5
Objective evaluation of clothing fit

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5.1 Introduction

Clothing fit is generally assessed by qualitative methods. Although a quantitative method is more desirable, it is difficult to achieve. The main drawback of the qualitative approach is the lack of precision in subjective assessment and ineffective communication. Kohn and Ashdown[1] first used video-captured images of slashed test jackets for the analysis of fit for women aged between 55 and 65. Expert analysts and this image analysis method were both found capable of defining the complex interactions of the garment/body interface. The standardisation of clothing fit remains a complex and controversial subject.[2] This chapter introduces five main approaches to the objective evaluation and computation of clothing fit, namely the use of moiré optics, an algebraic mannequin, waveform, pressure mechanics and computer fit modelling.

5.2 Moiré optics

For the measurement of unstable soft objects, such as clothing, contact methods are not applicable because the objects deform readily. Shadow moiré topography[3] is an effective non-contact technique for capturing a 3D form on a 2D fringe pattern. It is a well-known technique, commonly used in the analysis of spinal deformities in the human body.

For clothing applications, Japanese researchers in the 1980s attempted to measure and evaluate clothing drape,[4] bagging,[5] wrinkling[6] and body shape[7] by means of moiré topography (Fig. 5.1). During the 1990s, further applications of the moiré technique were found in the area of pattern construction. Tomita *et al.*[8] brought out several publications dealing with investigations on basic dress patterns for the figures of older women. Yu *et al.*[9] have applied moiré topography for evaluating the fit of various clothing types. Examples are given in the following sections.

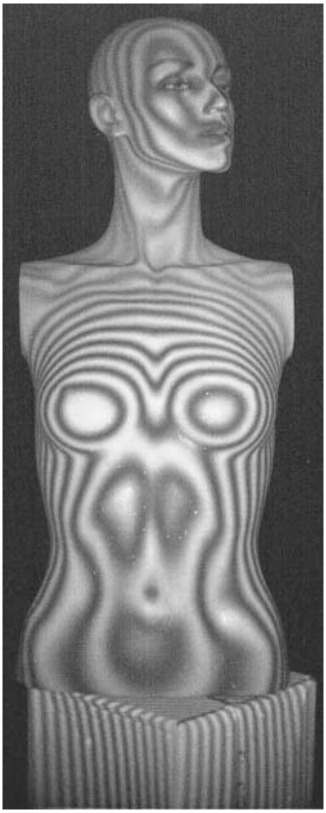


Figure 5.1 Moiré measurements of the human body.

5.2.1 Shape conformity of bra cup

Regarding the objective assessment of clothing shape, Yu[10] was the first to develop a moiré system for the measurement of bra cups, employing a special instrumental design[11] and technique to enhance the fringe visibility.[12] A metallic frame was constructed for controlling the position of the light source, the camera and the specimen with precise alignment (Fig. 5.2). To produce a moiré picture with a clear image, Yu developed a grid plate using photo-chemical processing and a pneumatic grid translation system for removing background 'noise'. The moiré picture was then digitised and the coordinates of the sectional profiles were quantified, using third-order polynomial functions (Fig. 5.3). Several measures of the shape characteristics were also derived.[13]

5.2.2 Moiré evaluation of clothing fit

For the non-contact shape measurement of a jacket, Yu *et al.*[14] developed another moiré topographic system (Fig. 5.4). The jacket worn by a mannequin

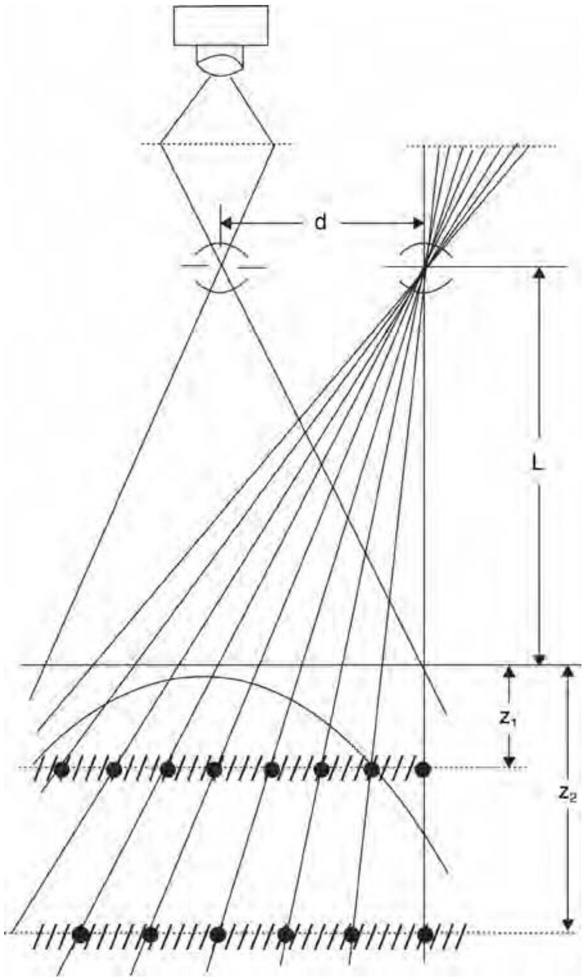


Figure 5.2 Schematic setup of the moiré system.

was placed close to the grid, enabling a sharp image of the moiré fringes to be obtained (Fig. 5.5).

For capturing the full size of the human figure, a vertical frame 605 mm (L) × 570 mm (W), was designed to mount the grid lines in an exact parallel manner. The grid plane was translated perpendicularly to the grid lines in its own plane, the movement being controlled by an electrical device, for the elimination of 'background noise' fringes.

Based on Pirodda's approach,[15] equation (5.1) was used for the computation of the distance between the object surface and the grid at a given position of the moiré fringe.

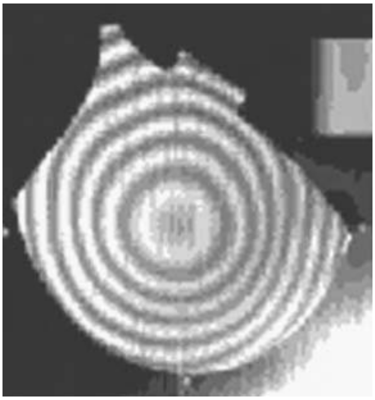


Figure 5.3 Moiré image of bra cup.

$$z = \frac{ngL}{d - ng} \tag{5.1}$$

where z corresponds to the fringe depth of the object surface measured from the grid plane, and the absolute fringe number $n = 0, 1, 2 \ldots$ for bright fringes, or $n = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots$, for dark fringes. L is the distance between the grid and the light source, g is the grid line spacing and d represents the distance between the light source and camera.

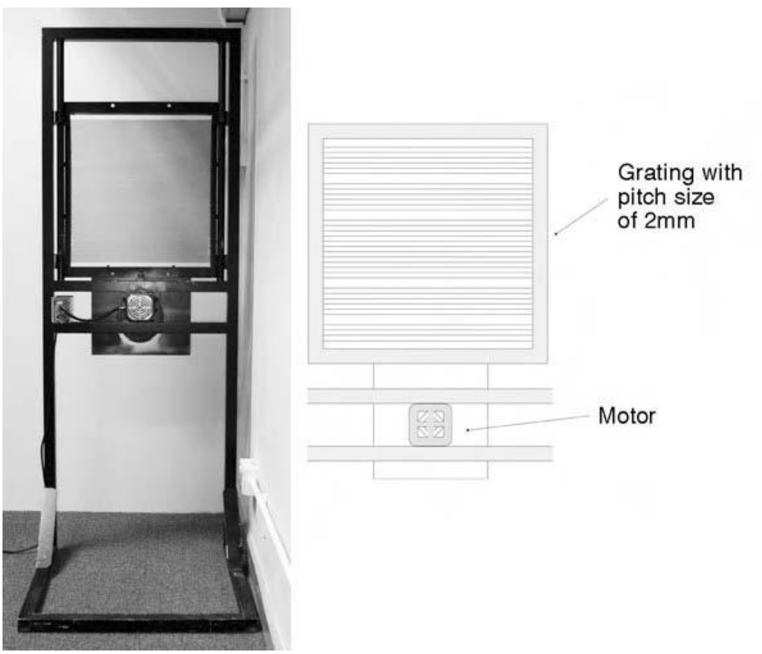


Figure 5.4 Moiré system for jacket measurement.

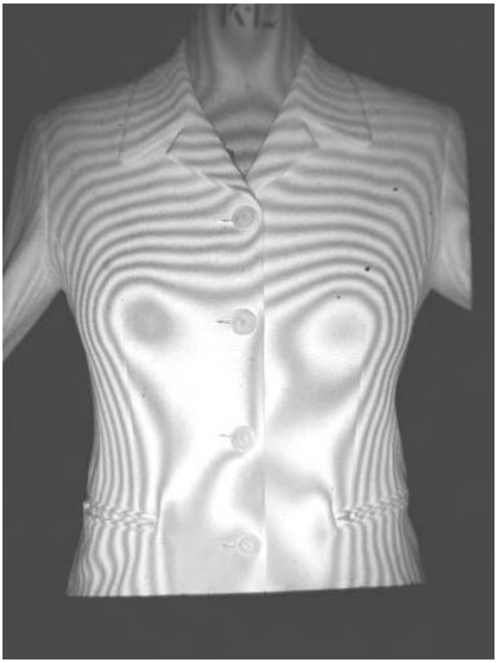


Figure 5.5 Moiré image of jacket.

The contour map of the moiré fringes generates the required shape information across the clothing surface. A visual interpretation of the fringe pattern is a good means for assessing the shape conformity of a three-dimensional clothing sample. If the clothing fits well, the contour lines appear round and symmetrical (Fig. 5.6). On the other hand, if it does not fit precisely, the fringe pattern will be distorted.

For the objective measurement of the jacket shape, a digital analysis of different sections of the front, back and side view was performed. The fringe pattern was then digitised and the co-ordinates of the sectional profiles were quantified using fourth-order polynomial functions, and root-mean-square measures of the shape characteristics were derived (Fig. 5.7).

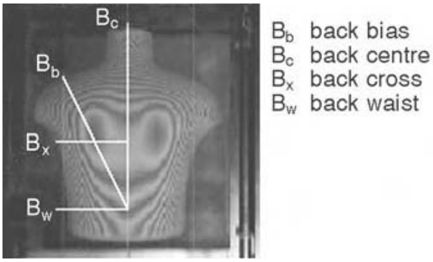


Figure 5.6 Sectional analysis of clothing fit.

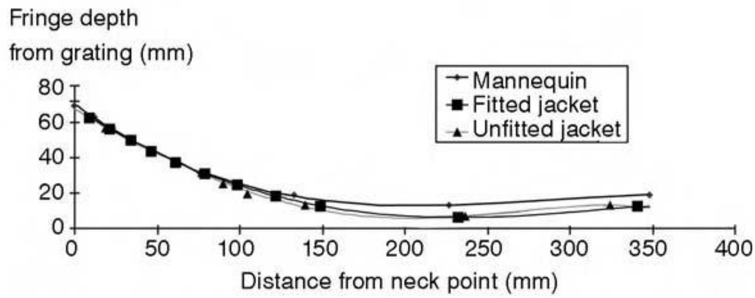


Figure 5.7 Polynomial curves of centre back profile.

To have a perfect fit, the depth of any point on the clothing sample should be the same as that on the mannequin. For outer-clothing, such as a jacket, it is generally agreed that the clothing should fit nicely from the neck to the cross-back level, from where it should hang naturally and parallel to the body. The depth deviation can therefore determine the fit. A single measure of the overall clothing fit is provided by a root mean square value.

If the depth deviation $D(x)$ represents the difference between a point on the mannequin and a point on the jacket corresponding to the same x-value, its mean value can be calculated by integrating $D^2(x)$ over the total investigated length. The square root of this mean value is calculated in order to obtain the root-mean-square (rms) of the depth deviation, i.e.:

$$\text{rms} = \sqrt{\mu_{D^2}} \tag{5.2}$$

Obviously, when the clothing shape fits the mannequin perfectly, the rms value is zero.

The above provides an objective technique for industry to compare differences in clothing appearance resulting from various pattern constructions and methods of assembly, and for monitoring variations in clothing shape in a production batch. The moiré system so developed, provides a quick and reliable device to evaluate the complex clothing shape and to assess the quantitative shape conformity in the critical area, with less reliance on experience and personal assessment.

Extending the above research, a new 3D body scanning system ‘Cubicam’, using modified projection moiré topography, was developed (see Chapter 8). This method of objective evaluation was then applied in the assessment of the ‘shaping up’ effects of foundation garments, such as push-up bras, girdles, maternity supports as well as outer suits (see Figs 5.8 and 5.9). In previously mentioned studies, mathematical analysis was essentially made on arbitrarily defined sectional profiles of the moiré fringes. Further research is required to study the overall measurement of the complex clothing shape and appearance.

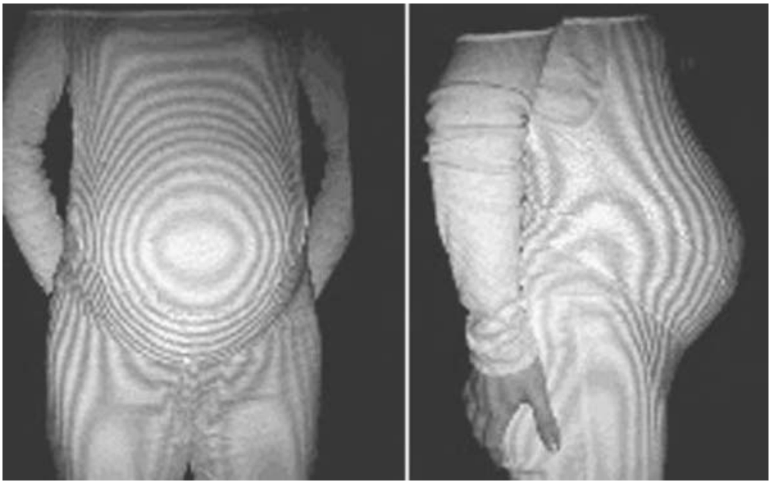


Figure 5.8 Maternity support.

5.3 Algebraic evaluation of clothing fit

Based on the mathematical concept of an 'algebraic mannequin', Ng *et al.*[16] rationalised a framework of fit measurements at four levels, namely linear dimension, sectional area, volume and overall. This provided simple indices to measure the distance, area or space between the body and the garment, the indices being the linear index, the cross-sectional index, the volume index and the signature curve index, respectively.

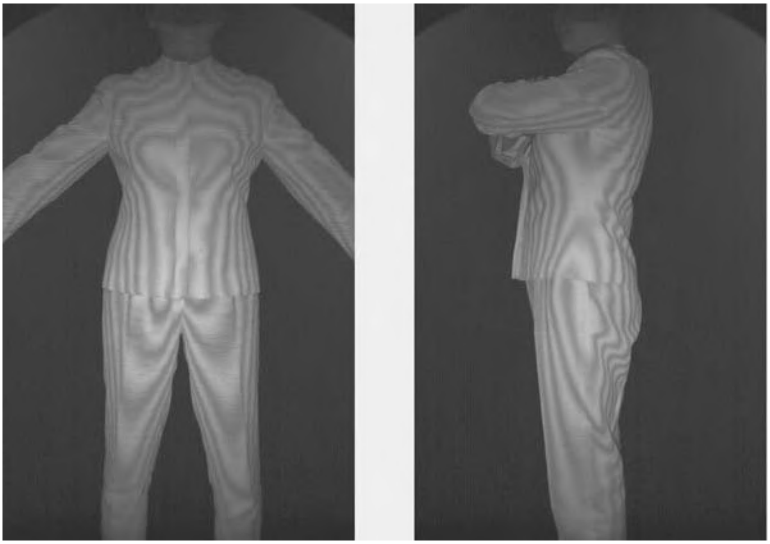


Figure 5.9 Outer suit.

5.3.1 Linear index

The Linear Index measures the difference in the linear measurements. It is the difference in the linear measurement between the garment and the body, representing an 'ease allowance' for breathing and other body movements and is calculated as follows:

$$\text{linear index (LI)} = (\text{LM}_{\text{Garment}} - \text{LM}_{\text{Body}})/\text{LM}_{\text{Body}} \tag{5.3}$$

where LM stands for linear measurement. There is no upper limit for such an index, while the minimum value is -1.

5.3.2 Cross-sectional index

The cross-sectional index measures the area between the garment and the body. It is the total cross-sectional area on the transverse plane. If there is an opening, a straight line connecting the endpoints is used to close the area for computational purposes. This is a more precise measure than the linear index in terms of the 'ease allowance' for body movement. The cross-sectional index can be further divided into regional areas, such as front and back. Since the lungs expand more at the front than the back during inhaling, the front part has a greater 'ease allowance'. The front cross-sectional index can be expected to be greater than that of the back. The formula is:

$$\text{cross-sectional index (XI)} = (\text{XA}_{\text{Garment}}\text{XA}_{\text{Body}})/\text{XA}_{\text{Body}} \tag{5.4}$$

where XA stands for the cross-sectional area. The XI value is typically greater than or equal to zero. XI is equal to zero only in the case of a stretchable garment. If the elasticity of the muscles is considered, the index may be negative.

5.3.3 Volume index

The volume index measures the total volume trapped between the garment and the dummy. This index is an indication of any jump in size. For example, the volume index of an overcoat must be greater than that of underwear. Volume is meaningful only for an enclosed surface, so the volume is measured as if the opening of the garment is closed and covered by a minimal surface. Since the opening lies on the same transverse plane as in the algebraic mannequin, the volume integral is taken up to such a plane. The general formula is:

$$\text{volume index (VI)} = (\text{volume}_{\text{Garment}} - \text{volume}_{\text{Body}})/\text{volume}_{\text{Body}} \tag{5.5}$$

VI is usually positive, being equal to zero when the garment is close fitting, like a second skin. If the elasticity of the muscle is considered, the index may be negative.

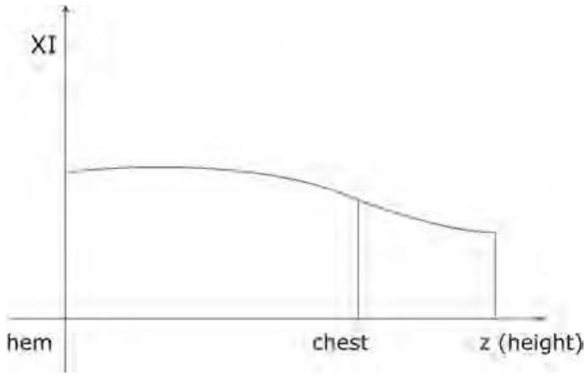


Figure 5.10 Example of a Signature Curve on the bodice.

5.3.4 Signature curve

The signature curve is a measure of the overall fit, referred to as a fit-spectrum diagram. It is a function of the cross-sectional index versus the height of the transverse plane. The curve reveals the characteristics of the garment. For example, the signature curve of a tight fitting garment appears relatively flat with consistently low values of XI (see Fig. 5.10).

Another type of signature curve, called the absolute signature curve, measures the actual trapped cross-sectional area versus the height. It is useful when reconstructing the surface of the garment,[17] since absolute measurements, instead of percentages, are needed for calculation.

In practice, the cross-sectional index is calculated at crucial levels. Therefore, the signature curve can be generated by fitting polynomials, Hermite, Bezier or B-spline, to the data points, the Lagrange polynomial not being recommended.

5.4 Clothing waveform

Taya *et al.*[18] published a series of papers which proposed various methods for evaluating clothing fit. In part 1, they digitised the 3D co-ordinates of measuring grids marked on the dummy, using a Vectron measuring apparatus. Three types of fabric were used for evaluating the clothing fit of a certain dress style. The cross-sectional profile at every altitude and the 3D shape of the body and clothing were reconstructed (Fig. 5.11). With the data obtained, the space between the body and clothing was then quantified as an index of fit (FI):

$$FI = F_i/F_o \tag{5.6}$$

where F_i is the apparent clothing space and F_o is the maximum clothing space. The results of fitting at the bust, waist and hip were presented on the basis of this evaluation index.

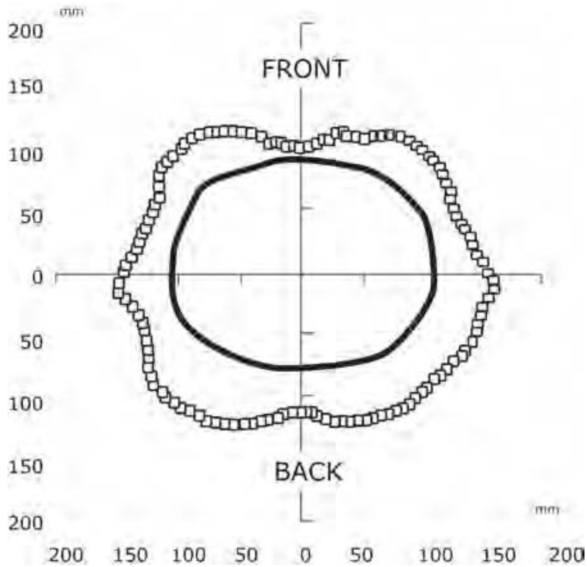


Figure 5.11 Cross-sectional profile of body and clothing at the waist line; body shape, clothing shape, calculated clothing shape. Source: Taya *et al.*, 1995.[18]

In part 2, Pickover's acoustic theory and symmetrised dot pattern (SDP) were applied to capture the subtle difference in clothing shape, which could be shown as an ellipse, rectangle, rhombus, dumbbell, or an ellipse combined with a cosine curve and a sine curve (Fig. 5.12). The amplitude of the clothing waveform was analysed for the detection and characterisation of the significant features of any clothing shape.[19]

In part 3, Taya *et al.*[20] studied the relationship between clothing size and shape. The amplitude of the clothing waveform was analysed using the probability density spectra and the new SDP method (Fig. 5.13).

In part 4, Taya *et al.*[21] found that the clothing waveform depended greatly upon physical size and the mechanical properties of the material. The best conditions showed a uniform distribution of the touch points and the space (Fig. 5.14).

As revealed in part 5 of Taya *et al.*'s paper,[22] it was difficult to extract local and detailed information from the clothing waveform because the clothing shape is localised and it has directional waves with different angles. The wavelet transform was therefore applied to extract a characteristic of clothing waveform for the fit evaluation. The clothing waveform is considered to be a periodic function of angle θ and amplitude $f(\theta)$, where $f(\theta)$ is defined as a distance to the outside surface of the clothing from the centre of the human body. The magnitude of the wavelet transform of the wave data at the angle offers detailed information of clothing waveform at each frequency (Fig. 5.15).

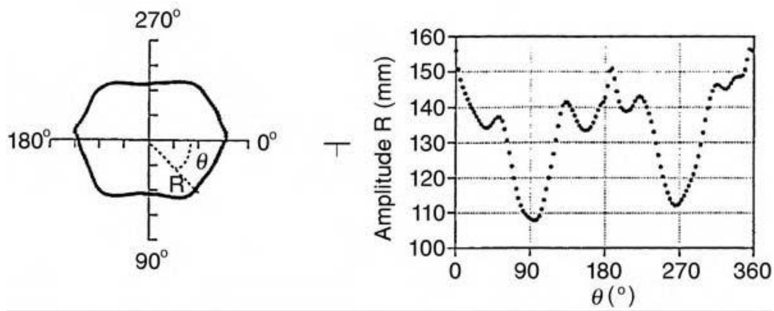


Figure 5.12 Cross-sectional shape of clothing at the waistline and its derived waveform. Source: Taya *et al.*, 1995.[19]

In part 6, Taya *et al.*[23] further investigated the influence of clothing size and material on clothing waveform. The experimental clothing waveform was compared to the standard. The contour colour figure of the wavelet transform can detect a small variation of clothing waveform at the bust line due to a

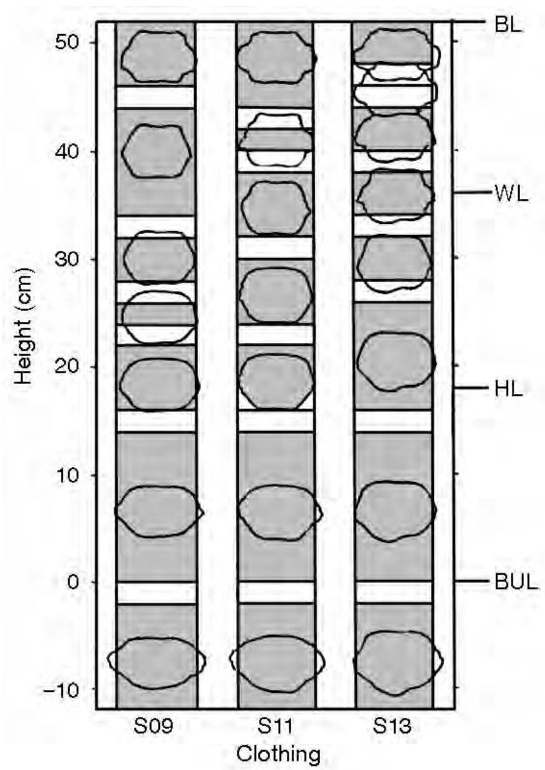


Figure 5.13 Clothing waveform of different sizes: 9, 11 and 13. Source: Taya *et al.*, 1995.[20]

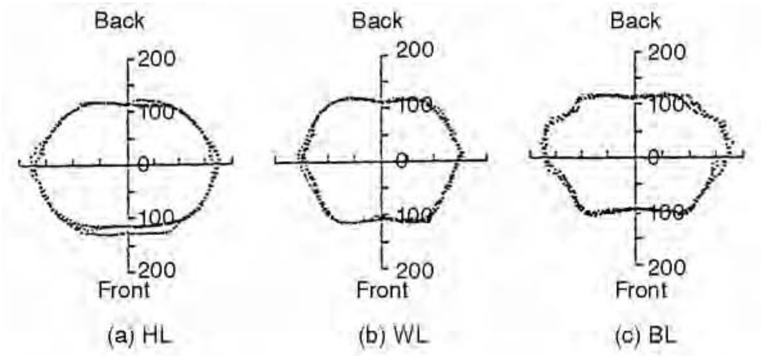


Figure 5.14 Cross-sectional waveforms of various clothing materials at (a) the hip level, (b) the waist level and (c) the bust levels for a body size no. 9. Source: Taya *et al.*, 1995.[21]

defined change in material and size. These can provide a good measure of clothing fit. It showed that material type significantly affects clothing fit. When the clothing material varied, the change of waveform was larger than that caused by a change in size.

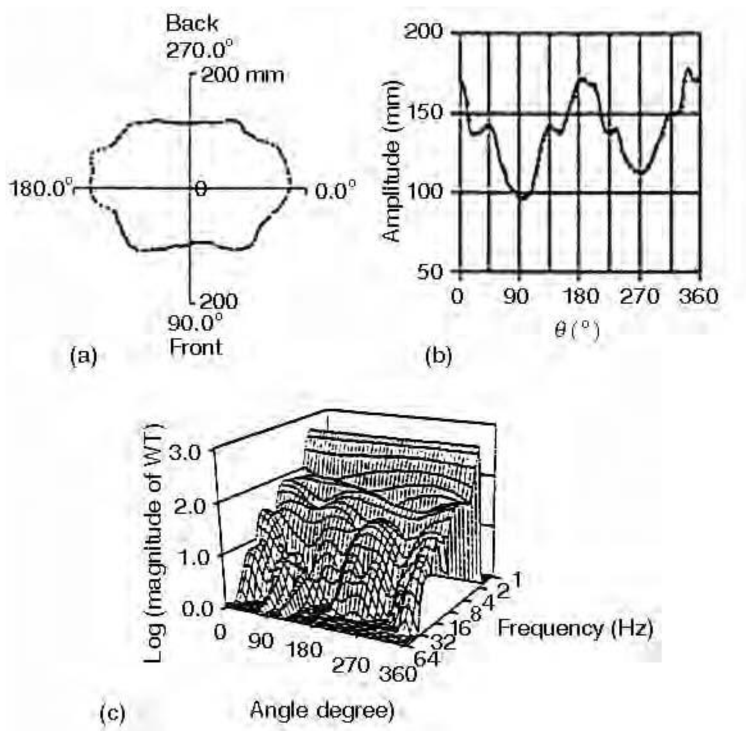


Figure 5.15 Magnitude of the wavelet transform at the bust line waveform of a body size no.9: (a) cross-sectional clothing shape, (b) amplitude of waveform, (c) magnitude of the wavelet transform. Source: Taya *et al.*, 1996.[23]

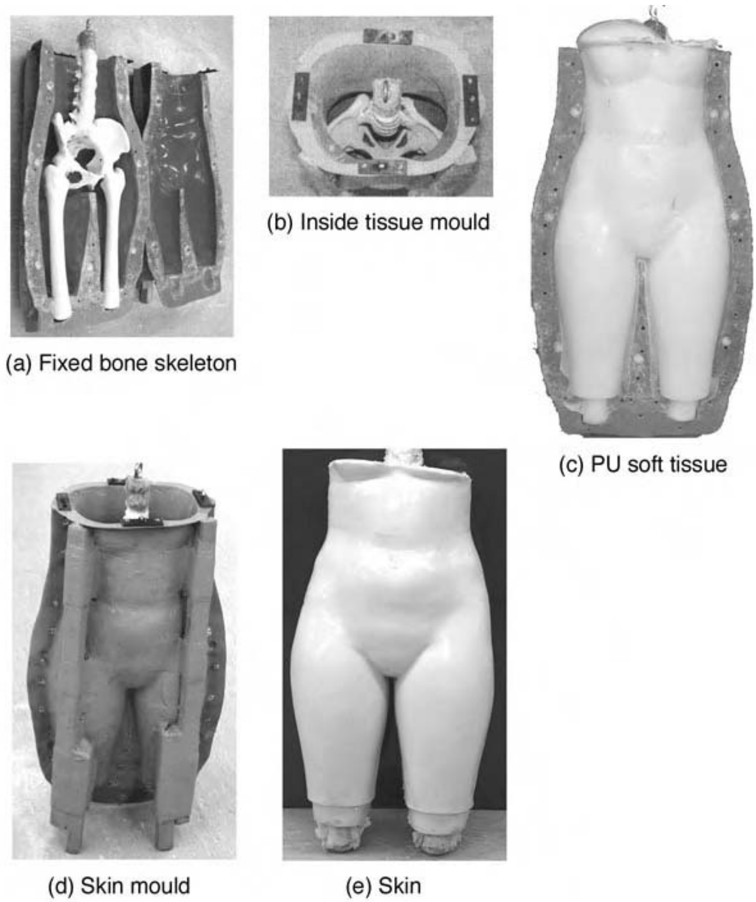


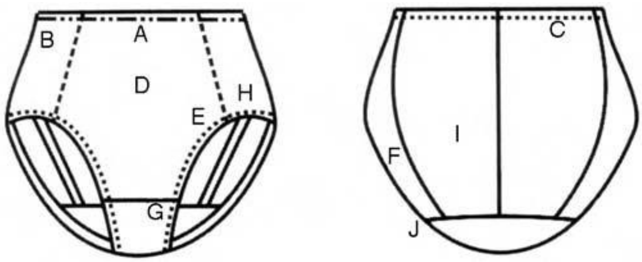
Figure 5.16 Manufacture of soft mannequin. Source: Yu *et al.*, 2001.[24]

5.5 Pressure evaluation of clothing fit

5.5.1 Soft mannequin

Apart from the algebraic indices of clothing fit and the geometric presentation of clothing shape, the pressure acting on the body's soft tissue also plays an important role in the evaluation of fit. In 2002 Yu *et al.*[24] developed a soft mannequin to simulate the human body for measuring contact pressure. It was developed with the exact dimensions of the lower torso of a female body, containing a full-size bone skeleton, also imitating soft tissue and skin. The imitated soft tissue is comprised of flexible polyurethane foam of different moduli. Silicone rubber is used to simulate the human skin. Figure 5.16 shows the different layers required in the manufacture of the soft mannequin. It was found that the clothing pressure on a live model can be predicted by using linear equations which correlate the relationship between the measurements obtained from the soft mannequin with those of the human body.

The pressure values *Pm* obtained from the soft mannequin are correlated with the contact pressure *Ps* imposed on the subject, at different body positions:



Point A:	$Ps = 0.72$	$Pm\ -320.65$	$R = 0.82$	
Point B:	$Ps = 3.08$	$Pm\ -1098.13$	$R = 0.87$	
Point C:	$Ps = 3.17$	$Pm\ -397.51$	$R = 0.88$	
Point D:	$Ps = 0.18$	$Pm\ -111.19$	$R = 0.88$	
Point E:	$Ps = 3.37$	$Pm\ -628.55$	$R = 0.94$	
Point F:	$Ps = 2.31$	$Pm\ -75.54$	$R = 0.71$	
Point G:	$Ps = 0.16$	$Pm\ +13.80$	$R = 0.47$	
Point H:	$Ps = 0.98$	$Pm\ -36.75$	$R = 0.77$	
Point I:	$Ps = 0$			
Point J:	$Ps = 0.33$	$Pm\ +81.65$	$R = 0.80$	(5.7)

5.5.2 Stretch test

People think that a stretch garment will automatically fit in the right places and provide ease of movement. This is a fundamental misunderstanding of stretch characteristics. Watkins[25] divided contour fit into three categories: form fit, action fit and power fit. Form fit exerts no pressure on the body; action fit holds and supports the body; and power fit moulds the body into the desired shape. A grid system was used as an aid to visualise the fabric curvilinear distortion in the study of stretch characteristics in relationship to the sculptural form of the body.

Stretch clothing presents unusual difficulties in the evaluation of fit. An appropriate stretch fit is essential to secure certain functionality, comfort and appearance. The clothing measurements have to be adjusted and usually made smaller than the body measurements by a percentage because wear will stretch the material. Therefore, the stress-strain behaviour of the material essentially influences the clothing fit. For intimate apparel, stretch tests contribute an essential part of fit testing. The fabric and/or elastic bands are stretched to actual body dimensions, and the force level is measured by a tension spring. Marks &

Spencer has also introduced a simple bra sensor to measure the pressure fit at several positions, such as the shoulder and rib cage around the body.

CETME equipment[26] is widely used by US hosiery manufacturers and testing laboratories in checking rise and 'in-seam' lengths (panty and lengths). MTL recommends cross-stretch tests in the waistband and thigh areas, as well as area/ volume stretching in the leg section, and the lateral and lengthwise directions of the panty. The pantyhose were fitted on 2D sliding flat forms, each clamped at the top and bottom jaws of a tensile testing machine. The force level required to stretch to the actual body dimensions was then recorded.

5.6 3D modelling of pressure fit

The National Institute of Materials and Chemical Research[27] in Japan developed a system using computer simulation to predict how clothing fits a person. In this system, clothing is divided into hundreds of small triangular finite elements. Each element is viewed as an elastic material. The formulation of the stress-strain relationships in terms of mechanical properties of the material will allow the measurement of potential energy and prediction of the 3D configuration of ease, the wearing silhouette and distribution of pressure without actually producing the clothing. Using computer graphics, technology enables the results to be shown on a 3D display. Thus the construction of apparel CAD software, including an evaluation of fit sensitivity, can be expected.

Using the finite element method, Zhang *et al.*[28] have simulated the garment-body dynamical interactions during wear in a 3D bio-mechanical model. They computed the 3D distribution of pressure, stress and deformation of the garment and body.

5.7 Conclusions

Objective evaluation of clothing fit is necessary but difficult to achieve, hence the limited number of researchers working in this area. The technologies are mainly based on optical methods, such as somatometry and moiré topography, which capture the clothing images using a non-contact approach. After image analysis, the three-dimensional fit of clothing can be calculated in quantitative terms. Objective techniques are valuable for the industry in comparing differences in clothing appearance obtained from various pattern constructions and methods of assembly, with less reliance on experience and personal assessment. More importantly, the quantitative approach of fit assessment is useful for the construction of basic block pattern.

Mathematically, clothing fit can be expressed in terms of the linear ratio and geometric index. The curved shape of the clothing surface and human body is illustrated in symmetrical shapes, while the clothing drape, generalised as different kinds of waveforms, may change with different clothing materials. The theory was developed using wavelet transformation.

At present, various technologies have been developed for the presentation of clothing appearance in a simulated 3D form. It is envisaged that these novel systems can provide a remote communication tool for industrial partners to discuss the 3D clothing fit, based on the clothing image. This may lead to more efficient and effective decision making in the process of product development and quality control.

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