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Development of a Prototype Pattern Based on the 3D Surface Flattening Method for MTM Garment Production

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Abstract

The purpose of this paper was to develop an individual prototype garment pattern based on 3D body scanning data. Firstly, the cross-sections of scanning data were preprocessed by three methods, including re-sampling, symmetrising and convex hull calculating. Secondly, NURBS modeling technology was adopted to create a basic garment model based on the curve network. According to different traditional flat prototype patterns, the corresponding feature lines are defined on the models through calculating the intersection curves of the body surface and local planes. Finally, three 3D garment models were subdivided by different cutting methods and the advancing front triangulation method. Surface flattening based on the energy model was adopted to generate the corresponding 2D patterns. In order to analyse the error, the area and length of the 3D and 2D patterns were calculated and compared, respectively, the results of which promote the practicability of the 2D pattern design system in MTM garment production through 3D CAD technology.

Key words: *prototype garment pattern, made to measure, three-dimensional modeling, surface flattening.*

Introduction

Recently many studies have been made on the application of information technology for the production of customer oriented fashion goods, such as MTM (mate-to-measure) garments [1]. The digital pattern customisation system is a vital part of MTM garment production because it can solve how to produce attractive and accurately fitting apparel according to customers' needs.

The digital pattern development process for customised apparel has two paths [2]. One path develops an individual garment based on 2D CAD technology. One of the typical approaches used in several commercial MTM pattern systems is modifying the pattern to a basic size according to traditional grading rules. It is the most practical method because of its simple theory, the pattern of which masters are familiar with. However, a basic pattern for altering is made based on one-dimensional measurements of the human body, but it is difficult to reflect a 3D body shape. Another path is just to develop a pattern through surface flattening directly from an individual 3D apparel model. Several 3D apparel CAD systems have been developed by some companies, such as Gerber, Lectra and Pad. However, it is difficult to construct a real 3D garment model in these systems, especially for apparel with a complex style. Therefore, many improvements should be made if 3D CAD systems are to be applied in apparel MTM production.

In a previous research [3] the authors presented a new scheme to customise a pattern according to the customer's body shape. ***Figure 1*** gives an overview of this scheme. Considering the advantages and disadvantages of 2D CAD and 3D CAD technology, the process of customising individual apparel patterns was separated into two steps. The fist step is the mapping process from a 3D virtual dummy to 2D patterns of an individual prototype garment. In this step, 3D CAD technology is adopted in order that the prototype pattern can reflect the 3D body shape roundly. The second step is the altering process from an individual prototype to the cutting patterns of a customised garment of given style using 2D apparel CAD technology.

The aim of this study was to undertake the task of the first step using surface flattening technology. Our work is not intended to replace the current successful industrial 2D pattern system but to try to promote its practicability through 3D CAD technology in order to satisfy the demand for making fit and individual garment patterns.

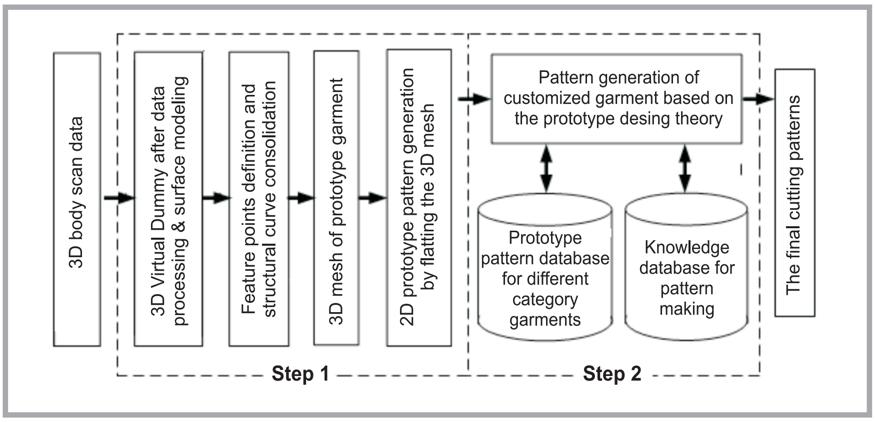

Figure 1. *Overview of individual pattern customisation.*

Method

Preparation of 3D garment model

The raw data scanned by the [TC]^2 body scanner can be outputed in a VRML (Vir-

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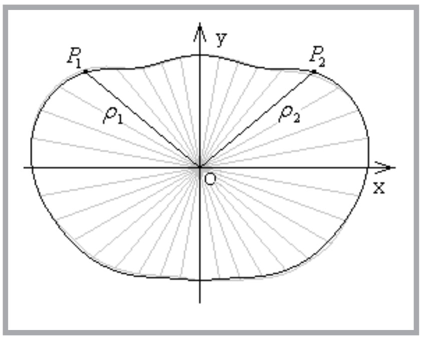

Figure 2. *Preprocessing of each cross-section data.*

tual Reality Modeling Language) file. In this research, only the point matrix of the torso part was used, and head data was deleted in advance. In order to ensure that each cross-section of the 3D body data had a common topological structure, the data of the cross-sections were preprocessed by three methods, including re-sampling, symmetrising and convex hull calculating. NURBS surface modeling technology was adopted to create a garment model based on the 3D curve network. The data preprocessing and surface modeling can be outlined by the following steps:

1) Sort the data points in order tofit the needs of B-spline interpolation.
2) Fit the horizontal B-spline curve along the cross-section points and calculate the center point O of the bounding rectangle of the curve.
3) Re-sample each cross-section at a uniform angle centered on point O and reorder the sample sequence (***Figure 2***).
4) Symmetrise the points with the y axis as the symmetry axis to ensure $\rho_1 = \rho_2$, as well as to get a symmetric torso model for the 3D garment CAD system.
5) Repeat step 1 and step 2 to get new samples and a center point of the cross-section again because the center point O is changed after carrying out step 3.
6) Calculate the convex hull of each cross-section point to create a dress-like 3D body model. The convex hull method is used to mimic the physical tape-measurement of the mannequin for the purpose of bust girth generation, as well as to simplify the body surface complicacy.
7) The build curve network of the torso according to the point matrix after preprocessing and the NURBS surface was generated based on the 3D curve network. ***Figure 3*** shows the process and result of surface modelling.

In this study, only the basic bodice pattern was focused on, as it is very difficult to design accurate bodice patterns by flat pattern processes only. The feature points on the model are set manually using a 3D cursor. As for the feature lines, they can be generated through calculating the intersection curves of the body surface and local planes, which are built according to the coordinates and normal vectors of the corresponding feature points. Regarding the intersection algorithm between the NURBS surface and plane, it has undergone a lot of study in the field of computer graphics and implemented by several types of 3D graph software.

Surface triangulation

As for the automatic triangulation over the three-dimensional parametric surface, there are two effective and reliable methods of generating high quality meshes, namely Delaunay triangulation and advancing front triangulation [4]. In the study, the second method was adopted.

In the advancing front method, the boundary of the problem domain is discretised first to form a current front, and then new nodes and elements are generated one by one based on the current front. The front is refreshed when it is completed, and the procedures mentioned above are reduplicated until the front is null, which means that the triangulation of the surface is finished. More specifically, the general algorithm of this method [5] involves the following steps:

1) Define the boundary of the domain to be discretised.
2) Initialise the front as a piecewise linear curve in conformity with the boundary.
3) The edge to be deleted from the front is chosen based upon certain criterion (generally the smallest edge is chosen as it gives good quality meshes).
4) For the edge to be deleted:
    a) Select the trial point position (the trial point is the point lying inside the domain and making an equilateral triangle with the edge to be deleted).
    b) Search for any already existing points within a certain proximity of the trial point. If any such point exists it becomes the trial point. Continue the search.
    c) Determine whether the element formed with the new ideal point crosses any edges. If yes, select a new trial point from the front and try again (go to step 4b).
5) Add the new point, edges and triangles to the respective lists.
6) Delete the base edge from the front and add the new edges.
7) If the front is non-empty, go to step 3.

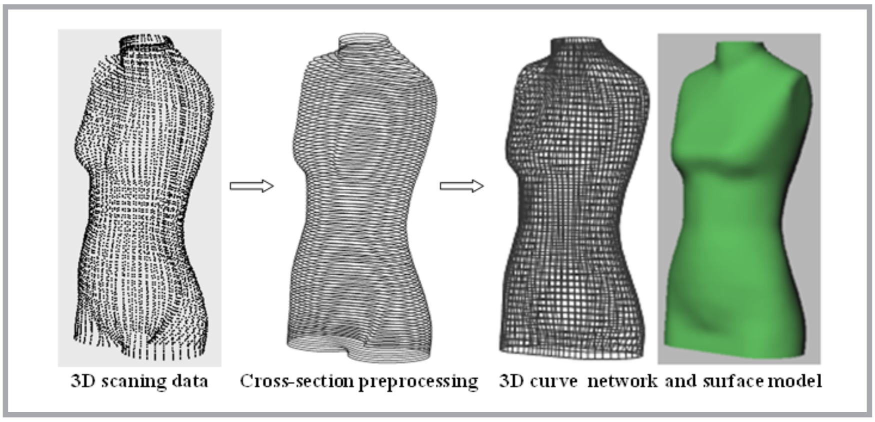

Figure 3. *3D curve network and surface model of the human body after data preprocessing.*

Surface mesh flattening

Surface flattening is an important process in many applications (e.g. the aircraft industry, ship industry, shoe industry, apparel industry, etc.) [6]. According to a relevant study investigation [1], there are two typical methods, namely geometry flattening and physical flattening. In a prior research [2], the authors adopted the geometry flattening method to generate a prototype garment pattern. The 2D cutting patterns created by this means have a coincident construction and shape for a conventional prototype and are of outstanding quality and precision. However, it is inconvenient to construct a general 3D prototype wire frame based on different 3D body models.

In the paper, physical flattening based on the energy model is adopted [5 - 9]. Be-

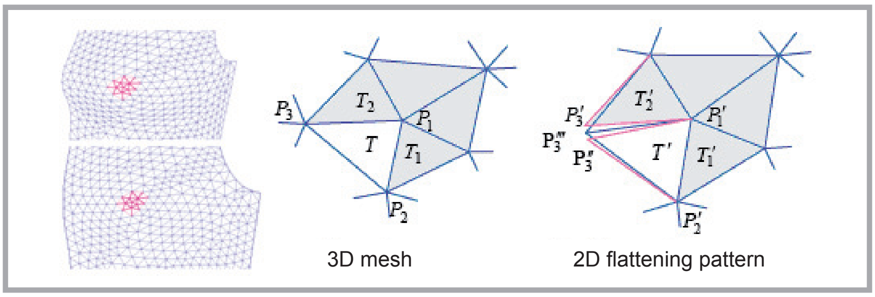

Figure 4. *Constrained triangle mesh flattening [6].*

fore being flattened, the surface mesh is assumed to have a degree of elasticity, so that the final flat pattern can be deformed to fit the 3-D surface. It is important that the material properties are taken into account whenever it is required to obtain an optimal 2-D pattern for a particular 3-D surface. If the surface is non-developable, some deformations will occur in order to achieve a 2-D pattern. Here an energy model is adopted. Each edge of the triangular mesh is assumed as a strut with elasticity. The energy required to flatten the surface from 3-D to 2-D is associated with the deformation of these edge struts only. The energy can be defined as

$$W = \frac{1}{2}\frac{EA\cdot(\Delta l)^2}{l} \qquad (1)$$

where l is the original length of the edge; A is the cross sectional area of the edge; E is Young's modulus; and EA can be considered a constant for a specific material structure or material type.

During the flattening process, there are two kinds of flattening: unconstrained triangle flattening and constrained triangle flattening [4, 6]. When one edge (P_1P_2) of the triangle T has been flattened, the third node (P_3) is then located on the flattened plan. The position P_3' on the 2-D flattening pattern could be decided by the intersection of two circles, which have origins at P_1' and P_2' and a radius of r_{13}, r_{23}, respectively. The flattening of point P_3 is called unconstrained triangle flattening. For this flattening, the edges on the flat pattern have the same length as that of the edges on the 3-D triangulated surface, and thus no distortions occur, with the strain energy being equal to zero. It is supposed that a triangle T shares edge P_1P_2 and edge P_1P_3 with the previously flattened triangle T_1 and T_2, respectively, as shown in ***Figure 4***. For point P_3, there exists a planar point P_3' in the flattened triangle T_2. If unconstrained triangle flattening were applied to triangle T_1, then it would probably provide another point P_3'' on the 2-D flattened pattern, as shown in ***Figure 2.b***. To simplify the computation, a mean position, $P_3''' = (P_3' + P_3'')/2$, is found to resolve this conflict so that a unique location is obtained. The point P_3''' is considered as an initial flattened point of P_3. After constrained triangle flattening, we can obtain $P_1P_3 \neq P_1P_3'''$ and $P_2P_3 \neq P_2P_3'''$. Thus the strain energy of the mean point P_3''' can be calculated by:

$$W_{P_3'''} = \frac{1}{2}EA\cdot\left[\frac{\left(|P_1P_3| - |P_1'P_3'''|\right)^2}{|P_1P_3|} + \right. \qquad (2)$$
$$\left. + \frac{\left(|P_2P_3| - |P_2'P_3'''|\right)^2}{|P_2P_3|}\right]$$

Therefore, if point P_i has k neighborhood points (P_{i1}, P_{i2}, ..., P_{ik}), the length of each edge will change after flattening. The energy of these points on the flat pattern can be described by:

$$W_{P_i'} = \frac{1}{2}EA\sum_{j=1}^{k}\frac{\left(|P_iP_j| - |P_i'P_j'|\right)^2}{|P_iP_j|} \qquad (3)$$

In order to reduce the deformation, the energy relaxing process is needed. The initial flattened point P_i' is adjusted to P_i'', and the energy $W_{P_i'}$ will decreased to $W_{P_i''}$. Here the energy relaxing process can be described as a minimum problem based on the constraints:

$$\begin{cases} \min \quad W_{P_i''} \\ s.t.: \quad |P_i'' - P_i'|^2 \leq r^2 \\ E_i^S \leq \varepsilon_S \end{cases} \qquad (4)$$

where r is a given small constant of the location adjustment; E_i^S is the difference in area after energy relaxing, and ε_S is a given constant of the area error.

Result and discussion

In this paper, a 3D model of a basic bodice garment (only half) was created based on 3D body scanning data. Each cross-section of the scan data was preprocessed by three methods successively, including re-sampling, symmetrising and calculating the convex hull. According to different traditional 2D prototype patterns, the corresponding feature points and lines are defined on the 3D model in advance through calculating the intersection curves of the body surface and the local planes. ***Figure 5*** illustrates surface models of half of a bodice with different feature lines. In the figure, there are three garment models created using different cutting methods, namely models A, B and C. Model A was split into two parts (front and back) along the shoulder line (SNP-SP) and side seam line (SXP-SWP). As for model B, the front part and back part were split into two parts again, respectively, along the princess line (P1-P2 and P1-P3). Model C was split into eleven parts according to a new 2D prototype pattern developed by Japanese Bunka Women's University [3]. Then all the parts of three surface models (A, B and C) were subdivided into a triangle mesh using theadvance front method. ***Figure 6*** gives the triangulation result of the three models. Finally, the 3D meshes were flattened into flat cutting patterns according to the algorithm presented in

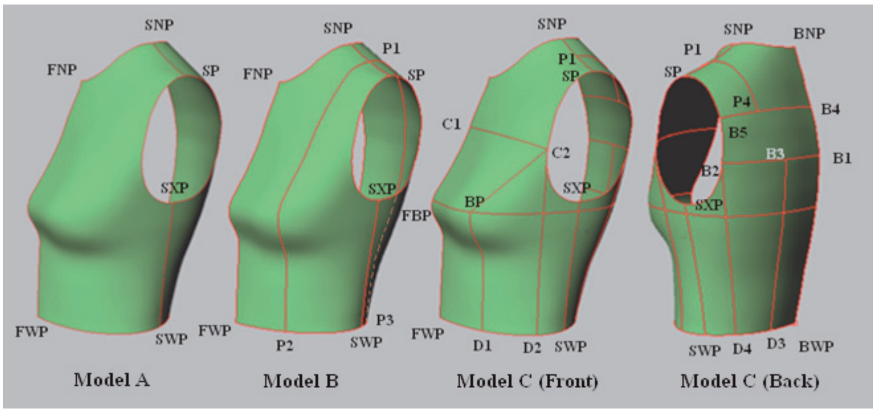

Figure 5. *Surface models of the half bodice with corresponding feature points and lines.*

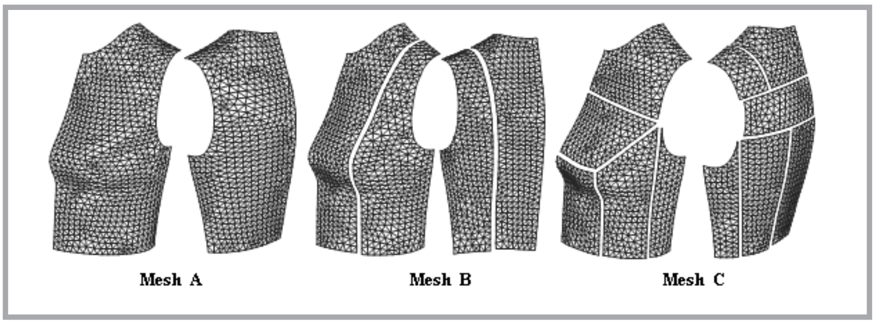

Figure 6. *Triangulation of 3D bodice models by different cutting methods.*

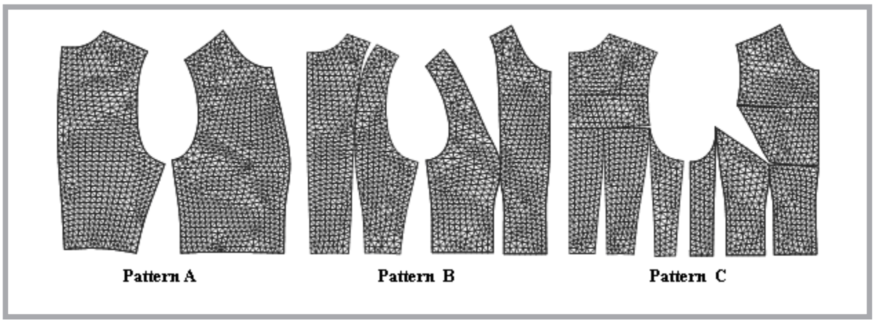

Figure 7. 2D bodice patterns after surface flattening.

Table 1. *Area comparison of 2D pattern, 3D mesh and 3D surface.*

Objects	Front piece, cm^2	Back piece, cm^2	Error, cm^2, (%)	
			Front	Back
3D Surface	668.119	600.084	-	-
3D Mesh	667.227	599.974	-0.892 (-0.13)	-0.110 (-0.02)
2D Pattern (A)	664.937	599.475	-3.182 (-0.50)	-0.609 (0.10)
2D Pattern (B)	666.325	599.654	-1.794 (-0.27)	-0.430 (-0.07)
2D Pattern (C)	666.860	599.763	-1.239 (-0.19)	-0.301 (-0.05)

Table 2. *Length comparison of the main structure curves of the 2D pattern and 3D surface in cm.*

Curves	3D Surface, cm	2D pattern, cm			Error, %		
		A	B	C	A	B	C
FNP-FWP	33.88	34.93	33.86	33.64	3.10	-0.06	-0.71
BNP-BWP	37.17	37.59	37.27	37.17	1.13	0.27	0.00
SXP-SWP	17.44	17.35	17.27	17.38	-0.52	-0.97	-0.34
SNP-SP	8.94	8.91	8.92	8.89	-0.34	-0.22	-0.56
SNP-FNP	11.95	11.81	11.77	11.72	-1.17	-1.51	-1.92
SNP-BNP	8.60	8.64	8.6	8.59	0.47	0.00	-0.12
FWP-SWP	19.23	18.98	19.06	19.15	-1.30	-0.88	-0.42
BWP-SWP	13.43	13.34	13.35	13.41	-0.67	-0.60	-0.15
SP-SXP(Front)	20.63	21.18	20.62	20.52	2.67	-0.05	-0.53
SP-SXP(Back)	22.96	23.45	23.03	23.03	2.13	0.30	0.30
P1-P2	40.47	-	40.49	-	-	0.05	-
P1-P3	39.40	-	39.51	-	-	0.28	-
C1-C2	14.96	-	-	14.94	-	-	-0.13
C2-BP	12.08	-	-	12.17	-	-	0.75
BP-D1	16.88	-	-	16.75	-	-	-0.77
C2-D2	24.05	-	-	23.93	-	-	-0.50
P1-P4	10.00	-	-	9.94	-	-	-0.60
B3-D3	23.28	-	-	23.31	-	-	0.13
B2-D4	23.51	-	-	23.67	-	-	0.68
B1-B2	14.74	-	-	14.75	-	-	0.07
B3-B4	14.45	-	-	14.49	-	-	0.28

section 2. ***Figure 7*** shows the three corresponding bodice patterns (A, B and C) after being flattened from 3D models A, B and C.

In the study, the flattening process from a 3D surface to a 2D pattern for apparel kept to the following principles. First, the length of key structure lines should be kept the same as much as possible. Second, the area of the 3D surface and 2D planner of the prototype should be controlled within a certain gap. Third, the shape of the pattern and 3D model should be kept the same as much as possible. In order to analyse the error after flattening, the area and Length of the 3D and 2D patterns were calculated. The total areas of the 3D surface, 3D mesh and 2D flattening pattern are compared in ***Table 1***. The areas of patterns A, B and C were decreased after flattening from a 3D surface. The error in the surface area was below 1%. As can be seen from ***Table 1***, part of the area error is caused by surface triangulation. The length of the main structure curves between the 3D surface model and 2D pattern were compared with each other (***Table 2***). Forpatterns A, B and C, the length error of pattern A was the biggest because no cutting was made for it. As for pattern A, the errors of curves FNP-FWP, SP-XP (Front) and SP-XP (Back) were large, and they were stretched by 3.10%, 2.67%, and 2.13%, respectively. For patterns A and B, the error values of most curves are below 1%, except curve SNP-FNP, with -1.51% and -1.92% of the compression ratio.

Conclusion

In this study, each cross-section of body scan data was re-sampled to ensure the same common topological structure. The symmetrised preprocessing and convex hull methods were employed to create a dress-like virtual dummy. The corresponding feature lines were defined on the models through calculating the intersection curves of the body surface and local planes. The 3D models were subdivided using different cutting methods and the advancing front triangulation method. Corresponding 2D prototype patterns were generated using the surface flattening method based on the energy model. The area error and length error between the 3D surface and 2D pattern were analysed, which was done with relatively good accuracy. The areas of patterns A, B and C decreased after flattening from a 3D surface, and the error in the surface area was below 1%. As for the length, it became stretched and in some cases compressed. The value of the length error was influenced by the cutting method and the curvature feature of the 3D surface. Finally, the prototype garment pattern developed in the paper will be applied in future research to customise the pattern of other garment styles through the 2D pattern design system.

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