	-6.055	-1.418	-14.832	-2.477
34	/	/	/	/	/	/	/	/	/
35	-0.727	0.967	1.067	-0.554	-7.791	-6.347	-1.499	-14.258	-4.792
36	-2.82	0.206	0.86	-2.148	-7.927	-5.598	/	/	/

37	-2.125	0.356	0.567	-1.065	-8.051	-6.029	-1.725	-14.175	-3.988
38	-1.25	1.113	0.721	-1.165	-6.7	-6.04	-2.144	-12.858	-5.25
39	-0.32	1.016	0.398	0.142	-6.298	-6.449	-0.522	-13.789	-4.374
40	-1.516	0.982	0.728	-0.467	-7.835	-6.248	-0.572	-15.005	-3.436
41	-0.68	0.886	0.67	-0.666	-7.537	-6.311	-0.56	-13.957	-3.118
42	/	/	/	/	/	/	/	/	/
43	-1.371	0.78	0.651	-1.034	-7.348	-6.203	-1.378	-16.578	-2.917
44	-0.676	0.872	0.57	-0.631	-7.727	-6.183	-0.197	-14.423	-2.564
45	-1.536	0.807	0.626	-0.568	-7.377	-6.258	-0.068	-15.546	-3.143
46	-1.396	0.596	0.572	-0.645	-8.04	-6.36	-0.616	-14.431	-4.229
47	-1.136	0.661	0.646	-0.517	-7.866	-6.325	0.081	-14.873	-1.731
48	-0.383	0.965	0.444	-0.22	-7.588	-6.447	0.143	-13.271	-3.917
49	-1.488	0.573	0.528	-0.581	-7.984	-6.608	-0.202	-14.017	-4.654
50	-0.972	0.78	0.369	-0.649	-6.99	-6.345	/	/	/
51	0.555	1.305	0.084	0.072	-5.755	-6.065	-0.887	-13.284	-5.442
52	-1.775	0.589	0.26	-0.243	-8.294	-6.503	-0.176	-14.801	-4.327
53	-1.244	0.837	0.4	-0.42	-8.175	-6.289	0.072	-13.532	-3.43
54	-1.301	0.794	0.422	-0.779	-7.861	-6.452	0.233	-14.371	-2.537
55	-0.268	1.04	0.479	-0.31	-5.635	-6.153	0.369	-13.426	-4.202
56	-1.342	0.727	0.306	-0.299	-8.194	-6.15	-1.145	-14.719	-4.651
57	-1.521	0.659	0.592	-0.413	-7.747	-6.266	-0.649	-14.898	-4.228
58	-0.881	0.857	0.513	-0.435	-7.11	-6.391	-0.279	-14.253	-4.501
59	-1.319	0.814	0.615	-1.003	-6.674	-5.925	-1.108	-14.237	-4.148
60	-1.956	0.653	0.654	-0.733	-7.825	-6.297	-0.81	-13.858	-3.656
61	-1.265	0.792	0.741	-0.836	-8.208	-6.111	-1.335	-13.881	-5.122
62	/	/	/	/	/	/	/	/	/
63	-1.368	0.805	0.646	-0.915	-6.707	-6.171	-1.642	-14.637	-5.121
64	-0.321	1.015	0.454	-0.226	-6.708	-6.362	-0.588	-14.521	-4.141
65	-0.62	0.951	0.287	-0.267	-7.431	-6.484	0.149	-13.631	-3.558
66	-1.576	0.794	0.776	-0.848	-7.658	-6.199	-0.246	-13.93	-3.323
67	-1.348	0.736	0.575	-1.361	-6.685	-6.07	-1.076	-14.471	-3.96
68	-1.33	0.784	0.67	-0.413	-8.529	-6.102	-0.619	-14.678	-4.251
69	-0.761	0.863	0.519	-0.162	-8.649	-6.283	-0.062	-13.854	-4.378
70	-0.393	0.914	0.259	-0.58	-5.743	-6.007	-0.991	-14.071	-5.174
71	-0.48	0.912	0.426	-0.998	-6.281	-6.228	-1.087	-14.169	-4.449
72	-1.349	0.816	0.709	-0.602	-7.488	-6.187	0.684	-15.069	-2.699
73	1.392	1.584	0.705	0.304	-3.897	-5.816	-0.576	-13.023	-3.644
74	-1.261	0.586	0.505	-0.2	-8.119	-6.189	-0.214	-14.107	-5.073
75	-1.424	0.917	0.667	-0.72	-6.543	-6.291	-1.372	-14.55	-4.12
76	-0.56	1	0.358	-0.133	-6.891	-6.515	-1.147	-15.548	-4.098
77	-0.687	0.891	0.664	-0.515	-6.654	-6.381	-0.939	-13.809	-3.662
78	-0.372	0.992	0.584	-0.21	-8.755	-6.193	-0.247	-13.111	-4.667
79	-1.251	0.772	0.449	-0.738	-6.856	-5.925	-0.532	-13.375	-4.172
80	-1.279	0.645	0.707	-0.665	-7.994	-6.01	-0.759	-13.557	-3.972
81	-0.942	1.209	0.927	-0.287	-8.691	-6.258	-0.213	-11.997	-5.739
82	-1.589	0.58	0.479	-0.97	-6.723	-6.198	-0.499	-14.404	-3.133

Notes: “/” means the coordinate value of this sample could not measure or singular value due to the pattern aspect reason.

Table F.2 - Feature point coordinates (A4 - A6), cm

number of jacket sample	Coordinates of points								
	A4			A5			A6		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-0.171	-15.618	0.171	-0.481	-14.397	3.79	0.041	-8.149	5.903
2	-1.537	-16.815	0.163	-0.421	-14.464	4.526	0.406	-7.54	6.055
3	-0.394	-16.438	0.56	0.046	-15.623	3.257	3.257	-9.361	5.931
4	-1.93	-17.585	0.352	-0.67	-16.16	3.727	0.554	-8.694	6.122
5	/	/	/	/	/	/	/	/	/
6	-2.609	-16.798	0.17	-1.159	-15.694	3.419	0.767	-8.619	6.225
7	-1.274	-15.84	0.3	-0.501	-14.514	3.705	0.431	-8.327	6.032
8	-1.827	-17.546	-0.084	-0.32	-15.372	4.264	0.728	-9.192	6.223
9	-2.372	-16.637	0.323	-0.904	-15.006	4.101	0.716	-8.052	6.211
10	-2.198	-16.745	0.182	-0.754	-15.261	3.723	0.399	-7.936	6.002
11	-1.216	-16.689	-0.225	-0.54	-15.386	3.42	0.588	-8.095	6.141
12	-4.554	-21.195	-0.275	-2.107	-17.819	4.077	-0.869	-10.355	5.654
13	-2.096	-17.231	-0.431	-1.166	-15.704	3.856	0.229	-8.186	6.094
14	-1.042	-16.266	0.717	-0.202	-14.903	4.188	0.589	-8.618	6.192
15	-2.495	-17.545	0.002	-0.899	-15.816	3.912	0.654	-8.427	6.275
16	-2.346	-16.469	0.019	-0.748	-15.335	3.537	0.741	-8.601	6.143
17	-1.221	-15.476	0.359	-0.301	-14.072	3.982	0.237	-7.704	5.937
18	-0.07	-16.715	0.459	0.056	-16.653	1.248	0.635	-9.039	6.07
19	-2.877	-18.462	0.435	-1.164	-16.535	4.355	0.009	-9.812	6.048
20	-1.611	-19.537	1.436	-0.259	-18.487	4.263	1.188	-11.321	6.944
21	-0.089	-15.85	0.172	0.173	-15.094	2.856	0.559	-8.056	5.961
22	-1.949	-16.203	-0.875	/	/	/	0.044	-8.839	0.044
23	-0.276	-16.949	0.253	0.18	-16.652	2.013	0.766	-8.8	6.263
24	-0.579	-15.621	0.571	-0.228	-15.096	2.913	0.405	-8.107	5.884
25	/	/	/	/	/	/	/	/	/
26	-0.328	-17.01	-0.112	-0.485	-16.091	2.73	-0.013	-9.401	5.679
27	0.326	-14.669	1.041	0.46	-13.937	2.981	0.215	-7.689	5.865
28	-0.327	-15.479	0.203	0.326	-13.834	3.892	0.674	-8.11	6.106
29	/	/	/	/	/	/	/	/	/
30	-1.565	-16.603	-0.234	-0.197	-15.371	3.438	0.899	-7.315	6.258
31	-0.504	-17.234	-0.068	-0.369	-16.028	3.343	0.065	-9.397	6.039
32	-2.083	-15.394	-0.04	-0.421	-12.034	5.192	-0.074	-8.152	5.818
33	-1.121	-15.396	0.74	-0.395	-14.397	3.552	0.53	-7.948	6.168
34	/	/	/	/	/	/	/	/	/
35	-0.845	-15.526	-0.416	-0.291	-13.807	4.139	0.737	-8.344	6.033
36	-0.862	-17.178	2.004	/	/	/	1.042	-11.349	6.349
37	-1.546	-15.937	0.763	-1.052	-15.007	3.315	0.044	-8.457	5.894
38	-2.817	-15.374	-0.434	-0.23	-11.765	5.149	0.076	-7.797	5.859
39	-0.651	-15.234	0.332	0.021	-14.012	3.473	0.865	-7.563	6.151
40	-0.284	-15.619	0.687	0.078	-14.604	3.605	0.59	-8.624	6.062
41	-0.358	-15.328	0.033	0.413	-13.119	4.701	0.694	-8.035	6.096

42	/	/	/	/	/	/	/	/	/
43	-1.285	-17.408	0.462	-0.602	-16.618	3.068	0.276	-9.472	5.977
44	-0.171	-15.15	0.352	0.137	-14.236	3.126	0.637	-7.616	6.054
45	0.244	-15.998	-0.188	0.316	-12.907	4.839	0.54	-8.235	5.967
46	0.171	-15.425	-0.307	0.27	-14.149	3.283	0.484	-8.109	5.842
47	0.192	-15.355	0.191	0.178	-14.713	2.508	0.508	-7.897	5.85
48	0.544	-15.228	0.136	0.523	-13.954	3.303	0.711	-7.733	5.871
49	0.249	-15.412	-0.35	0.113	-13.194	4.267	0.273	-8.098	5.851
50	-1.137	-15.995	-0.582	/	/	/	0.232	-7.747	5.85
51	-1.078	-14.891	-0.284	-0.386	-13.014	4.303	0.447	-6.86	5.912
52	-0.646	-15.429	0.63	-0.195	-14.216	3.587	0.244	-7.873	5.896
53	0.381	-14.894	0.253	0.263	-13.47	3.593	0.462	-7.791	5.778
54	0.134	-14.634	-0.129	0.186	-12.126	4.709	0.473	-7.743	5.881
55	0.535	-15.59	0.134	0.541	-14.5	3.116	0.302	-7.742	5.987
56	-1.216	-15.364	-0.237	0.113	-12.109	5.296	0.645	-8.653	6.043
57	0.003	-15.474	-0.512	-0.15	-13.412	4.363	0.349	-8.257	5.846
58	0.451	-15.666	-0.412	0.606	-13.154	4.413	0.822	-7.947	6.023
59	-0.914	-15.574	0.663	-0.055	-13.415	4.597	0.22	-8.326	5.872
60	-1.13	-15.687	0.196	-0.571	-13.281	4.748	-0.294	-8.584	5.802
61	-1.746	-15.61	0.421	-0.046	-12.39	5.229	0.221	-8.059	5.965
62	/	/	/	/	/	/	/	/	/
63	-1.308	-16.055	0.62	-0.373	-14.733	3.494	0.244	-7.905	5.884
64	-0.103	-16.591	0.423	0.213	-15.339	3.623	0.681	-8.218	6.168
65	0.202	-15.3	0.158	0.018	-14.133	3.173	0.29	-7.471	5.805
66	0.393	-15.608	0.928	0.484	-14.559	3.577	0.965	-8.96	5.85
67	-0.576	-15.833	0.281	-0.017	-14.481	3.751	0.284	-8.614	5.741
68	-0.522	-16.506	0.011	-0.113	-15.507	3.006	0.416	-8.307	5.965
69	-0.183	-15.08	0.316	-0.073	-14.031	3.476	0.511	-7.333	5.818
70	-1.234	-15.741	-0.221	0.289	-12.017	5.468	0.577	-8.014	6.098
71	-0.423	-15.889	-0.332	-0.062	-14.034	4.128	0.226	-7.584	5.808
72	0.963	-15.96	0.096	0.995	-15.288	2.398	0.618	-8.117	5.888
73	-0.067	-14.432	0.622	0.947	-13.599	3.828	1.976	-7.269	6.848
74	0.449	-15.521	-0.635	0.465	-12.045	4.811	0.419	-8.225	5.823
75	-1.543	-15.47	0.008	-0.437	-12.631	4.877	0.122	-7.886	5.86
76	-0.72	-17.042	0.374	0.142	-15.41	3.825	0.853	-8.747	6.069
77	-0.843	-14.796	0.519	-0.532	-14.511	2.397	0.51	-7.774	6.16
78	-0.405	-15.771	0.514	0.178	-12.081	5.408	0.395	-7.765	6.148
79	-0.414	-15.141	0.301	0.025	-13.698	3.834	0.411	-7.776	5.929
80	-0.562	-15.251	0.401	-0.063	-14.42	3.155	0.519	-7.901	6.05
81	-0.401	-15.492	0.741	0.236	-13.541	4.527	1.003	-9.006	5.993
82	-0.29	-15.21	0.587	0.097	-14.126	3.644	0.314	-7.922	5.971

Notes: "/" means the coordinate value of this sample could not measure or singular value due to the pattern aspect reason.

Table F.3 - Feature point coordinates (S1 - S3), cm

number of jacket sample	Coordinates of points								
	S1			S2			S3		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-1.529	0.875	-0.736	0.966	-7.659	-7.13	3.063	-14.885	-5.006
2	-0.898	1.259	-0.103	0.329	-6.761	-6.964	1.757	-14.022	-5.755
3	-1.376	1.02	-0.119	0.426	-6.967	-7.039	2.517	-14.897	-5.195
4	-1.011	1.417	-0.198	0.904	-7.8	-7.29	2.17	-14.973	-6.035
5	/	/	/	/	/	/	/	/	/
6	-0.713	1.409	-0.328	0.726	-6.407	-7.104	2.872	-15.262	-5.32
7	-1.12	0.979	-0.067	0.83	-7.674	-7.108	3.197	-15.192	-4.733
8	-0.933	1.544	-0.221	0.389	-7.266	-7.14	2.674	-15.413	-5.573
9	-0.872	1.298	-0.038	0.46	-6.58	-6.927	2.721	-14.771	-5.522
10	-1.188	1.347	-0.22	0.665	-6.978	-7.129	2.67	-14.544	-5.692
11	-1.044	1.3	-0.132	0.666	-6.96	-7.062	3.333	-15.324	-5.051
12	-3.017	-0.183	-0.041	-0.26	-9.739	-6.888	3.294	-18.897	-4.105
13	-0.755	1.617	-0.151	0.346	-6.85	-6.996	1.991	-14.548	-6.084
14	-0.893	1.309	-0.249	0.864	-7.434	-7.159	3.041	-14.756	-5.432
15	-0.477	1.694	-0.204	0.808	-7.45	-7.255	2.857	-15.194	-5.628
16	-1.009	1.313	-0.206	0.556	-7.317	-7.015	2.427	-14.468	-5.79
17	-1.232	1.048	-0.184	0.509	-7.262	-7.017	2.732	-14.195	-5.627
18	-1.017	1.216	-0.248	0.845	-7.579	-7.136	3.604	-16.495	-2.784
19	-1.809	0.929	-0.047	-0.171	-7.194	-6.731	3.526	-16.745	-4.238
20	-1.252	1.255	-0.188	0.266	-6.917	-7.461	3.35	-18.108	-4.324
21	-0.928	1.314	-0.231	0.642	-6.039	-7.079	3.362	-15.345	-4.081
22	-1.188	1.307	-0.121	0.454	-6.563	-6.985	2.37	-12.745	-6.803
23	-0.162	1.477	-0.491	0.6	-6.636	-7.053	3.611	-15.89	-4.148
24	-1.474	1.007	-0.204	0.769	-7.708	-7.071	3.442	-16.153	-4.241
25	/	/	/	/	/	/	/	/	/
26	-1.609	0.846	0.221	0.66	-8.411	-6.912	3.624	-16.661	-3.462
27	-0.971	1.475	-0.862	1.352	-8.097	-7.176	3.224	-12.918	-4.256
28	-0.826	1.177	-0.295	0.885	-7.633	-7.125	3.102	-14.649	-5.101
29	/	/	/	/	/	/	/	/	/
30	-0.037	1.62	-0.47	0.927	-6.4	-7.265	3.383	-15.422	-4.911
31	-1.417	1.059	-0.231	0.303	-6.467	-7.074	3.388	-15.524	-4.525
32	-1.217	0.832	-0.102	0.476	-7.251	-6.962	2.718	-14.236	-5.31
33	-1.021	1.315	-0.531	0.648	-7.063	-7.118	3.384	-14.554	-3.667
34	/	/	/	/	/	/	/	/	/
35	-0.524	1.447	0.015	0.762	-7.708	-7.119	2.767	-14.341	-5.637
36	-2.159	0.654	-0.018	-0.602	-7.191	-6.537	/	/	/
37	-2.212	0.325	-0.72	0.816	-8.557	-6.903	2.885	-15.142	-4.742
38	-1.061	0.998	-0.363	0.512	-6.697	-6.987	2.073	-12.88	-5.959
39	-0.055	1.711	-0.587	1.232	-5.711	-7.413	3.082	-13.199	-5.047
40	-1.483	1.135	-0.384	0.861	-7.828	-7.08	3.381	-15.47	-5.169
41	-0.64	1.355	-0.28	0.805	-7.496	-7.124	2.94	-14.205	-4.842
42	/	/	/	/	/	/	/	/	/
43	-1.092	1.46	-0.525	0.346	-7.078	-6.943	3.344	-16.378	-4.063
44	-0.541	1.526	-0.912	1.17	-7.802	-7.211	3.328	-14.228	-3.48

45	-1.374	1.263	-0.272	0.612	-6.956	-7.097	3.445	-15.6	-4.529
46	-1.396	0.995	-0.275	0.708	-7.939	-7.019	2.987	-14.483	-5.211
47	-1.372	0.685	-0.362	1.056	-8.14	-7.073	3.598	-15.404	-2.755
48	-0.346	1.264	-0.281	0.937	-7.388	-7.158	2.822	-13.378	-5.194
49	-1.334	0.989	-0.314	0.709	-7.892	-7.021	2.701	-13.933	-5.189
50	-0.6	1.512	-0.41	0.436	-6.252	-7.127	/	/	/
51	0.504	1.873	-0.762	0.853	-5.495	-7.093	2.448	-13.011	-6.087
52	-1.728	1.119	-0.687	1.115	-7.876	-7.154	3.09	-14.354	-4.903
53	-1.197	1.143	-0.303	0.932	-8.041	-7.064	2.997	-13.564	-4.758
54	-1.101	1.347	-0.635	0.598	-7.604	-7.019	3.395	-14.308	-3.67
55	-0.445	1.376	-0.62	0.721	-5.796	-7.144	3.034	-13.75	-5.179
56	-0.989	1.204	-0.577	0.838	-7.497	-7.139	2.556	-14.068	-5.692
57	-1.319	1.082	-0.283	0.752	-7.5	-7.124	2.972	-15.25	-5.805
58	-0.657	1.442	-0.418	0.674	-6.713	-7.119	2.848	-14.077	-5.311
59	-1.066	1.426	-0.339	0.398	-6.282	-6.992	3.099	-13.67	-4.745
60	-1.793	0.926	-0.212	0.89	-7.844	-7.069	2.871	-14.181	-5.222
61	-1.263	1.162	-0.149	0.764	-8.165	-6.967	2.142	-13.915	-5.728
62	/	/	/	/	/	/	/	/	/
63	-1.398	1.076	-0.335	0.337	-6.771	-6.959	2.347	-14.761	-5.314
64	-0.086	1.696	-0.645	0.864	-6.447	-7.22	2.903	-14.52	-5.703
65	-0.518	1.278	-0.581	0.996	-7.458	-7.193	3.124	-13.896	-4.767
66	-1.388	1.374	-0.551	0.777	-7.581	-7.099	3.263	-13.541	-4.394
67	-1.218	1.189	-0.302	0.085	-6.614	-6.778	2.977	-14.455	-5.185
68	-1.169	1.322	-0.448	1.09	-8.191	-7.117	3.021	-14.358	-5.343
69	-0.274	1.671	-0.508	1.054	-8.077	-7.15	3.016	-13.189	-5.026
70	-0.292	1.448	-0.584	0.472	-5.387	-6.953	2.524	-13.722	-5.745
71	-0.44	1.477	-0.45	0.105	-6.134	-6.809	2.508	-14.038	-5.479
72	-1.613	0.959	-0.337	0.581	-7.701	-7	3.376	-15.623	-3.964
73	0.739	2.061	-0.33	0.951	-3.798	-6.862	2.978	-13.635	-5.099
74	-1.197	1.158	-0.508	0.994	-7.878	-7.118	2.642	-13.973	-5.313
75	-1.518	1.192	-0.369	0.394	-6.541	-6.989	2.473	-14.91	-5.238
76	-0.411	1.664	-0.81	1.145	-6.421	-7.687	3.246	-15.191	-5.157
77	-1.004	0.703	-0.435	1.234	-7.314	-7.242	3.415	-14.345	-3.887
78	-0.256	1.599	-0.475	1.15	-8.49	-7.107	2.413	-12.755	-5.758
79	-0.763	1.62	-0.638	0.402	-6.219	-7.111	2.971	-12.426	-5.182
80	-1.509	0.242	-0.124	0.949	-8.459	-6.958	2.871	-14.166	-5.228
81	-0.903	1.318	0.089	1.002	-8.49	-7.036	1.791	-11.785	-6.359
82	-1.117	1.325	-0.659	0.523	-6.322	-7.176	3.329	-13.76	-3.955

Notes: “/” means the coordinate value of this sample could not measure or singular value due to the pattern aspect reason.

Table F.4 - Feature point coordinates (S4 - S6), cm

number of jacket sample	Coordinates of points								
	S4			S5			S6		
	X	Y	Z	X	Y	Z	X	Y	Z
1	3.635	-16.591	-1.594	3.466	-14.965	2.058	1.654	-8.393	4.235
2	3.696	-16.848	-1.715	3.366	-14.352	2.69	2.024	-7.276	4.436
3	3.755	-17.075	-1.313	3.519	-15.992	1.507	2.251	-9.509	4.216
4	3.669	-17.3	-1.706	3.433	-15.882	1.892	2.017	-8.387	4.605
5	/	/	/	/	/	/	/	/	/
6	3.707	-17.11	-1.472	3.401	-15.879	1.951	2.068	-8.41	4.605
7	3.74	-16.842	-1.487	3.533	-15.363	1.821	2.237	-8.804	4.39
8	3.608	-17.4	-2.037	3.379	-15.144	2.527	2.193	-8.896	4.747
9	3.668	-17.025	-1.369	3.411	-15.276	2.275	2.191	-7.948	4.589
10	3.668	-16.82	-1.728	3.425	-15.197	2.054	1.907	-7.849	4.598
11	3.663	-17.068	-1.771	3.438	-15.619	1.956	2.046	-8.048	4.579
12	3.883	-19.619	-0.696	2.445	-16.631	3.703	1.497	-9.577	4.062
13	3.668	-16.846	-1.674	3.382	-15.353	2.078	1.687	-7.862	4.681
14	3.706	-17.031	-1.598	3.491	-15.364	1.943	2.306	-8.923	4.442
15	3.663	-16.993	-1.384	3.233	-15.379	2.815	1.405	-7.956	5.682
16	3.705	-16.831	-1.678	3.39	-15.441	2.051	2.03	-8.362	4.534
17	3.711	-16.37	-1.857	3.615	-14.611	1.918	2.069	-7.962	4.242
18	3.656	-16.833	-1.598	3.843	-16.838	-0.845	2.421	-9.084	4.389
19	3.745	-17.623	-1.193	2.958	-15.793	2.954	1.005	-9.184	4.806
20	3.645	-18.658	-0.979	3.597	-17.708	2.183	2.215	-10.706	5.584
21	3.729	-16.764	-1.582	3.447	-15.909	1.289	2.127	-8.502	4.308
22	3.63	-16.403	-2.189	/	/	/	2.027	-8.704	4.45
23	3.786	-17.313	-0.994	3.569	-16.961	0.729	2.179	-8.789	4.622
24	3.739	-16.852	-1.492	3.745	-16.223	1.039	2.08	-8.633	4.274
25	/	/	/	/	/	/	/	/	/
26	3.685	-17.33	-0.997	3.462	-16.275	1.729	1.646	-9.536	4.399
27	4.263	-14.731	0.042	3.455	-13.951	1.918	1.734	-7.58	4.335
28	3.736	-16.725	-1.556	3.504	-14.529	2.101	2.208	-8.418	4.193
29	/	/	/	/	/	/	/	/	/
30	3.621	-16.535	-1.866	3.418	-15.307	2.04	2.03	-7.073	4.786
31	3.744	-16.915	-1.518	3.47	-15.661	1.885	1.891	-9.05	4.43
32	3.626	-16.611	-1.657	3.193	-12.725	3.302	2.262	-8.758	4.089
33	4.211	-15.647	-0.651	3.539	-14.196	2.101	1.895	-7.601	4.575
34	/	/	/	/	/	/	/	/	/
35	3.588	-16.298	-1.913	3.474	-14.102	2.45	2.4	-8.22	4.257
36	3.773	-17.3	-1.119	/	/	/	2.583	-11.63	4.364
37	3.683	-18.207	-0.618	3.438	-16.697	1.786	1.802	-9.109	4.096
38	3.699	-16.159	-2.02	2.873	-12.098	3.837	1.931	-7.95	4.323
39	4.23	-15.484	-0.674	3.431	-13.988	2.324	1.882	-7.245	4.755
40	3.755	-16.822	-1.415	3.437	-15.211	1.485	2.341	-8.89	4.124
41	3.558	-16.072	-2.177	3.309	-13.331	2.745	2.246	-8.213	4.479
42	/	/	/	/	/	/	/	/	/
43	3.7	-17.405	-0.885	3.429	-16.487	1.732	1.658	-9.259	4.387
44	4.041	-15.134	-0.525	3.459	-14.047	2.274	1.879	-7.345	4.762

45	3.628	-16.56	-1.987	3.31	-13.137	3.071	2.231	-8.45	4.429
46	3.69	-16.188	-1.708	3.479	-14.858	1.941	2.117	-8.542	4.249
47	3.563	-16.337	-1.024	3.453	-15.692	1.504	1.987	-8.468	4.287
48	3.664	-16.139	-1.71	3.453	-14.614	1.565	2.409	-8.161	4.261
49	3.627	-16.172	-1.51	3.412	-13.711	2.747	2.164	-8.379	4.242
50	3.594	-16.043	-2.245	/	/	/	2.122	-7.592	4.387
51	3.735	-15.606	-2.16	3.439	-13.405	2.446	2.266	-7.177	4.341
52	3.492	-16.123	-0.186	3.341	-14.893	2.426	1.73	-8.295	4.351
53	3.489	-15.712	-1.486	3.455	-14.154	1.889	2.289	-8.278	4.174
54	4.08	-14.904	-1.376	3.195	-12.1	3.407	2.125	-7.594	4.357
55	3.79	-16.645	-1.355	3.456	-15.328	1.631	2.058	-8.16	4.184
56	3.678	-15.779	-2.232	3.316	-12.423	3.279	2.437	-8.898	4.175
57	3.587	-16.494	-2.303	3.414	-13.869	2.574	2.229	-8.546	4.178
58	3.642	-16.209	-1.819	3.393	-13.449	2.783	2.377	-8.012	4.327
59	4.181	-15.81	-0.178	2.789	-13.28	3.387	1.744	-8.2	4.54
60	3.761	-16.336	-1.658	3.335	-13.607	2.901	2.02	-8.869	4.109
61	3.812	-16.76	-1.567	3.048	-12.871	3.484	2.159	-8.37	4.257
62	/	/	/	/	/	/	/	/	/
63	3.795	-17.343	-0.51	3.377	-15.446	2.195	1.904	-8.164	4.417
64	3.73	-17.093	-1.439	3.63	-15.392	1.606	2.183	-8.082	4.493
65	3.778	-16.182	-1.503	3.446	-14.736	1.691	2.061	-7.649	4.244
66	4.087	-15.646	-0.263	3.458	-14.294	2.219	1.946	-8.647	4.478
67	3.759	-16.492	-1.567	3.488	-14.784	1.992	2.099	-8.829	4.197
68	3.652	-16.766	-1.544	3.444	-15.628	1.44	1.906	-8.338	4.549
69	4.286	-14.981	-0.652	3.478	-13.561	2.356	1.775	-6.921	4.622
70	3.705	-16.515	-1.807	3.085	-12.31	3.537	2.224	-8.194	4.253
71	3.564	-16.423	-1.934	3.47	-14.436	2.344	1.963	-7.812	4.236
72	3.748	-17.01	-1.378	3.5	-16.44	1.001	2.094	-8.675	4.156
73	3.573	-16.202	-1.589	3.564	-14.829	1.618	2.721	-7.762	4.501
74	3.759	-15.971	-1.548	3.151	-12.265	3.389	2.208	-8.355	4.197
75	3.619	-16.521	-1.871	3.205	-13.043	2.912	2.072	-8.188	4.174
76	3.776	-17.182	-1.159	3.417	-15.313	2.195	2.027	-8.513	4.395
77	3.637	-16.398	-0.051	3.57	-15.946	1.535	2.066	-8.443	4.401
78	3.462	-15.584	-0.939	3.027	-11.806	3.708	2.194	-7.476	4.534
79	4.136	-14.609	-1.048	3.534	-13.049	2.417	1.735	-7.26	4.485
80	3.735	-16.858	-1.511	3.454	-15.911	1.359	2.276	-8.871	4.133
81	3.796	-16.416	-1.405	3.42	-14.134	2.566	2.548	-9.381	4.17
82	3.016	-15.16	-0.539	3.43	-13.827	2.362	1.54	-7.548	4.351

Notes: “/” means the coordinate value of this sample could not measure or singular value due to the pattern aspect reason.

APPENDIX G

Coding for sleeve-armhole fit judgement by feature points coordinate

```
class RV(): # RV means RangeValue
    A2xU = -7.16 #point Armhole2 AxisX Under
    A2xM = -6.14 #point Armhole2 AxisX More than
    A2yU = 8.09
    A2yM = 10.07

    A3xU = -5.01
    A3xM = -3.21
    A3yU = 1.14
    A3yM = 2.23

    A5xU = 2.57
    A5xM = 4.86
    A5yU = 0.59
    A5yM = 2.29

    A6xU = 5.67
    A6xM = 6.84
    A6yU = 6.99
    A6yM = 8.26

    TexU = -10.37 #Top point of elbow seam AxisX Under
    TexM = -9.13
    TeyU = 8.99
    TeyM = 10.31

    TcxU = -1.15 #Top point of sleeve cap AxisX Under
    TcxM = 0.03
    TcyU = 15.67
    TcyM = 16.89

    TfxU = 7.4 #Top point of front seam AxisX Under
    TfxM = 8.48
    TfyU = 7.04
    TfyM = 9.02


A2x = float(input('Point Armhole2 X coordination is：'))
A2y = float(input('Point Armhole2 Y coordination is：'))
A3x = float(input('Point Armhole3 X coordination is：'))
```

```
A3y = float(input('Point Armhole3 Y coordination is：'))
A5x = float(input('Point Armhole5 X coordination is：'))
A5y = float(input('Point Armhole5 Y coordination is：'))
A6x = float(input('Point Armhole6 X coordination is：'))
A6y = float(input('Point Armhole6 Y coordination is：'))


if A2x >= RV.A2xU and A2x <= RV.A2xM:
    if A2y >= RV.A2yU and A2y <= RV.A2yM:
        if A3x >= RV.A3xU and A3x <= RV.A3xM:
            if A3y >= RV.A3yU and A3y <= RV.A3yM:
                if A5x >= RV.A5xU and A5x <= RV.A5xM:
                    if A5y >= RV.A5yU and A5y <= RV.A5yM:
                        if A6x >= RV.A6xU and A6x <= RV.A6xM:
                            if A6y >= RV.A6yU and A6y <= RV.A6yM:
                                print('\nCongratulation!\nThis is a Fit Armhole,
let us continue check Sleeve Cap.')

else:
    print("\nSorry!\nMisfit Armhole, please check again.")
    input('')

Tex = float(input('Top point of elbow seam coordination X is：'))
Tey = float(input('Top point of elbow seam coordination Y is：'))
Tcx = float(input('Top point of sleeve cap coordination X is：'))
Tcy = float(input('Top point of sleeve cap coordination Y is：'))
Tfx = float(input('Top point of front seam coordination X is：'))
Tfy = float(input('Top point of front seam coordination Y is：'))

if Tex >= RV.TexU and Tex <= RV.TexM:
    if Tey >= RV.TeyU and Tey <= RV.TeyM:
        if Tcx >= RV.TcxU and Tcx <= RV.TcxM:
            if Tcy >= RV.TcyU and Tcy <= RV.TcyM:
                if Tfx >= RV.TfxU and Tfx <= RV.TfxM:
                    if Tfy >= RV.TfyU and Tfy <= RV.TfyM:
                        print('\nCongratulation!\nWe predict this sleeve will have
defect after sewing.')

else:
    print("\nSorry!\nMisfit sleeve, please amend this sleeve.")
```

APPENDIX H

Coding for recommend sleeve index range

```
bust_girth = float(input('bust girth is：'))
Closed_armhole_depth = float(input('Closed armhole depth is：'))

if 47.15 <= bust_girth <= 50.43 and    15.5 <= Closed_armhole_depth <=18:
    print('\nThis is a perfect armhole, let us continue.')
elif 46.7 <= bust_girth <= 51.44 and    14.8 <= Closed_armhole_depth <= 19.7:
    print('\nThis is Good fit armhole, please check again and amend it to perfect ')
else:
    print('\nThis sample is out of fit range')
    input('')#for blank

Armhole_length = float(input('the Armhole_length of pattern is：'))

if 43.32 <= Armhole_length <= 45.44:
    print('''recommed sleeve pattern index range are:\n
sleeve cap curve length(48.66-50.36)\r
difference ratio between SCL and AHL(8.5%-11.1%)\r
sleeve cap height(15.57-17.66)\r
sleeve cap width(31.52-37.84)\r
''')

elif 45.45 <= Armhole_length <= 46.96:
    print('''recommed sleeve pattern index range are:\n
sleeve cap curve length(48.62-50.98)\r
difference ratio between SCL and AHL(6%-9.4%)\r
sleeve cap height(15.57-17.66)\r
sleeve cap width(31.52-37.84)\r
''')

elif 46.97 <=Armhole_length <= 48.54:
    print('''recommed sleeve pattern index range are:\n
sleeve cap curve length(48.62-51.62)\r
difference ratio between SCL and AHL(2.5%-7.9%)\r
sleeve cap height(15.57-17.66)\r
sleeve cap width(31.52-37.84)\r
''')

elif 48.55 <=Armhole_length <= 50.88:
    print('''recommed sleeve pattern index range are:\n
sleeve cap curve length(51.53-54.13)\r
```

```
difference ratio between SCL and AHL(4.4%-8.5%)\r
sleeve cap height(15.57-17.66)\r
sleeve cap width(31.52-37.84)\r
''')

else:
    print('the Armhole length may not right, please check again')
```

APPENDIX I

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No. 03006712

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2018年09月14日

14,09,2018

APPENDIX J

Processing of pressure measurement

Table J.1 - Initial pressure measurement results

Jacket	Sensor point	Pressure measurement results,kPa																				$\overline{x}$	S_n
Material 1																							
1	Ps1	0.39	0.82	0.99	1.1	1.07	1.29	1.1	1.27	1.69	1.42	1.18	1.34	1.35	1.03	0.68	1.11	-	-	-	-	1.1	0.3
	Ps2	0.15	0.19	0.52	0.54	0.69	0.77	0.8	0.61	0.74	0.61	0.59	0.52	0.63	0.52	0.4	0.74	0.83	0.78	-	-	0.59	0.1
	Ps3	0.52	0.34	0.54	0.51	0.57	0.63	0.71	0.63	0.62	0.67	0.63	0.62	0.49	0.49	0.39	0.48	0.43	0.36	-	-	0.53	0.1
	Ps4	1.23	1.99	1.91	1.62	1.78	1.59	1.73	1.63	1.37	1.14	1.23	1.24	1.19	1.54	1.48	1.59	-	-	-	-	1.51	0.2
2	Ps1	0.29	0.51	0.52	0.27	0.87	0.66	1.19	1.18	1.19	1.29	1.22	0.75	1.43	0.96	1.14	1.1	1.25	1.42	-	-	0.95	0.3
	Ps2	0.25	0.67	0.36	0.27	0.33	0.22	0.22	0.3	0.4	0.31	0.32	0.36	0.37	0.47	0.5	0.48	0.57	0.18	-	-	0.36	0.1
	Ps3	0.16	0.27	0.25	0.35	0.29	0.27	0.25	0.28	0.3	0.35	0.33	0.3	0.27	0.28	-	-	-	-	-	-	0.28	0.04
	Ps4	0.52	0.55	0.83	0.86	0.73	0.78	0.83	0.79	0.81	0.74	0.81	0.84	0.88	0.97	0.93	0.61	-	-	-	-	0.78	0.1
3	Ps1	0.36	0.66	0.93	0.99	0.85	0.74	0.99	0.95	1	1	1.15	0.93	1	0.99	0.93	0.91	0.94	0.79	-	-	0.89	0.2
	Ps2	0.15	0.22	0.4	0.38	0.3	0.39	0.39	0.45	0.42	0.24	0.41	0.48	0.38	0.48	0.46	0.31	0.4	0.41	-	-	0.37	0.09
	Ps3	0.11	0.08	0.18	0.19	0.14	0.3	0.08	0.16	0.28	0.21	0.12	0.22	0.24	0.21	-	-	-	-	-	-	0.18	0.06
	Ps4	0.11	0.22	0.32	0.45	0.37	0.41	0.29	0.36	0.35	0.4	0.36	0.44	0.4	0.42	0.42	0.38	-	-	-	-	0.35	0.08
4	Ps1	0.14	0.15	0.47	0.59	0.67	0.85	0.56	0.79	0.74	0.47	0.52	0.68	0.97	0.99	0.88	0.81	0.77	0.6	-	-	0.6	0.3
	Ps2	0.45	0.28	0.44	0.25	0.21	0.15	0.17	0.26	0.17	0.27	0.24	0.21	0.19	0.13	0.14	0.27	-	-	-	-	0.22	0.07
	Ps3	0.13	0.07	0.16	0.18	0.15	0.22	0.17	0.21	0.22	0.12	0.18	0.23	0.22	0.15	0.18	0.14	0.11	0.16	-	-	0.16	0.04
	Ps4	0.14	0.34	0.34	0.3	0.54	0.38	0.33	0.38	0.37	0.32	0.32	0.37	0.31	0.29	0.35	0.39	-	-	-	-	0.32	0.1
Material 2																							
1	Ps1	0.24	0.13	0.11	0.09	0.16	0.2	0.52	0.35	0.15	0.42	0.48	0.14	0.2	0.17	0.34	0.47	-	-	-	-	0.26	0.1
	Ps2	0.5	0.46	0.66	0.55	0.47	0.54	0.44	0.58	0.53	0.59	0.49	0.61	0.51	0.54	0.32	0.24	0.37	0.27	0.19	0.25	0.45	0.08
	Ps3	0.16	0.17	0.21	0.12	0.2	0.21	0.11	0.18	0.17	0.23	0.21	0.11	0.16	0.2	0.14	0.22	0.29	0.15	-	-	0.18	0.04
	Ps4	0.29	0.48	0.63	0.64	0.6	0.54	0.66	0.74	0.77	0.81	0.75	0.8	0.82	0.75	0.78	0.77	0.68	0.74	-	-	0.68	0.1
2	Ps1	0.12	0.25	0.65	0.9	0.73	0.07	0.12	0.07	0.07	0.03	0.12	0.15	0.33	0.17	0.09	0.07	-	-	-	-	0.24	0.2
	Ps2	0.11	0.21	0.16	0.17	0.22	0.21	0.29	0.26	0.38	0.48	0.29	0.42	0.45	0.41	0.25	0.19	-	-	-	-	0.28	0.1
	Ps3	0.18	0.13	0.19	0.23	0.18	0.15	0.11	0.14	0.08	0.08	0.1	0.06	-	-	-	-	-	-	-	-	0.14	0.04
	Ps4	0.38	0.58	0.52	0.71	0.4	0.38	0.38	0.42	0.44	0.42	0.4	0.45	0.41	0.42	0.48	0.45	0.48	0.56	-	-	0.44	0.1
3	Ps1	0.36	0.01	0.12	0.29	0.61	0.22	0.19	0.04	0.04	0.14	0.08	0.02	0.18	0.11	-	-	-	-	-	-	0.17	0.1
	Ps2	0.12	0.11	0.14	0.18	0.11	0.19	0.18	0.09	0.17	0.19	0.07	0.18	0.07	0.1	0.27	0.11	-	-	-	-	0.14	0.05
	Ps3	0.12	0.11	0.07	0.13	0.1	0.07	0.13	0.1	0.08	0.13	0.09	0.09	0.13	0.08	0.08	0.14	-	-	-	-	0.1	0.02
	Ps4	0.14	0.34	0.34	0.3	0.34	0.38	0.33	0.38	0.37	0.32	0.32	0.37	0.31	0.29	0.35	0.39	-	-	-	-	0.33	0.05
4	Ps1	0.48	0.34	0.27	0.27	0.1	0.05	0.06	0.21	0.19	0.2	0.09	0.03	0.11	0.05	0.23	0.17	-	-	-	-	0.17	0.1
	Ps2	0.18	0.14	0.09	0.11	0.18	0.14	0.14	0.19	0.18	0.12	0.26	0.17	0.14	0.12	-	-	-	-	-	-	0.15	0.04
	Ps3	0.13	0.07	0.07	0.08	0.1	0.14	0.1	0.07	0.11	0.12	0.05	0.04	0.07	0.05	0.03	0.05	-	-	-	-	0.08	0.03

	Ps4	0.11	0.51	0.23	0.3	0.3	0.29	0.32	0.26	0.33	0.37	0.34	0.32	0.32	0.31	0.28	0.3	0.27	0.27	-	-	0.29	0.1
Material 3																							
1	Ps1	0.13	0.01	0.12	0.01	0.07	0.05	0.02	0.02	0.01	0.01	-	-	-	-	-	-	-	-	-	-	0.05	0.04
	Ps2	0.5	0.53	0.36	0.55	0.5	0.47	0.35	0.35	0.25	0.3	-	-	-	-	-	-	-	-	-	-	0.41	0.1
	Ps3	0.11	0.14	0.22	0.16	0.18	0.1	0.13	0.13	0.19	0.17	0.16	0.16	0.14	0.14	0.17	0.17	-	-	-	-	0.15	0.02
	Ps4	0.4	0.36	0.49	0.75	0.61	0.47	0.63	0.53	0.44	0.55	0.56	0.55	0.64	0.6	0.59	0.65	-	-	-	-	0.55	0.1
2	Ps1	0.15	0.01	0.02	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.04
	Ps2	0.14	0.31	0.21	0.15	0.29	0.33	0.34	0.23	0.29	0.35	-	-	-	-	-	-	-	-	-	-	0.26	0.7
	Ps3	0.14	0.1	0.19	0.11	0.07	0.13	0.12	0.16	0.18	0.17	0.16	0.15	0.12	0.18	0.18	0.23	-	-	-	-	0.14	0.04
	Ps4	0.17	0.25	0.28	0.23	0.33	0.33	0.38	0.35	0.34	0.49	0.38	0.33	0.44	0.47	0.35	0.43	-	-	-	-	0.34	0.08
3	Ps1	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
	Ps2	0.15	0.04	0.11	0.15	0.18	0.35	0.33	0.04	0.08	0.23	0.14	0.21	0.13	0.12	0.18	0.11	0.14	0.16	-	-	0.15	0.08
	Ps3	0.14	0.06	0.08	0.06	0.06	0.04	0.01	0.12	0.12	0.16	0.09	0.08	0.14	0.12	0.14	0.18	0.17	0.2	-	-	0.1	0.05
	Ps4	0.27	0.25	0.25	0.27	0.23	0.24	0.26	0.25	0.23	0.25	0.27	0.25	0.25	0.27	0.25	0.25	-	-	-	-	0.25	0.01
4	Ps1	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
	Ps2	0.07	0.03	0.03	0.03	0.01	0.02	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.02
	Ps3	0.12	0.06	0.07	0.05	0.05	0.1	0.07	0.05	0.02	0.01	-	-	-	-	-	-	-	-	-	-	0.06	0.03
	Ps4	0.15	0.13	0.13	0.11	0.12	0.11	0.1	0.14	0.17	0.16	0.21	0.16	0.22	0.28	0.21	0.14	-	-	-	-	0.16	0.04

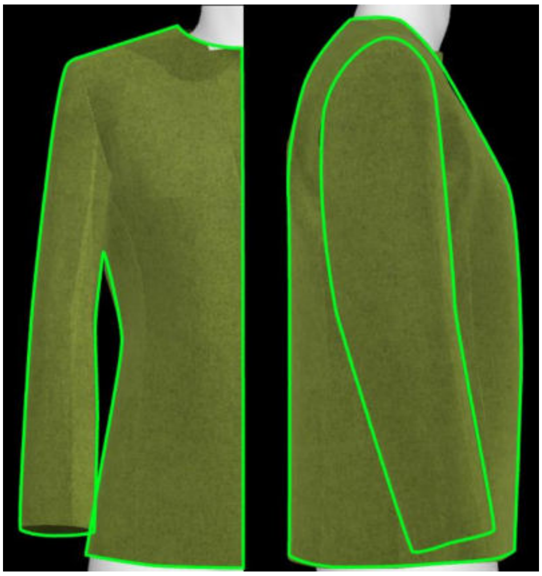
Table J.2 - Pressure measurement results after data clearing

Jacket	Sensor point	Pressure measurement results,kPa																	$\overline{X}$	S	$m_r \pm$
Material 1																					
1	Ps1	0.82	0.99	1.1	1.07	1.29	1.1	1.27	1.69	1.42	1.18	1.34	1.35	1.03	0.68	1.11	-		1.1	0.3	0.04
	Ps2	0.52	0.54	0.69	0.77	0.8	0.61	0.74	0.61	0.59	0.52	0.63	0.52	0.4	0.74	0.83	0.78		0.6	0.02	0.05
	Ps3	0.52	0.34	0.54	0.51	0.57	0.63	0.62	0.67	0.63	0.62	0.49	0.49	0.39	0.48	0.43	0.36	0.63	0.52	0.1	0.04
	Ps4	1.23	1.99	1.91	1.62	1.78	1.59	1.73	1.63	1.37	1.23	1.24	1.19	1.54	1.48	1.59	-	-	1.51	0.2	0.09
2	Ps1	0.51	0.52	0.87	0.66	1.19	1.18	1.19	1.29	1.22	0.75	1.43	0.96	1.14	1.1	1.25	1.42	-	0.95	0.3	0.14
	Ps2	0.25	0.36	0.27	0.33	0.22	0.22	0.3	0.4	0.31	0.32	0.36	0.37	0.47	0.5	0.48	0.57	-	0.36	0.1	0.04
	Ps3	0.27	0.25	0.35	0.29	0.27	0.25	0.28	0.3	0.35	0.33	0.3	0.27	0.28	-	-	-	-	0.28	0.04	0.02
	Ps4	0.52	0.55	0.83	0.86	0.73	0.78	0.83	0.79	0.81	0.74	0.81	0.84	0.88	0.97	0.93	0.61	-	0.78	0.1	0.05
3	Ps1	0.66	0.93	0.99	0.85	0.74	0.99	0.95	1	1	1.15	0.93	1	0.99	0.93	0.91	0.94	0.79	0.89	0.2	0.08
	Ps2	0.22	0.4	0.38	0.3	0.39	0.39	0.45	0.42	9.24	0.41	0.48	0.38	0.48	0.46	0.31	0.4	0.41	0.37	0.09	0.04
	Ps3	0.11	0.08	0.18	0.19	0.14	0.3	0.08	0.16	0.28	0.21	0.12	0.22	0.24	0.21	-	-	-	0.18	0.06	0.03
	Ps4	0.22	0.32	0.45	0.37	0.41	0.29	0.36	0.35	0.4	0.36	0.44	0.4	0.42	0.42	0.38	-	-	0.35	0.08	0.03
4	Ps1	0.47	0.59	0.67	0.85	0.56	0.79	0.74	0.47	0.52	0.68	0.97	0.99	0.88	0.81	0.77	0.6	-	0.6	0.3	0.14
	Ps2	0.28	0.25	0.21	0.15	0.17	0.26	0.17	0.27	0.24	0.21	0.19	0.13	0.14	0.27	-	-	-	0.22	0.07	0.03
	Ps3	0.13	0.16	0.18	0.15	0.22	0.17	0.21	0.22	0.12	0.18	0.23	0.22	0.15	0.18	0.14	0.11	0.16	0.16	0.04	0.02
	Ps4	0.34	0.34	0.3	0.54	0.38	0.33	0.38	0.37	0.32	0.32	0.37	0.31	0.29	0.35	0.39	-	-	0.32	0.1	0.05
Material 2																					
1	Ps1	0.24	0.13	0.11	0.09	0.16	0.2	0.35	0.15	0.42	0.48	0.14	0.2	0.17	0.34	0.47	-	-	0.26	0.1	0.05

	Ps2	0.5	0.46	0.66	0.55	0.47	0.54	0.44	0.58	0.53	0.59	0.49	0.61	0.51	0.54	0.32	0.37	0.27	0.45	0.08	0.03
	Ps3	0.16	0.17	0.21	0.12	0.2	0.21	0.11	0.18	0.17	0.23	0.21	0.11	0.16	0.2	0.14	0.22	0.15	0.18	0.04	0.02
	Ps4	0.48	0.63	0.64	0.6	0.54	0.66	0.74	0.77	0.81	0.75	0.8	0.82	0.75	0.78	0.77	0.68	0.74	0.68	0.1	0.04
2	Ps1	0.12	0.25	0.65	0.73	0.07	0.12	0.07	0.07	0.03	0.12	0.15	0.33	0.17	0.09	0.07	-	-	0.24	0.2	0.09
	Ps2	0.11	0.21	0.16	0.17	0.22	0.21	0.29	0.26	0.38	0.29	0.42	0.45	0.41	0.25	0.19	-	-	0.28	0.1	0.05
	Ps3	0.18	0.13	0.19	0.23	0.18	0.15	0.11	0.14	0.08	0.08	0.1	-	-	-	-	-	-	0.14	0.04	0.02
	Ps4	0.38	0.58	0.52	0.4	0.38	0.38	0.42	0.44	0.42	0.4	0.45	0.41	0.42	0.48	0.45	0.48	0.56	0.44	0.1	0.04
3	Ps1	0.36	0.12	0.29	0.22	0.19	0.04	0.04	0.14	0.08	0.18	0.11	-	-	-	-	-	-	0.17	0.1	0.05
	Ps2	0.12	0.11	0.14	0.18	0.11	0.19	0.18	0.09	0.17	0.19	0.07	0.18	0.07	0.1	0.11	-	-	0.14	0.05	0.02
	Ps3	0.12	0.11	0.07	0.13	0.1	0.07	0.13	0.1	0.08	0.13	0.09	0.09	0.13	0.08	0.08	0.14	-	0.1	0.02	0.01
	Ps4	0.34	0.34	0.3	0.34	0.38	0.33	0.38	0.37	0.32	0.32	0.37	0.31	0.29	0.35	0.39	-	-	0.33	0.05	0.02
4	Ps1	0.34	0.27	0.27	0.1	0.05	0.06	0.21	0.19	0.2	0.09	0.11	0.05	0.23	0.17	-	-	-	0.17	0.1	0.05
	Ps2	0.18	0.14	0.09	0.11	0.18	0.14	0.14	0.19	0.18	0.12	0.17	0.14	0.12	-	-	-	-	0.15	0.04	0.02
	Ps3	0.13	0.07	0.07	0.08	0.1	0.14	0.1	0.07	0.11	0.12	0.05	0.04	0.07	0.05	0.03	0.05	-	0.08	0.03	0.01
	Ps4	0.23	0.3	0.3	0.29	0.32	0.26	0.33	0.37	0.34	0.32	0.32	0.31	0.31	0.28	0.3	0.27	27	0.29	0.1	0.05
Material 3																					
1	Ps1	0.01	0.12	0.01	0.07	0.05	0.02	0.02	0.01	0.01	-	-	-	-	-	-	-	-	0.05	0.04	0.02
	Ps2	0.5	0.53	0.36	0.55	0.5	0.47	0.35	0.35	0.25	0.3	-	-	-	-	-	-	-	0.41	0.1	0.06
	Ps3	0.11	0.14	0.22	0.16	0.18	0.1	0.13	0.13	0.19	0.17	0.16	0.16	0.14	0.14	0.17	0.17	-	0.15	0.02	0.01
	Ps4	0.4	0.36	0.49	0.61	0.47	0.63	0.53	0.44	0.55	0.56	0.55	0.64	0.6	0.59	0.65	-	-	0.55	0.1	0.05
2	Ps1	0.01	0.02	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-	0.02	0.04	0.03
	Ps2	0.14	0.31	0.21	0.15	0.29	0.33	0.34	0.23	0.29	0.35	-	-	-	-	-	-	-	0.26	0.07	0.04
	Ps3	0.14	0.1	0.19	0.11	0.07	0.13	0.12	0.16	0.18	0.17	0.16	0.15	0.12	0.18	0.18	0.23	-	0.14	0.04	0.02
	Ps4	0.25	0.28	0.23	0.33	0.33	0.38	0.35	0.34	0.49	0.38	0.33	0.44	0.47	0.35	0.43	-	-	0.34	0.08	0.04
3	Ps1	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	0	0
	Ps2	0.15	0.11	0.15	0.18	0.35	0.33	0.08	0.23	0.14	0.21	0.13	0.12	0.18	0.11	0.14	0.16	-	0.15	0.08	0.04
	Ps3	0.14	0.08	0.06	0.06	0.04	0.01	0.12	0.12	0.16	0.09	0.08	0.14	0.12	0.14	0.18	17	0.2	0.1	0.05	0.02
	Ps4	0.27	0.25	0.25	0.27	0.23	0.24	0.26	0.25	0.23	0.25	0.27	0.25	0.25	0.27	0.25	0.25	-	0.25	0.01	0
4	Ps1	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	0	0	0
	Ps2	0.03	0.03	0.03	0.01	0.02	0.01	0.01	-	-	-	-	-	-	-	-	-	-	0.03	0.02	0.01
	Ps3	0.12	0.06	0.07	0.05	0.05	0.1	0.07	0.05	0.02	0.01	-	-	-	-	-	-	-	0.06	0.03	0.02
	Ps4	0.15	0.13	0.13	0.11	0.12	0.11	0.1	0.14	0.17	0.16	0.21	0.16	0.22	0.28	0.21	14	-	0.16	0.04	0.02

APPENDIX K

Virtual and real jacket comparison (surface, silhouette)



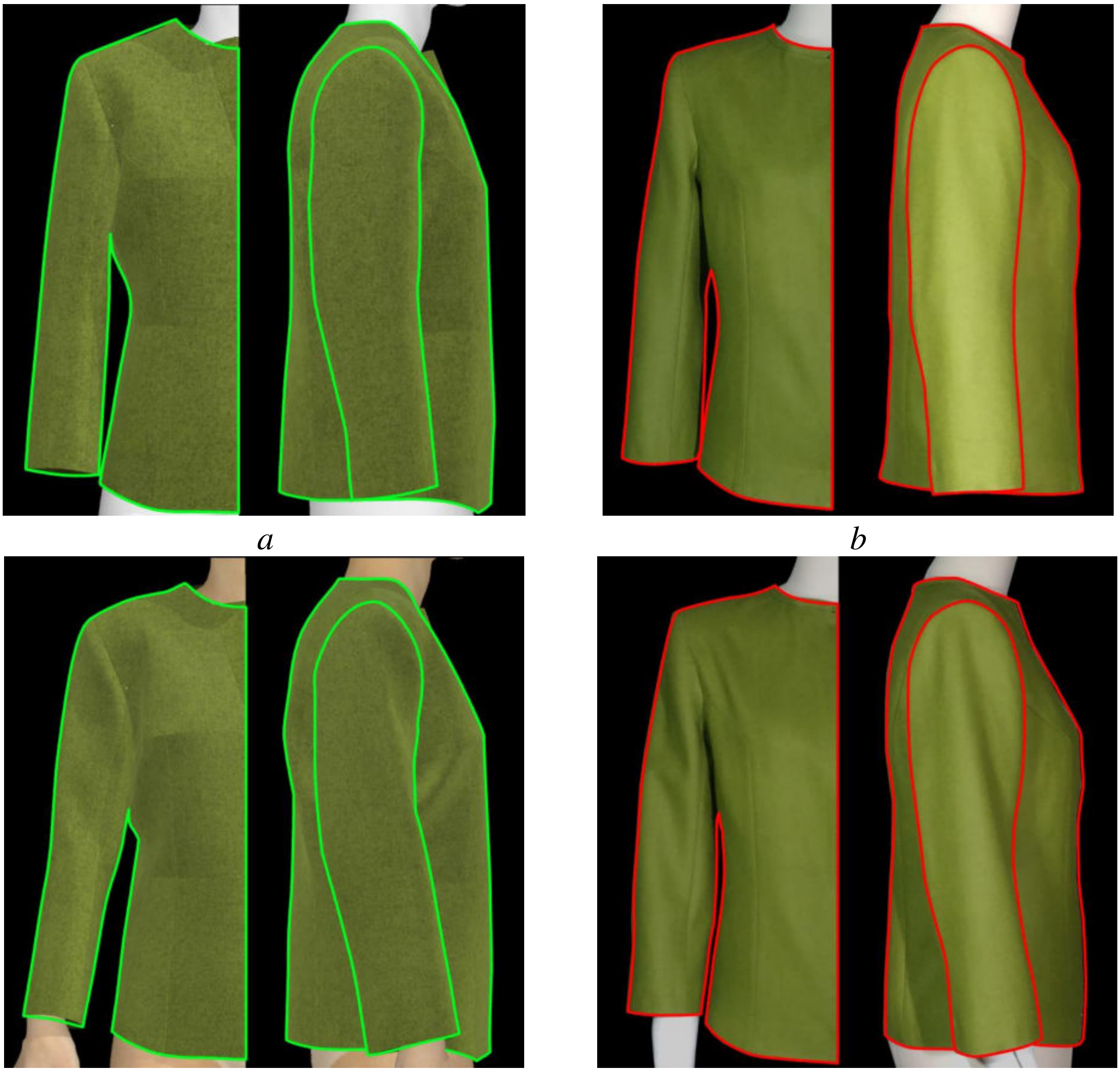
a

b

c

d

Figure K.1 - Virtual and real comparison on perfect fit jacket (front, profile): *a* - Sd, *b* - real dummy without sleeve, *c* - Sa, *d* - real dummy with sleeve



a *b* *c* *d*

Figure K.2 - Virtual and real comparison on poor fit jacket (front, profile): *a* - Sd, *b* - real dummy without sleeve, *c* - Sa, *d* - real dummy with sleeve

APPENDIX L

APPROVEMENT

Director of Yachi Apparel Company (China)

Wen, hui

16 March 2021

ACT of testing the technology result
of the dissertation of Wan Sida

We, the undersigned, Production Director Xu, Cheng, technologist Xu, Yuzhang of Yachi apparel company, and the head of department of clothing design V. Kuzmichev, graduate student Wan Sida from FSBEI HE "IVGPU", have compiled this testing act of the results obtained during the dissertation "Development of fit evaluation and prediction system of digital twins for women's classic jacket sleeves".

Date of testing: March 2021 - June 2022.

The system was implemented by the following components: (1) Software of drawing garments (ET, BUYI Technology, China); (2) Digital twins simulation (Clo3D, Clo virtual fashion LLC, Korea); (3) Module for sleeve fit judgment and prediction (Spyder-IDE, Python); (4) Grayscale evaluation (ImageJ, NIH,USA).

The system was used to evaluate and predict the fit of sleeve in actual production at the enterprise. Three mass-produced women's jackets were tested. The test result found that the system was effective in predicting the fit before actual production.

CONCLUSION

The developed jacket sleeve fit evaluation and prediction system met the requirement of enterprise, which improved the productivity of sleeve with consumer satisfaction.

From Yachi Apparel Company

Production director Xu, Cheng

Technologist Xu, Yuzhang

From IVGPU

Head of the Department clothing design V. E. Kuzmichev

Graduate student Wan, Sida