

Interactive garment design

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A method for the design of garments at a workstation is proposed. An underlying body form analogous to a trade mannequin is first represented in the computer. Garment panels are considered to be surfaces of complex shape, whose fit with respect to body form may vary over the surface. A method of easy entry of data for representing panels is proposed, whereby fit around panel edges can be defined. The problems of controlling fit in the interior of panels is considered and a scheme is proposed which accomplishes design with economy of effort from the designer.

Key words: Garment design – Interactive three-dimensional design

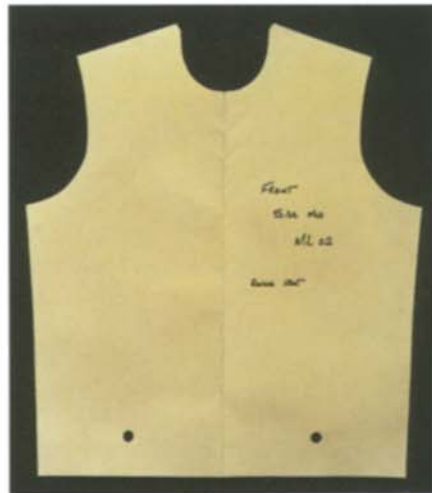
1 Introduction

The possibility of using computers to assist with the design of garments is currently a topic under consideration. The traditional tools of a designer have been crayons and paper. The design process has a number of stages [1]. The initial sketch depicting the designers creation has to be ultimately interpreted by a pattern technologist. The latter will define the patterns which, when assembled, will hopefully fulfil the original concept. To arrive at the style patterns, the pattern technologist consults precise block patterns retained as cardboard templates. There will be a process of modifying these in a controlled way in order to arrive at the style patterns. Following this, a sample garment will be made-up in a defined material which can be assessed for fit and drape. A single size only is considered at this stage. If it is decided that production should proceed, then a set of grading rules are used to determine how the dimensions of the original pattern should be changed to cater for the range of sizes required.

Computer-based sketching systems have made an impact in the garment visualisation area. Designers' sketches can have garment outlines filled with a video-captured texture in order to synthesise an image of a garment. Such systems have a contribution to make in marketing by generating an interest in particular styles and cloth-texture combinations. In essence, however, such systems are essentially sketches and do not impinge on the work of the pattern technologist.

In order to progress to this area it is necessary to consider a garment as an assembly of three-dimensional (3 D) surface panels, which can be represented by mathematical models. If such surfaces can be created and viewed at a workstation, then the possibility exists of performing the 3 D to 2 D mappings in order to arrive at the cutting patterns. The requirements are that a garment composed of panels can be readily defined with due regard to fit and drape, that a chosen texture can readily be applied to the surface and that the resulting cutting patterns can be defined to allow assembly and make-up to occur as quickly as possible. A design tool of this nature would permit not only the visualisation of a garment but would short circuit the process of defining the style patterns.

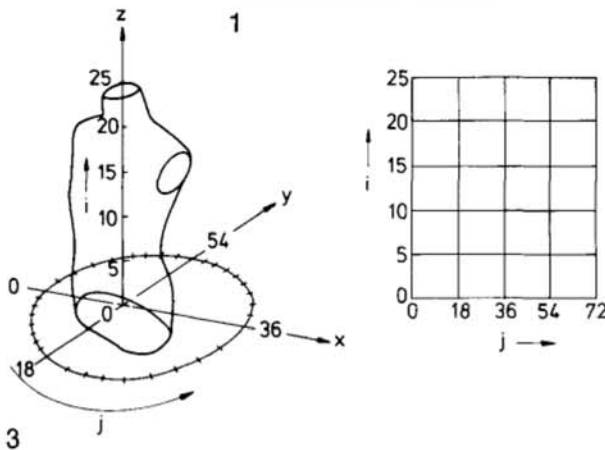
However, such a design tool would demand a new approach to evaluating patterns and to the assessment of fit. At present the clothing trade considers a typical size measurement as the distance around the body between two defined points. In parts it will be desired that a garment fits closely to the



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Fig. 1. Conventional pattern for garment panel

Fig. 2. Digitising frame for trade mannequin

Fig. 3. Co-ordinate reference frame and generating array

body. Elsewhere extra fullness may be required to allow folds or drape to occur. An alternative to modifying the inter-point distance is to consider the garment fit in terms of the offset from the body. A garment panel would then be a surface offset from the body by varying amounts determined by the designer. If a fold pattern were to be designated as part of the design, it could perhaps be implemented as an offset expressed as a harmonic function.

A design process based on the above approach is presented in this paper. A geometry editor allows garment panels to be defined as surfaces with respect to an underlying body form. A mapping from digitiser coordinates to body surface points is proposed which overcomes the problems associated with 3 D point placement with respect to the body. Garment panels can then be defined by setting

points and edges which pass through these points.

Although not discussed here, progress has been made on the complementary task of 3 D to 2 D mapping. The ultimate objective is that the garment panel defined in 3 D form by the method proposed, can be reduced to the 2 D cutting pattern, an example of which is shown in Fig. 1.

2 Body representation

A tailor's dummy or mannequin is frequently used in the clothing trade as a reference model for a given size and shape of person. It was necessary at the outset to create such a model in the computer before proceeding to define garment surfaces. Although there is an obvious need for geometric

data relating to the body, no authoritative source for such data could be found. Major retail outlets frequently monitor long-term trends in population body forms, but recourse is still made to standard anthropometric dimensions which are essentially curvilinear. This method is inappropriate [2] if a 3D form is required which, after all, is the ultimate yardstick for determining fit. To remedy this situation current projects are underway which are attempting to obtain 3D data by automatic scanning [3].

To obtain data for a computer model, in the present case, a mannequin was digitised in a measuring frame (Fig. 2). A simple mechanical turntable was used to rotate the mannequin while a pointer could be used to measure the radius at different heights. It will be apparent that such an arrangement yields body points with reference to a cylindrical coordinate system (R, θ, Z). Points were measured at height intervals of 24 mm and angular increments of 5° .

For the particular mannequin used, a child size 10, a $[25 \times 72]$ dimensional array of radius values was compiled to produce a suitable body representation. With adequate precautions to ensure a complete "wrap-around" from 360° to 0° and with extra control points to provide definition at the high and low edges, the surface points contained in this array provided a control point mesh for a B-spline surface interpolation. Figure 3 illustrates the coordinate reference frame and the generating array.

At this stage it is convenient to consider the 2D array described above as constituting an $i-j$ plane, where the index i refers to the z height and the index j refers to the angular displacement. Positions on the body are easily referred to by their $i-j$ values.

This data structure has proven to be an adequate representation for a computer-based B-spline model of the body, though some further improvements are possible. As the z heights were measured at equal intervals, there was a reduction in the density of points in the shoulder regions, which caused the B-spline model to undercut the true dimensions to a slight degree. More data points in these regions would help. Also arms are not at present digitised. This would require a more subtle measurement frame to be organised but would not present a fundamental difficulty.

The use of $i-j$ indices to locate points on the body also provides a convenient basis for defining offset points. When creating surfaces at a CAD worksta-

tion, the conventional way to define points in 3D space is to select an orthogonal plane within an x, y, z reference frame and to use a digitiser to choose or move points about in this plane. This method is commonly provided as a utility on modern graphic workstations. Recalling that the prime requirement in the present application is to provide curves and surfaces which have a quantified fit with respect to the body, it was considered that this approach would lead to confusion and to the need for frequent switching of planes. It is in fact much easier to use the $i-j$ curvilinear coordinates, especially as the body model is a relatively smooth surface of mostly, but not always, elliptical curvature.

3 Digitiser interaction

The $i-j$ plane forms a 2D reference frame for accessing any point on the 3D body form. This is achieved by interpolating between measured nodes. For instance, if an x, y, z triple is required for any point (i_p, j_p) on the $i-j$ plane, then the appropriate B-spline patch is obtained by reference to the 16 bounding measured nodes. Further, the values of (i_p, j_p) are used to generate local patch parameters, (s_p, t_p) , which specify a unique cartesian point within the prescribed B-spline (Fig. 4). If the $i-j$ plane representation is now mapped onto a region of a digitising tablet, then this can be used to interactively generate (i, j) pairs. These in turn specify the geometry matrix for the B-spline patch, which locally describes the surface containing the required point. Precise points are interpolated by calculating the appropriate values of the parameters s and t that are required to generate the x, y, z triple.

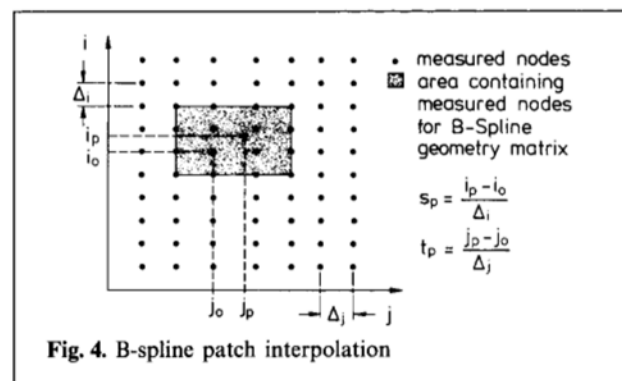


Fig. 4. B-spline patch interpolation

Hence 2D movement of a digitiser is simultaneously translated into 3D movement on the surface of the body, providing sufficient computational speed is available to ensure continuity of the graphical representation. This level of computational performance is now possible by making full use of the dedicated 4×4 matrix multiplication processors now available within modern graphics workstations which are normally devoted to graphical transformations. In fact, the performance is such that the B-spline representation need only be stored in geometry matrix form, not in bicubic coefficient form, since the additional matrix computations can be carried out without sacrificing graphical performance. This represents a significant saving in storage requirements.

If constrained to move only on the surface of the body, the cursor would prove of limited use to free-form design. To obtain the additional degree of freedom, it was decided to construct a surface normal of variable length k , from the body point defined above. The calculation of the direction of the surface normal is readily obtained from the cross-product formed by the tangential vectors with respect to each of the B-spline parameters s and t . Again the computational speed of the workstation proved sufficient to perform the additional matrix computations. The length of the surface normal is controlled by depressing digitiser puck buttons.

The overall result is that 3D interaction is possible which is ergonomically practical and which is consistent with the industry's important and quantifiable parameter of fit, which is interpreted here as the normal distance from the surface. The first stage of the design process consists of the entry of offset points, called design points, nominated by this 3D interaction. These are used to fix the edges of garment panels. The determination of offsets for the interior of panels is considered below.

4 Three-dimensional surface representation of garment panels

The creation of garment panels in the present work is based on four requirements:

1. There should be freedom to choose any number of edges for each panel. In the present case the number can range between two and ten.
2. There should be positional continuity C^0 , where two panels meet.

3. The interactive build-up of panels should be based on the body model and cursor movement.

4. Panels should be capable of accommodating enhancements such as drapes and folds.

The approach adopted has been to consider edge definitions as existing in two forms simultaneously. While being visualised using a normal cartesian coordinate system, another form exists where each curve is represented by a parametric curve defined in the dimensions of $i-j-k$. Here i and j are the height and angular indices described above and k represents the offset along the normal which connects a body point to a point in 3D space outside the body. Figure 5 illustrates this dual form. The need for duality can be explained by a simple example. Suppose it is required to generate a curve which is to represent a close fitting edge of a garment panel. In order to maintain a certain fit, the curve should have a constant offset, say d , from the underlying contour of the body form. A typical example of this type is also shown in Fig. 5 with its equivalent dual form in $i-j-k$ space. As can be seen, the dual form is a simple straight line, whereas the equivalent cartesian curve is more complex and would have required a more elaborate definition if reference had not been taken of the underlying body model.

It is worth noting that the definition of the curve in this example requires only the interactive definition of two points P_1 and P_2 , using the previously described cursor. It is possible to have between two and four design points in $i-j-k$ space to specify an edge, four points using a parametric cubic, three points a quadratic and two points a linear representation. The scope exists for making an edge have a more complicated form, but for the present this would have to be done by aggregating the basic form within the constraint on the maximum number of edges.

In turn these edges can be "picked" to form a contiguous boundary in cartesian coordinates and its equivalent representation in $i-j-k$ space. For the moment, consider the projection of the latter on the $i-j$ plane only (Fig. 6). This 'plan view' is used to define two further parameters which generate the surface required. The new parameterisation relies on the positioning of a surface centre point C , which must have the property that all lines connecting it to each vertex of the surface representation do not intersect any of the edge curves in the $i-j$ plane (Fig. 7). Of course, the positioning of the

point *C* places a limitation on the complexity of surface that can be represented. However, surfaces that do not contain a feasible position for *C* are extreme and are not representative of the patterns normally used by the clothing trade. This has not proven to be a major limitation.

By assigning a *u* parameter value of zero to an arbitrary edge vertex, a rotation around the panel allows *u* to increase, adopting integer values at vertices. The *v* parameter is assigned values within the interval [0-1], with *v* equal to 0 at the centre point *C* and *v* equal to 1 on one of the edges specified by the *u* parameter (Fig. 8). This arrangement provides a convenient mechanism for generating all points on the *i-j* plane that are enclosed by the garment panel.

It remains now to define a suitable interpolation method for the offset value *k* in order to produce a satisfactory surface representation. In order to economise on data entry, the value of any interpolated offset is taken to be a weighted function of the entered design points, interactively defined and subsequently "picked" to be edge curves. After some trials a simple two-stage interpolation procedure has been adopted.

The objective here has been to interpolate an offset for any (*u, v*) combination, e.g. (*u_r, v_i*), based upon the offsets at the design points. The first stage is to nominate an offset value for the centre point *C*. This is simply taken as the average of all offsets of the edge design points. Suppose this offset is *k_c*. Next, a parametric cubic function is fitted to each edge in the same way that *i* and *j* were interpolated. Thus for a given (*u_r, v_i*), the *u* value is used to interpolate an offset *k_(u)* on the edge and the *v* value is used to linearly interpolate between *k_(u)* and *k_c* (Fig. 9). Thus

$$k_{(u_r, v_i)} = k_c + v_i(k_{(u)} - k_c). \quad (1)$$

While proving easy to implement, the resulting surface appears "tent-like" due to the lack of slope continuity across the boundaries at *u* = 1, 2, 3 etc. A typical surface of this type is shown in Fig. 10. The discontinuous effect is more pronounced at lower values of *v*, that is towards the centre point *C*.

The problem can be traced to the fact that the offset weighting only uses offset values appropriate to the edge sector indicated by the integer interval of *u*, except for the calculation of *k_c*. Therefore, it is necessary to consider a weighting process

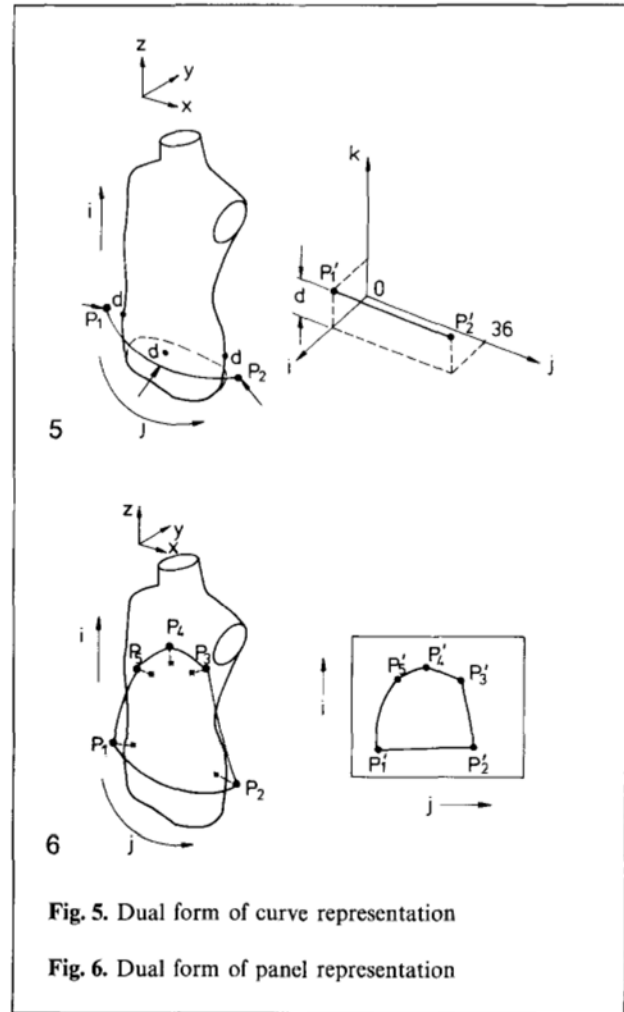


Fig. 5. Dual form of curve representation

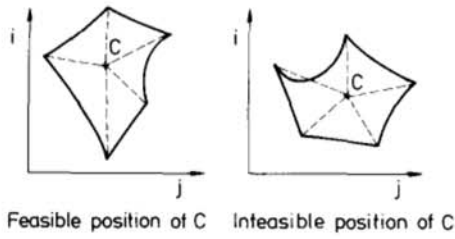
Fig. 6. Dual form of panel representation

which places greater emphasis on all offset values, rather than on those of the edge sector involved. Such a weighting process is available [3]. This method directly uses all offsets and employs the linear distance between the design point and the interpolated point as an indicator of the relative weighting to be given to that design point. The interpolated offset *k_s* is obtained as

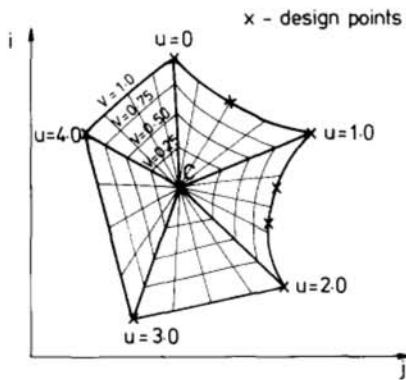
$$k_s = \sum_{p=1}^n (k_p \times A_p)$$

where

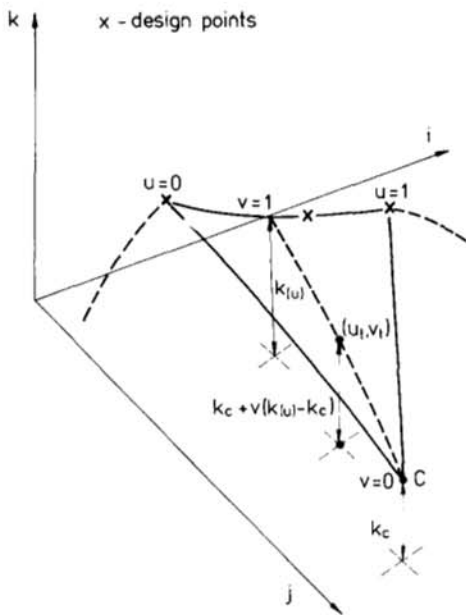
$$A_p = \frac{\prod_{q=1}^n d_q^u}{\sum_{r=1}^n \prod_{m=1}^n d_m^u} \quad (2)$$



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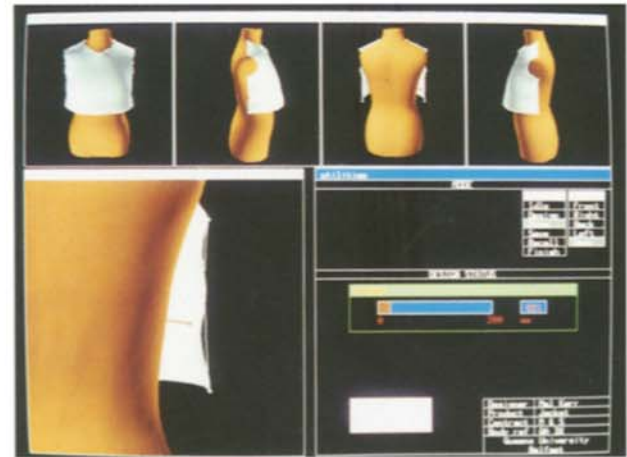
Fig. 7. Positioning of point C

Fig. 8. Parameterisation of garment panel

Fig. 9. Linear interpolation of panel offsets



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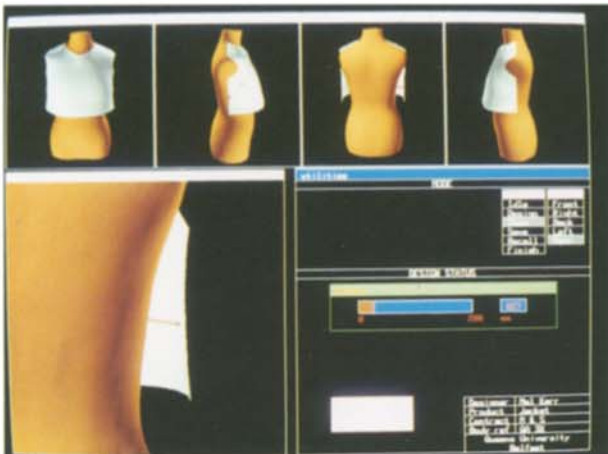
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Fig. 10. Lack of smoothness with linear interpolation

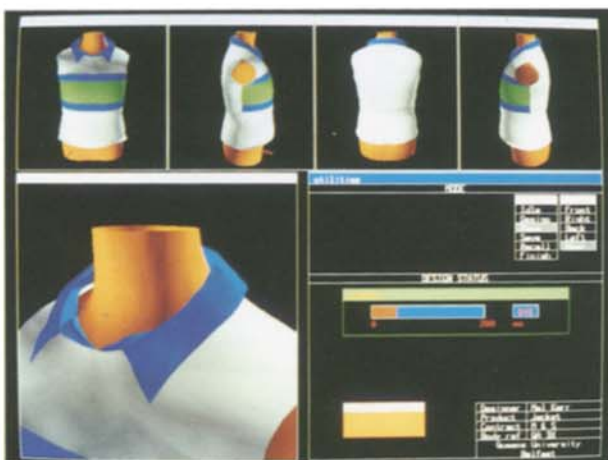
Fig. 11. Edge undulations with Shepherd's interpolation

with A_p = weighting given to p^{th} design point; k_p = offset at p^{th} design point; d_p = distance between interpolated point and design point (on $i-j$ plane); n = total number of design points on edges of panel; μ = constant.

The surface produced by this weighting procedure is smoother overall but particularly so in the central area. Also, although the surface produced includes the design points, it tends to undulate along edges between the design points. This is evident in the lower left image in Fig. 11 where gaps appear between the shaded surface and the required edge, coincidence only occurring at the design points. Considering the joining of two separate garment panels along a common edge, C^0 continuity is required. Since the shape of each garment panel is



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Fig. 12. Panel representation with composite interpolation

Fig. 13. Garment representation

separately defined by the design points picked along its edges, C^0 continuity is not likely to be achieved with this process alone.

A compromise between the two methods was developed whereby the v parameter was used to quantify the relative contribution of both processes. As $v \rightarrow 0$, then the second method would predominate, while as $v \rightarrow 1$ the first method would predominate. This compromise retained the benefits of both weighting processes, with the following form providing the best results

$$k_{(u,v)} = k_s(1 - v^3) + \{k_c + v(k_{(u)} - k_c)\} v^3. \quad (3)$$

As can be seen, this method provides positional continuity between neighbouring surfaces, since at the boundary $v = 1$, the above equation reduces to

$$k_{(u,1)} = k_{(u)} \quad (4)$$

and as such uses only the designed points of the edge concerned. A typical garment panel using this surface representation is shown in Fig. 12.

If appropriate surfaces, designed using this process, are suitably enhanced with features now common on high performance graphics workstations, the garment design can be obtained (Fig. 13) which approaches the quality required by a discriminating industry with high artistic standards.

5 Graphics representation

It is true to say that the techniques described here are now only practical as a result of modern advances in graphics workstations. Hence, it is worth indicating the features of these workstations that contribute to the functionality of the proposed design tool for the garment industry.

Where possible, use has been made of the dedicated processors available to perform the multiplication of $[4 \times 4]$ matrices. Although ostensibly provided for the speedy manipulation of graphical transformations, the same facility proves invaluable for the real-time conversion of digitiser co-ordinates into body points, surface normals and then design points which are offset from the body. All of these calculations are performed sufficiently fast to give the impression of continuity of movement of a graphical cursor moving around the body in 3 D.

The multi-window facility provides a useful means of obtaining a comprehensive visual feedback of

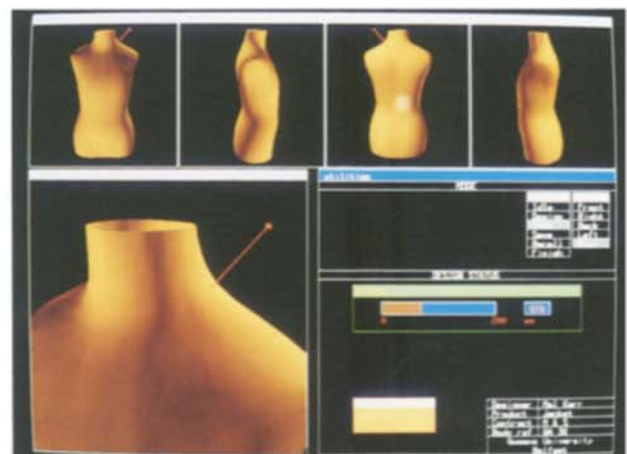


Fig. 14. 3D cursor movement

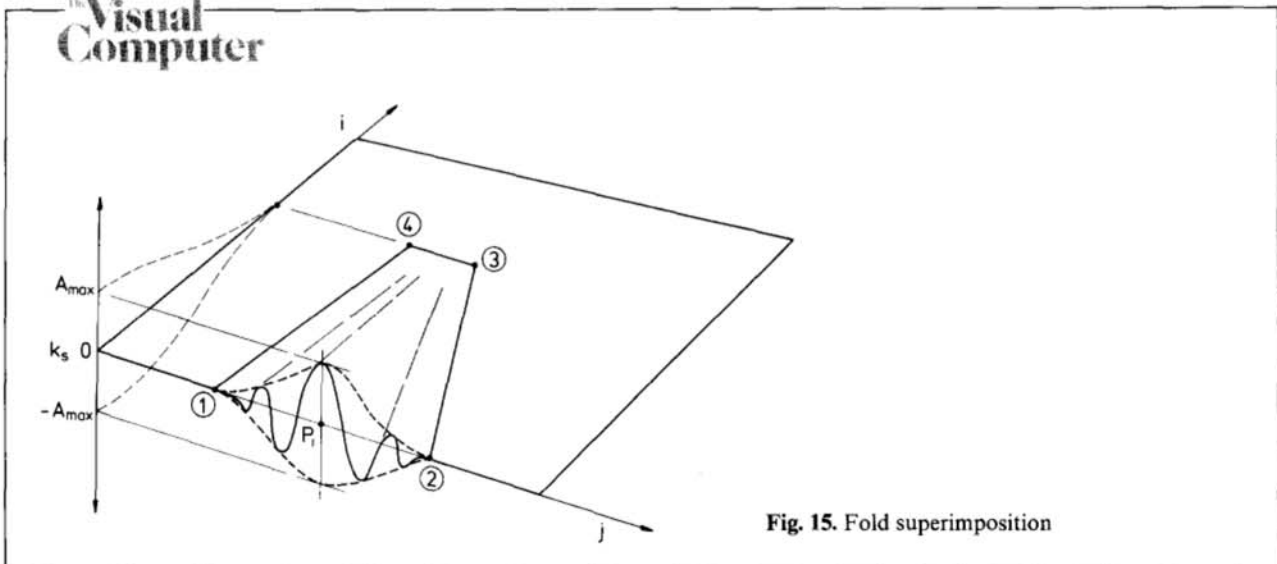


Fig. 15. Fold superimposition

the cursor position in 3D space. The configuration adopted is that of four orthogonal plus an additional arbitrary view being simultaneously presented in five windows. The user-defined view makes full use of the 3D data base for storing both the body model and the garment design, since it permits complete scope for selection of zoom and viewing direction. As the digitiser puck moves, the 3D cursor responds on all views simultaneously with some obviously being affected by hidden surface removal (Fig. 14). Any one of the views can be nominated as the main view with subsequent exchange of the respective windows.

The Gouraud shading utility is invaluable in producing realistic images as well as reducing the polygonal density required to produce a desired visual effect. The lighting model used is a simple diffuse type with an ambient component to prevent complete darkness in certain areas of the garment panel surface.

The Z-buffer utility for hidden surface removal has proven unpredictable and difficult to use for 3D interactive cursor movement. Superficially, it should have been straightforward to achieve the effect of the cursor disappearing from view as it travelled around the body by a combination of masking of bit planes and selective updating of the Z-buffer. However, when this was attempted, it was found that programmable control of the contents of bit planes was not sufficiently comprehensive. In particular, it was not possible to suppress selectively the Z-buffer updating while still retaining its ability to decide whether to draw or not. It does appear that lower level commands should be made available to provide the required level of control.

6 Discussion

Three of the four requirements of the surface representation specified in Sect. 4 have been successfully overcome. At present, work is continuing on the fourth requirement, namely to incorporate features such as drape and fold embellishments within the surface description. This work exploits the offset feature further by superimposing harmonic functions of the k parameter defined on the $i-j$ plane. With suitable precautions to avoid the offset value from becoming negative, this method has proved most amenable to fold macros being developed. The form of the fold macro which is presently used is outlined in Fig. 15. It is fixed on a quadrilateral region of the $i-j$ plane defined by the corner points (1), (2), (3) and (4). A sinusoidal function is then defined which reaches maximum amplitude A_{max} at the point P_1 , and decreases to zero along the other three sides. As a result, the fold macro generates a



Fig. 16. Fold visualisation

superimposed offset k_s , which is added to the normal panel offset k , for any $i-j$ pair falling within the defined quadrilateral. This structure also facilitates folds being produced which can cross the boundary between two neighbouring garment panels.

When the fold macro is used in conjunction with a development algorithm which generates the 2D-3D mapping, an effective rendering can be achieved (Fig. 16). These results demonstrate the level of realism that can be obtained for the design process outlined here.

As regards the other requirements, the surface representation has proved robust for simple garment styles. More complex styles will eventually violate the limits of the positioning of the midpoint C as described in Sect. 4. At present this point is obtained by a simple averaging process. It is intended to develop a strategy for finding the best position for this point, if one exists. If one does not exist, then appropriate partitioning of the $i-j$ plane representation will circumvent this problem.

As work progressed, two further features have emerged as a consequence of designing with reference to the underlying body form.

Firstly, as realistic designs were attempted, it became apparent that in fact designers require two basic criteria for deriving curve forms in 3D and subsequent surfaces. As described above, when the required body panel is located close to the body, then fit is the major influence in controlling the geometry of the edge curves. However, as garment panels move further from the body, there is a subtle shift to normal cartesian standards, whereby straight lines and drape predominate. This does present some difficulties and is currently the subject of refinements.

Secondly, the approach described here offers a mechanism for providing different sizes of the same garment design, i.e. grading. The industry has traditionally used empirical rules for grading a range of sizes of patterns from one particular size. If a repertoire of body forms are stored which represent standard sizes, it can be seen that dimensionally correct variants can be obtained by simply changing the underlying body form, i.e. the $i-j-k$ to $x-y-z$ mapping. Since garment panels are all stored in the $i-j$ plane, dimensionally independent garments are designed which only assume $x-y-z$ dimensions after the body has been specified. Coupled with the ability to generate 2D style patterns, this can be used to provide the complete size range of patterns.

7 Conclusion

The 3D interactive design of garments is now possible due to recent advances in workstation performance. These advances in hardware are currently being matched by advances in software that address this new situation. Garments designed in this way are stored on a 3D data base and, as such, offer the opportunity of automatic pattern generation.

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