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Garment pattern definition, development and application with associative feature approach

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ABSTRACT

Garment virtual design has been evolved significantly with the rapid development of 3D CAD tools, especially with the convenient availability of NURBS surface modeling capability. Parametric development of clothes is demanded in line with the trend of mass customization according to the true measures of customers or regulated sizes of certain markets. Virtual design features with well-defined associations with the parametric mannequins are enablers. To achieve an intelligent mass customization approach, the development of surface patches from 3D clothing designs to 2D flattened patterns become essential. This article addresses the definition, development and application of garment features with an associative feature approach.

1. Introduction

Apparel manufacturing is traditionally conducted using two-dimensional patterns to produce sample garments to be fitted on a three-dimensional mannequin. The fitness of a garment is largely dependent on the experience of the pattern designer. This process is usually time-consuming and inefficient. There is a demand for automation in garment industry to overcome the issues of shortening the time to market and reducing intensive labour effort [1]. Traditionally, garment production is based on patterns; hence two-dimensional features are commonly applied in computer-aided solutions [2]. However, advanced CAD tools allow accurate modeling of mannequins [2], hence, early virtual concurrent design for garment mass customization becomes feasible [3].

Perhaps, computers are more involved in the downstream applications such as numerically controlled cutting path generation or automatic machine stitching of garment patterns. The garment design process still follows the traditional approach which designs the garment pattern two-dimensionally. Although the work reported in [4] can show the final garment in spatial dimensions after putting on the human body, this approach is not intuitive. This is mainly due to the variation of mannequin parameters according to the customers; and clothes should be generated from them, instead of the other way around. In addition, a procedure of draping simulation is necessary to evaluate the design [5]. The whole design process is iterative with trial and error [1,6].

Geometry representation and modeling methods are explored when garment patterns are designed three-dimensionally. Comparing with rigid objects which have fixed topology and geometry, for a piece of fabric, only topology is fixed [18–20]. Its geometry is influenced by the environment and the object underneath. Different from the two-dimensional pattern designs, curvature is introduced in the three-dimensional garment patterns, which is induced by the mannequin underneath. Depending upon the types of garment design, different kinds of mannequin are used. A detail digital human body as a mannequin [7–9] is necessary for designing a fitted bodice since the three-dimensional garment patterns take up the contours of the body. Otherwise, convex hull method is applied to idealize the model as a traditional mannequin for pattern design.

The garment geometry is represented by a set of geometric surfaces. Various methods are proposed to generate the surface information. These include surfaces interpolation based on the spatial curve defined with reference to a mannequin [9,10]. Much effort is put on the continuity between different patches in the garment patterns [7,11]. Mesh is another alternative to generate the pattern geometry [10,12]. The mesh is associated with the mannequin feature points so that the changes of mannequin size and shape are reflected in the mesh.

Flattening the three-dimensional garment patterns onto a plane is another challengeable issue. It should be an isometric transformation from three-dimension to two-dimension with the assumption that the fabric is non-elastic in most of the cases. Geometric methods for mapping the three-dimensional pattern

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geometry onto a plane with some geometric constraints are commonly used. Darts are often necessary to be assigned at certain locations on the pattern when a highly curved garment pattern is flattened [13,10]. However, geometry distortion is usually involved which causes inaccuracy of the pattern designed. Alternatively, an energy model for the fabric can be defined if a mesh is used to represent the pattern geometry. Mapping the three-dimensional mesh onto a two-dimensional mesh involves optimizing the strains of the pattern to yield the number of darts and their locations. But the dart suggested is usually of arbitrary shape which will not be adopted by traditional tailors and fashion designers.

Recently, Non-Uniform Rational B-spline (NURBS) surfaces are used to model the garment pattern. Various methods were employed to define the control points of the patterns [14]. These control points provide a designer the means to modify their design interactively.

Instead of designing the garment patterns two-dimensionally as on a sketch plan, this paper suggests the three-dimensional pattern approach. The garment patterns are defined as associative features spatially with reference to a mannequin. Two-dimensional patterns are obtained by flattening them on a plane. This idea is generated based on the associative feature concept suggested by [15] where features are defined with references and associated relations to a set of intelligent parametric objects. The feature properties and their behaviors are modeled and managed to cover its lifecycle of the concurrent engineering. Applying this advanced modeling approach requires the explicit relations and constraints defined to associate related entities. For example, a mannequin model can be defined by a set of parametric features [2] while 3D garment patches can be automatically generated to fit it. Then the patterns can be automatically developed by flattening those 3D patches. This approach gives a more direct visualization of the garment to the pattern designers, and iterative evaluations and changes can be achieved effectively. Fig. 1 gives an illustration on the possible system data flow and association configuration. Detailed association relations and feature objects definitions will be explored in a separate research paper.

In this paper, the pattern geometry is expressed in terms of boundaries and surfaces. These boundaries are the wireframe representation of the pattern geometry embedded in three-dimensional space. A set of developable surfaces is employed to represent the pattern geometry which can be flattened easily. With this method, the associations among parametric mannequins, 3D garment patches, and 2D cutting patterns can be modeled in associative features mathematically and generically. Then the object-oriented features classes can be further developed to support intelligent mass customization of garment products although this area can only be dealt with in future research works.

The major contribution of the proposed approach is to provide an intuitive method to design the boundaries of the garment patterns three-dimensionally. By representing the geometry of garment with a set of developable surfaces, the garment pattern distortion due to the Gaussian curvature (which is induced by the mannequin) is avoided. Hence, the two-dimensionally garment patterns can be obtained efficiently.

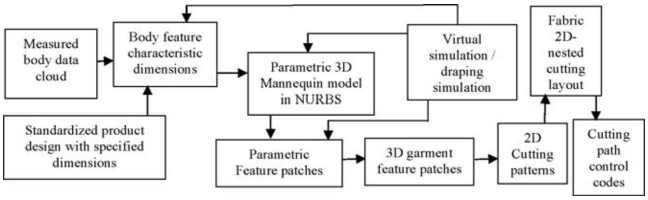


Fig. 1. Proposed feature association configuration in an integrated garment design and manufacturing system.

2. Definition of a developable surface

A piece of fabric possesses zero *Gaussian curvature*; hence, its geometry can be represented by a ruled developable surface.

A ruled surface is a linear interpolation between two curves $\mathbf{c}_1(u)$ and $\mathbf{c}_2(u')$:

$$\mathbf{s}(u, u', v) = (1 - v)\mathbf{c}_1(u) + v\mathbf{c}_2(u') \qquad (1)$$

A *developable surface* [16,12] is a sub-class of the ruled surface with the zero Gaussian curvature everywhere. In theory, it can be flattened onto a plane without stretching or tearing, hence, a developable surface is isometric after flattening. However, the condition of zero Gaussian curvature does not warrant generating a developable surface.

A ruled surface is developable if the tangent planes at all points along the line segment with the corresponding end points on both curves $\mathbf{c}_1(u)$ and $\mathbf{c}_2(u')$ coincide. The developability of a ruled surface is given by the condition:

$$(\mathbf{c}_2(u') - \mathbf{c}_1(u))\left(\frac{d\mathbf{c}_1(u)}{du} \times \frac{d\mathbf{c}_2(u')}{du'}\right) = 0 \qquad (2)$$

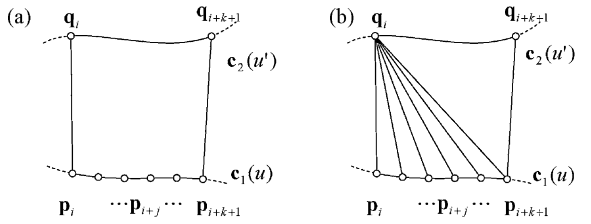
If a curve $\mathbf{c}_1(u)$ degenerates into a point $\mathbf{r}$, then $(d\mathbf{c}(u)/du) = (d\mathbf{r}/du) = 0$. This implies a ruled surface generated between a point and a curve is always developable.

An algorithm to generate a discretized approximation to a developable surface defined between two given curves $\mathbf{c}_1(u)$ and $\mathbf{c}_2(u')$ is listed in Fig. 2.

Suppose both curves run in the same direction. The curve $\mathbf{c}_1(u)$ is discretized into a set of n points $\mathbf{p}_i(\forall i \in \{1, 2, \ldots, n\}$. For every point, $\mathbf{p}_i$, the corresponding point on $\mathbf{c}_2(u')$, $\mathbf{q}_i$, which satisfies Eq. (2), is searched. When point $\mathbf{p}_i$ (for a specific integer i) on the curve $\mathbf{c}_1(u)$ pairs up with the point $\mathbf{q}_i$, the index i increases by one. Based on the next point on curve $\mathbf{c}_1(u)$, $\mathbf{p}_{i+1}$, the search for its corresponding ruling point $\mathbf{q}_{i+1}$ starts from $\mathbf{q}_i$ along the curve $\mathbf{c}_2(u')$. If the point $\mathbf{q}_{i+1}$ exists, $\mathbf{p}_{i+1}$ pairs up with $\mathbf{q}_{i+1}$; otherwise $\mathbf{p}_{i+1}$ will be a *dangling* point. The search for pairing up points $\mathbf{p}_{i+2}$ and $\mathbf{q}_{i+2}$ will resume from point $\mathbf{q}_{i+1}$. The process proceeds until all the points ($\mathbf{p}_i$, $\forall_i = 1, 2, \ldots, n$) on the curve $\mathbf{c}_1(u)$ are done.

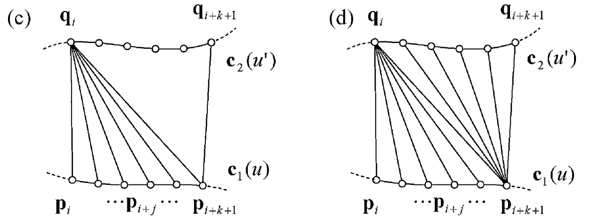
```
u'=0                                /*assign starting point
                                      on $c_2(u)$ for search*/
u″=0                                /*initialize register*/
for i from 1 to n+1
  if u′> 1                          /*check if end of $c_2(u)$
                                      is reached*/
    u′=u″                           /*reset to last
                                      successful u′*/
  endif
  $p_i = c_1\left(\frac{i-1}{n}\right)$                 /*for every point on $c_1(u)$*/
  flag = 0                          /*initialize flag*/

  while (flag = 0 and u′<1)         /*check the conditions*/
    /*check developability*/
    if$\left(\mathbf{c}_2(u')-\mathbf{c}_1(u)\right)\left(\frac{d\mathbf{c}_1(u)}{du}\times\frac{d\mathbf{c}_2(u')}{du'}\right)=0$
      $q_i = c_2(u')$                 /*assign the point $q_i$*/
      flag = 1                      /*set flag*/
      u″=u′                         /*store the successful u′*/
    else
      u'=u'+Δu'                     /*try another $q_i$*/
    endif
  endwhile
endfor
```

Fig. 2. An algorithm for generating a discretized developable surface between two given curves.



k dangling points on curve $\mathbf{c}_1(u)$

the dangling points pair up with point $\mathbf{q}_i$



points are generated on curve $\mathbf{c}_2(u')$

points $\mathbf{q}_{i+j}$ pair up with point $\mathbf{p}_{i+k+1}$

Fig. 3. Generating developable surface between dangling points.

The algorithm outputs a set of m ($\leq n$) points $\mathbf{q}_j$ ($\forall_j = 1, 2, \ldots, m$) which pairs up with the m points $\mathbf{p}_i$ on the curve $\mathbf{c}_1(u)$. The lines $\mathbf{p}_i\mathbf{q}_j$ between the two curves $\mathbf{c}_1(u)$ and $\mathbf{c}_2(u')$ are termed *generators*.

If there are k ($k = n - m$) dangling points between points $\mathbf{p}_i$ and $\mathbf{p}_{i+k+1}$ on the curve $\mathbf{c}_1(u)$, then points $\mathbf{p}_{i+j}$ ($\forall_j = 1, 2, \ldots, k + 1$) pair up with point $\mathbf{q}_i$. In addition, correspondingly between $\mathbf{q}_i$ and $\mathbf{q}_{i+k+1}$ on the other side $\mathbf{c}_2(u')$, another set of points $\mathbf{q}_{i+j}$ ($\forall_j = 1, 2, \ldots, k$ if $\mathbf{q}_{i+k+1}$ exists; otherwise, $\forall_j = 1, 2, \ldots, k + 1$) are generated on curve $\mathbf{c}_2(u')$ and pair up with point $\mathbf{q}_{i+k+1}$ as shown in Fig. 3.

In Fig. 3(a), there are k dangling points on curve $c_1(u')$. In Fig. 3(b), the k dangling points from $\mathbf{p}_i$ to $\mathbf{p}_{i+k+1}$ pair up with point $\mathbf{q}_i$ on curve $\mathbf{c}_2(u)$ while $\mathbf{p}_{i+k+1}$ pairs up with $\mathbf{q}_{i+k+1}$. Another k points $\mathbf{p}_{i+j}$ ($\forall_j = 1, \ldots k$) are generated on curve $\mathbf{c}_2(u')$ in Fig. 3(c). These points pair up with point $\mathbf{q}_{i+k+1}$ as shown in Fig. 3(d).

3. Three-dimensional garment pattern design

Garment patterns are designed three-dimensionally with reference to a mannequin which is an idealization of a human torso. It only consists of the major torso features that are important to garment pattern design. A set of feature points and construction curves are discussed in Ref. [7,2].

Datum planes are inserted into the mannequin and are used as sketch planes to design the patterns. The measurements of a human torso are based on two basic orientations: longitudinal (the heights) and cross-sectional (the girths). Therefore, the datum planes are usually inserted with these two orientations although it should not be limited to it. The boundaries of a garment pattern are outlined on these datum planes so that it is design spatially. For instance, four datum planes are used for pattern design in Fig. 4. One longitudinal plane halves the mannequin into left side and right side. The other longitudinal plane passing though the shoulder seam divides the mannequin into front part and back part. Two more cross-sectional planes, bust datum plane and waist datum plane, are installed at the bust level and the waist level. The bust girth and waist girth are obtained by intersecting the mannequin with the two datum planes. The boundaries of the front (left) pattern of a woman shirt are shown on all the datum planes.

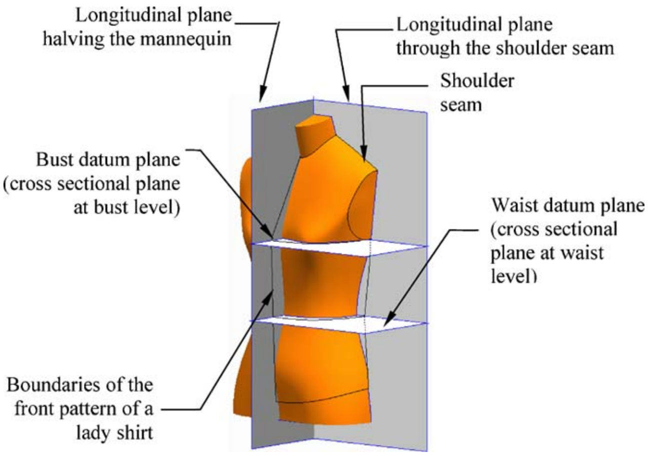
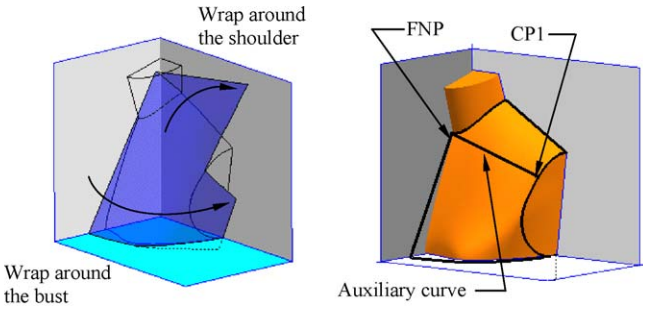


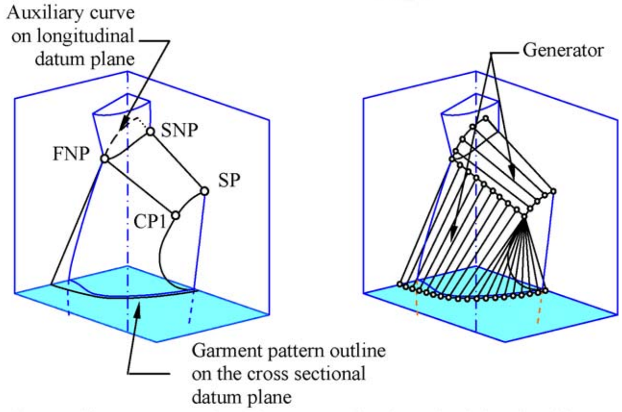
Fig. 4. A mannequin with datum planes and garment pattern outlines.

Besides the boundaries of the garment pattern, auxiliary lines are added when necessary. Consider the geometry of a front garment pattern of a lady shirt. There are two wrapping directions for a pattern to cover the upper part of the mannequin: one is around its shoulder while the other is around its bust. Fig. 5(a) shows the wrapping of the chest of a mannequin by a piece of (blue and transparent) fabric (with the assumption of no folds and wrinkles). The top right corner of the fabric is cut because the two axis of wrapping intersect with each other. Since these two wrapping directions are different, the garment pattern has to be split. A line is drawn to connect the front neck point FNP and the front armpit CP1 as depicted in Fig. 5(b). Another auxiliary curve is obtained by projection the armpit between the shoulder point SP and the front armpit CP1 on the datum plane along the two directions SP-SNP and CP1-FNP where SNP is the side neck point as shown in Fig. 5(c). The geometry of the garment pattern is represented by a set of developable surfaces and each developable



(a) Wrapping directions of the upper part of the mannequin

(b) Auxiliary curve connecting the front neck point and front armpit



(c) Auxiliary curve projected on the datum plane

(d) Discretized developable surfaces generation

Fig. 5. The geometry of the upper part of a garment pattern.

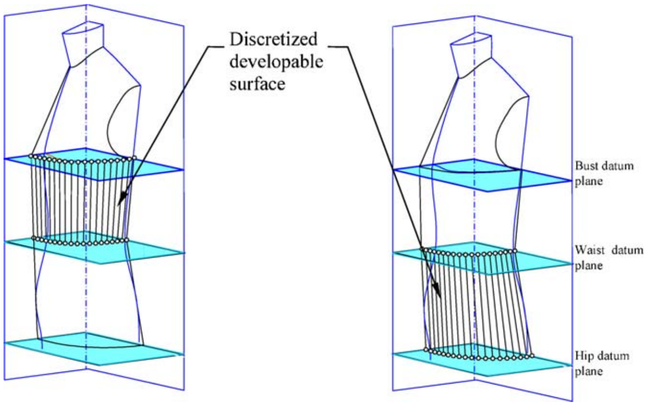


Fig. 6. The geometry of the lower part of a 3D garment pattern.

surface is defined by a pair of two curves. As a result, two pairs of curves are used to generate the developable surfaces for the upper part of a garment pattern. They are:

(i) The armpit segment SP-CP1 and the auxiliary curve projected on the longitudinal datum plane and;
(ii) The auxiliary curve CP1-FNP and the pattern outline on the cross-sectional datum plane at the bust level.

Two discretized developable surfaces are generated and shown in Fig. 5(d) by using the algorithm presented previously. The points are represented by the small circles and they are connected by the generators.

The geometry of the lower part of the garment pattern is simpler. A discretized developable surface is generated based on the boundaries on the bust datum plane and waist datum plane. Similarly, another discretized developable surface is defined by the boundaries on the waist datum plane and hip datum plane as depicted in Fig. 6.

4. Development of two-dimensional garment patterns (flattening)

The geometry of a three-dimensional garment pattern is described by a set of several developable surfaces which are approximated by their discretizations. Once the discretized developable surface is generated, it can be flattened on a plane by a series of rotations along the generators. The flattening process also includes the transformation of the three-dimensional garment pattern boundaries into the two-dimensional flattened pattern.

Surface flattening is essentially mapping of a three-dimension surface into a plane *isometrically* where the *geodesic distance* between surface points have to be preserved. This is a common requirement in most of the situation for flattening a garment pattern with non-elastic fabric property. A geodesic is the shortest path connecting two points on a surface. It is considered as a “straight” line even it is curved because its curvature is completely induced by the surface. The geodesic distance between two points on a surface is the arc length of the geodesic limited by these two points.

The geodesic equation with respect to the local coordinates on a surface is expressed as [17]:

$$\frac{d^2x^\lambda}{ds^2}+\Gamma^\lambda_{\mu\nu}\frac{dx^\mu}{ds}\frac{dx^\nu}{ds}=0 \tag{3}$$

where $x^\mu(s)$ are the coordinates of the geodesic $\gamma(s)$ and $\Gamma^\lambda_{\mu\nu}$ are the Christoffel symbols for the surface. The geodesic distance between two points, p and r, with parametric values of s_p and s_r on a surface, respectively is:

$$l_{p,r}=\int_{s_p}^{s_r}\sqrt{g_{\mu\nu}\frac{dx^\mu}{ds}\frac{dx^\nu}{ds}}\,ds \tag{4}$$

where $g_{\mu\nu}$ are the metric of the surface. Both Christoffel symbols and metric characterize the geometry (curvature) of a surface. For a plane, the metric $g_{\mu\nu}=\delta_{\mu\nu}$ such that:

$$\delta_{\mu\nu}=\begin{cases}0, & \text{when } \mu\neq\nu\\ 1, & \text{when } \mu=\nu\end{cases} \tag{5}$$

and

$$l_{p,r}=d_{p,r}=\int_{s_1}^{s_2}\sqrt{\frac{dx^\mu}{ds}\frac{dx^\nu}{ds}}\,ds \tag{6}$$

which is the Euclidean distance.

A point $\mathbf{r}$ on a surface $\mathbf{s}$ is denoted as $(l_{\mathbf{p}_1,\mathbf{r}}, l_{\mathbf{p}_2,\mathbf{r}})$ where $\mathbf{p}_1\in\mathbf{s}$ and $\mathbf{p}_2\in\mathbf{s}$. Then a bijective mapping between a surface $\mathbf{s}$ and a plane π is defined as:

$$\begin{aligned}&\varphi:\mathbf{s}\to\pi \text{ such that } \varphi(\mathbf{r})=(l_{\mathbf{p}_1,\mathbf{r}}, l_{\mathbf{p}_2,\mathbf{r}})\\ &\quad=(d_{\mathbf{q}_1,\mathbf{r}}, d_{\mathbf{q}_2,\mathbf{r}})\in\pi \text{ for } \mathbf{q}_1\in\pi \text{ and } \mathbf{q}_2\in\pi\end{aligned}$$

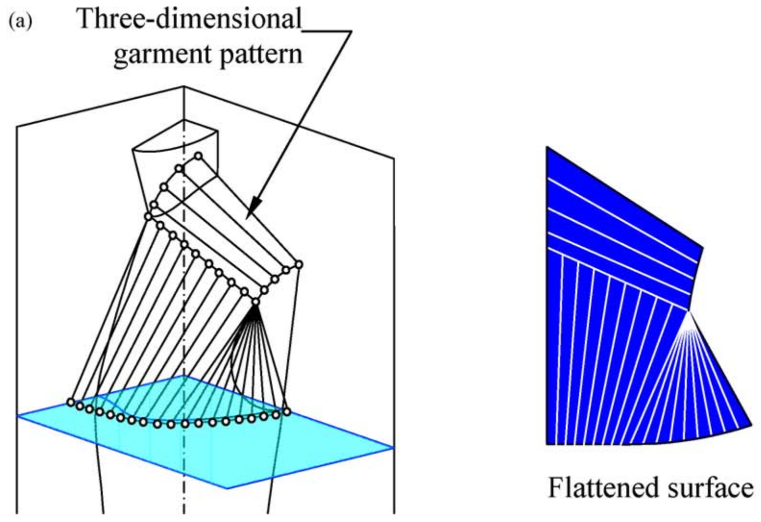
The pairs of points $(\mathbf{p}_1,\mathbf{p}_2)$ and $(\mathbf{q}_1,\mathbf{q}_2)$ are reference points fixed on surface $\mathbf{s}$ and plane π for arc length measurement.

Both Eqs. (3) and (4) can be very complicated for a highly curved surface. However, for the situation of mapping the boundaries of the garment pattern expressed as the discretized developable surface onto a plane, Eq. (3) degenerates into the equation of straight line and the geodesic distance is equivalent to the Euclidean distance. Fig. 7(a) shows the flattening of the three-dimensional developable surface. Some strips of the three-dimensional developable surface have internal boundaries. These boundaries are mapping onto the corresponding flattened strip with the bijective mapping φ as illustrated in Fig. 7(b).

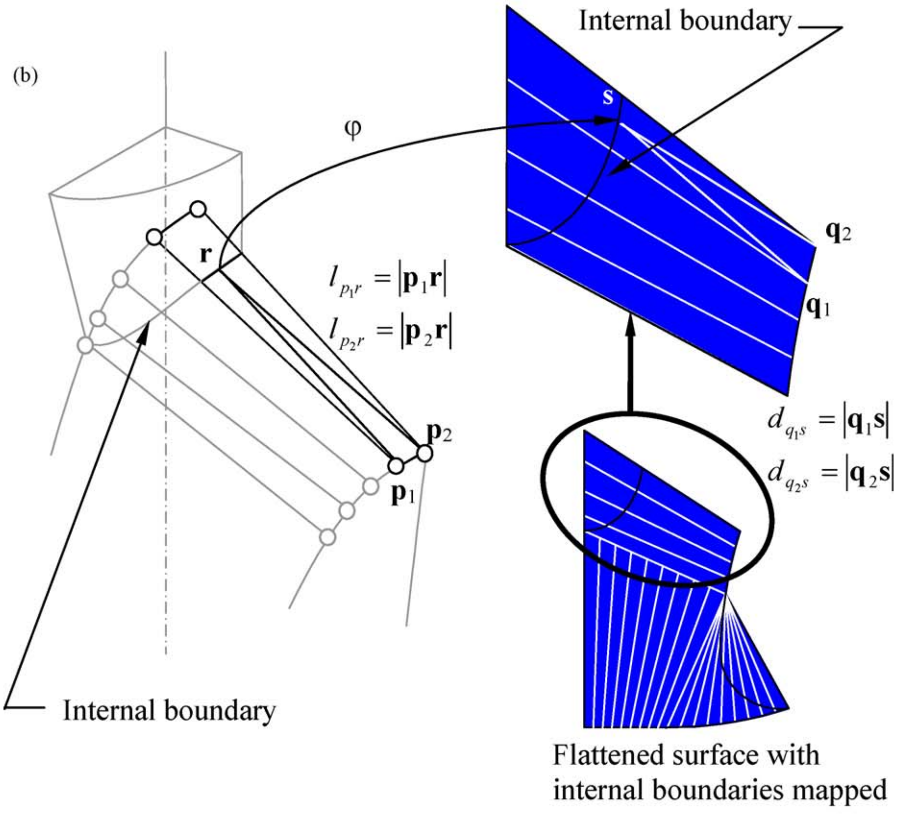
The lower parts of the three-dimensional garment pattern (between the bust-waist and between waist and hip) are also flattened individually. The internal boundary is mapped onto the two-dimensional pattern between the waist and the hip. The final two-dimensional garment pattern is completed by combining all three parts. The combination of the part above the bust level and the part between the bust level and waist level is exact with a horizontal dart introduced. However, the part between the bust and the waist level and; the part between waist and hip level are combined with certain area overlapping. This is mainly due to non-developability of the joint at the waist which is relatively shorter than the bust girth and the hip girth. Fig. 8(a) shows the lower part of a three-dimensional garment pattern which is flattened separately into two-dimensional in Fig. 8(b). Fig. 8(c) yields the joint of these two parts.

Similar approach is adopted to produce the rest of the garment pattern. The final patterns are put back on the mannequin as shown in Fig. 9. Fig. 9(a) shows a mannequin with all the front and back patterns and the datum plane while Fig. 9(b) has all the datum plane uninstalled. The fabric is set to 50% transparent so that the fitness of the patterns can be determined based on the amount of space between the fabric and the mannequin. Fig. 9(c) has the fabric transparence removed.

Fig. 10 shows another example of a male T-shirt design. Fig. 10(a) shows a male mannequin with the T-shirt designed three-dimensionally with four datum planes installed. Fig. 10(b) shows the flattened patterns of the T-shirt.



Flattening a garment pattern



mapping the boundaries

Fig. 7. Flattening the upper part of a three-dimensional garment pattern.

5. Discussion

One of the approaches to automate the garment production process starts with computer-aided pattern generation [4,6] which creates various sizes according to the grading rules [5]. The fabric is cut based on these patterns and is then stitched together to form a garment. The major problem of this approach is its non-intuitiveness especially for the close fit clothes design. Since the patterns are designed two-dimensionally while the garment has a three-dimensional form after putting on the human body. The timely process of draping simulation is necessary to visualize the design for every design-analysis iteration.

A more intuitive approach is to design the garment pattern directly on the three-dimensional mannequin [1,2]. A set of feature lines are pre-defined on the mannequin which are linked to the two-dimensional garment patterns. The garment prototypes are generated in the form of three-dimensional surface. The two-dimensional garment patterns are obtained by flattening the surface with the introduction of cuts and darts. However, the process of flattening a curved surface can be an issue for this

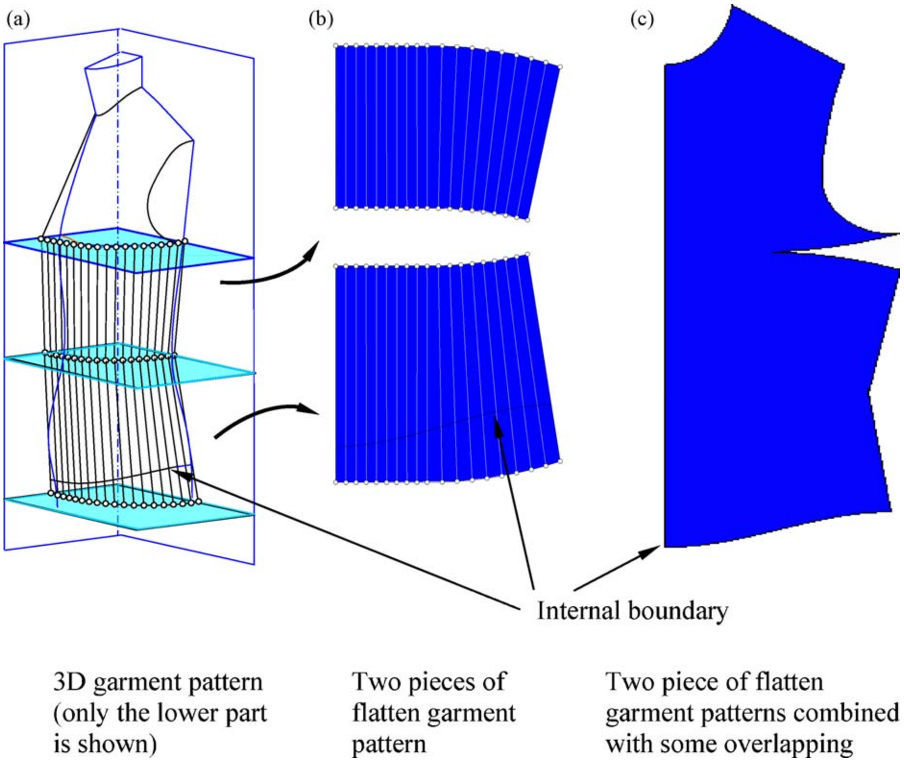


Fig. 8. Flattening the lower part of a three-dimensional garment pattern.

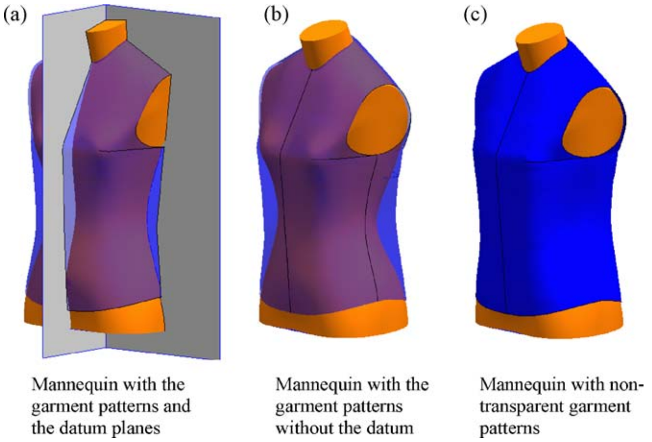


Fig. 9. A female mannequin with the garment patterns.

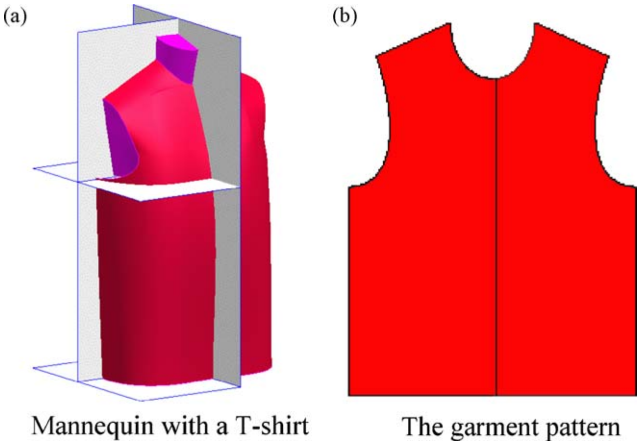


Fig. 10. A male mannequin with the garment patterns.

approach since distortion and additional cuts are induced to the garment patterns. Hence, a highly curved surface may cause great distortion to the garment pattern which may have large deviation from the traditional shape.

The presented method takes the advantages of both first and second approach. The garment patterns, which are developable surfaces, are designed on the three-dimensional mannequin directly using a set of datum planes. The surfaces are flattened isometrically. This can avoid the large distortion due to Gaussian curvature of the mannequin. Furthermore, the datum planes can be installed at any locations of the mannequin which gives more flexibility than employing the pre-defined features lines.

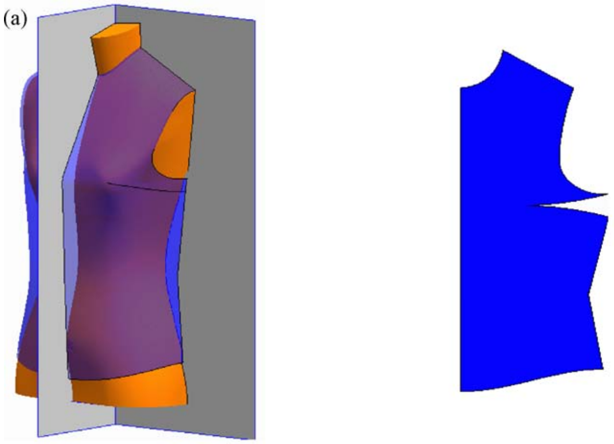
Since the garment patterns are decomposed into patches of developable surfaces, only C^0 continuity between the patches is considered. In addition, the boundaries of each flattened patch may not match exactly when they are combined to form the garment pattern. Hence, the metric is not totally preserved when the three-dimensional patterns are flattened. Both limitations introduce inaccuracy into the final garment product. As a result, draping simulation for visualization check is still necessary.

Fit measurement is necessary to consider during the garment pattern design. Fitting of a garment can be measured by the space between the garment and the human body underneath. It may be categorized into *static fit* and *dynamic fit* based on whether the wear is stationary or moving. A *cross-sectional fit index* μ_x can be defined by the ratio:

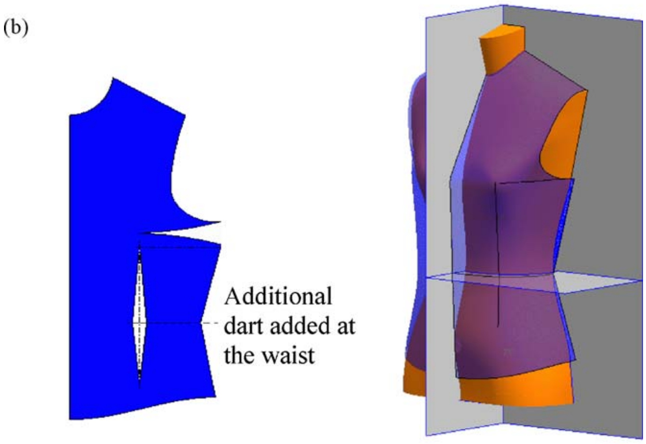
$$\mu_x = \frac{A_g - A_m}{A_m} \tag{7}$$

where A_g is the cross-sectional area of the garment at a specific girth; and A_m is the cross-sectional area of the mannequin at the same girth.

Since a garment is hung around the mannequin, this ratio will approach to zero at the upper near the shoulder and varies along the longitudinal direction according to the fittings of fitted, semi-fitted and straight loose fitting. In fact, the cross-sectional area is



Three-dimensional and two-dimensional (front) garment pattern of a woman shirt with $\mu_x \approx 10\%$ at the waist



Three-dimensional and two-dimensional (front) garment pattern of a woman shirt with $\mu_x \approx 5\%$ at the waist, additional dart is imposed on the pattern.

Fig. 11. Fitness index controlled by darts.

controlled by introducing the darts. Fig. 11 shows two types of three-dimensional (front) garment patterns of a woman shirt. In Fig. 11(a), the waist is just of semi-fitted with the two-dimensional pattern shown. If the fitting at the waist is fitted as illustrated in Fig. 11(b), additional dart is added to control the geometry of the pattern.

Furthermore, a *location fit index* μ_r may also be defined linearly to show the garment fit locally.

$$\mu_r = \frac{R_g - R_m}{R_m} \tag{8}$$

where R_g is radial distance at a point **p** on the garment pattern from a reference point **o**; R_m is the radial distance at a projected point from point **p** onto the mannequin along the direction of **op** (refer to Fig. 12).

Both static fit indices (μ_x and μ_r) are defined based on the idea of geometry comparison. They just give a rough idea to the designer to design the pattern boundaries on the datum planes.

On the other hand, dynamic fit is more complicated. Unlike the static fit which is purely geometric measurement, the fabric material properties and body motion are involved in dynamic fit measurement. Since the fabric stress and strain computations are necessary for cloth draping simulation, it may be used as a fit measurement index. If the garment strains are high, redesign and resize may need to consider. This area deserves more investigation.

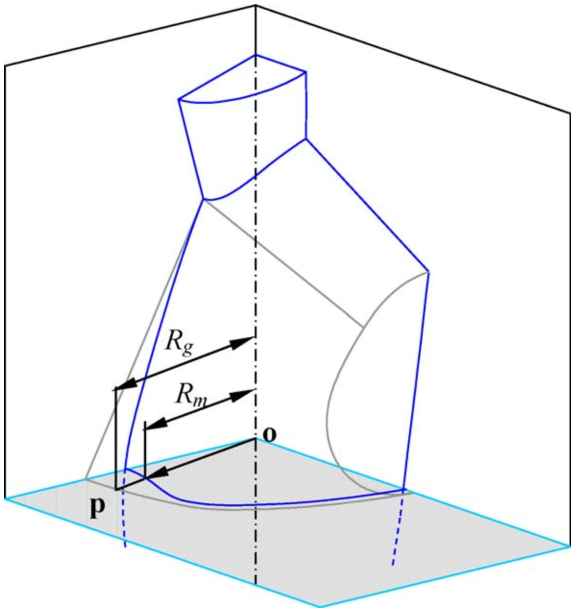


Fig. 12. Location fitness index definition.

6. Conclusion

The proposed modeling approach for three-dimensional garment patterns is basically similar to the design of rigid objects. Datum planes are inserted into the mannequin to control the geometry of the three garments. Traditionally, the tailors or fashion designers use papers to produce the block patterns to guide the cutting of fabric. Hence, the garment geometry should be considered as a set of developable surfaces.

Comparing with the approach of using other surface type to represent the pattern geometry, the developable surface has zero Gaussian curvature so that the surface can be flattened easily with the dart being introduced. Such flattening process is an isometric transformation without distortion.

However, since the pattern geometry is represented by more than one developable surfaces, the continuity at the surface joint is not guaranteed to be of order one. As a result, certain areas between two developed surfaces overlap which implies the area of the pattern is not preserved. Additional of darts can reduce this area overlapping and improve the area preservation.

Associative feature-based CAD tools are common in mechanical engineering design. However, it is not so popular in the area of garment and fashion design. This is partially due to the complex mathematical modeling of the deformable fabric. But more importantly is that the approach is too much mechanical, it lacks the aesthetic sense which is important in garment and fashion design. Hence, the garment and fashion designers may not consider advanced computer assisted approach, and are to be educated that associative feature-based approach works better than their traditional methods which emphasizes on personal experience and feelings.

Computer-aided design is an important tool to aid the design process. However, it should not be limited to the area of mechanical engineering in many industries. The same principle should be equally applicable in the garment and fashion industry to support the design activities. Although the material handled in mechanical engineering and garment industry is totally different. Rigid objects are involved in traditional mechanical engineering while the garment industry is dealing with deformable objects. The data structure and the manipulation algorithms may need certain modifications to fit the application.

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