

Real-time Cloth Simulation for Garment CAD

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Abstract

For decades, Computer Graphics has played an important role in many kinds of design works, especially, industrial design of solid objects. However, most available methods can not work well for soft and deformable object like cloth. The quality of works mostly depends on the efficiency of hardware as same as the cloth and garment pattern modeling methods. In this research, real time cloth modeling for costume design and making is proposed using mass-spring model and cellular structure space model. For representing realistic cloth, mass-spring model is parameterized under Newton laws, while cellular structured space model is defined for keeping the structure of each garment pattern. Then, the pattern is scaled to fit the input user's body size and clothed on user's virtual body. Furthermore, this pattern can be printed out as a set of ready-to-cut patterns. Proposed 3D modeling for costume design can reduce material cost and computational time for pattern making, and also enable dress remaking and refitting process in real time.

Categories and subject descriptors: I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling--physically based modeling

Keywords: cloth model, human model mass-spring model, garment model, cellular structured space.

1. Introduction

Several methods for modeling cloth in computer graphics have been investigated for years in order to make the most realistic model in real time. Most methods generally start from cloth's characteristic studies following by construction of mathematical models. Nowadays, CG applications play a major role in film and game industry. At the same time, the usage of computer in fashion or garment making is also growing up. Virtual try-on [Gross et al. 2004; Spanlang et al. 2003] is an example of popular software used in garment industry. The virtual representation of a user is acquired via a 3D scanner where the body information is extracted, and the user can instantly try garments or dresses on the automatically constructed virtual bodies displayed on computer screen. However, the cost for 3D scanning is not cheap, and this technique requires high performance hardware, so this system still is limited only in some high end boutiques.

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Some realistic cloth simulations based on graphic workstations have been proposed [Terzopoulos and Metaxas. 1991; Metaxas and Terzopoulos 1993]. On the other hand, static human and cloth model [Kakadiaris et al. 1996] can trade off the cost of computation. Parallel projection and coplanar viewing direction [Wang et al. 1989] have also been used to reduce the complexity and enable the interactivity of the system. However, merging of reconstructed surface patches from different views is still not trivial.

In this research, an adaptive way to construct virtual body and display real-time cloth simulation of user chosen patterns is presented. First, a human shape generating algorithm based on body measurement [Narong 2004] using cross-sectional contours is proposed. We then construct 2D garment patterns and define a topological garment structure, which can be remade. This structure can be transformed for performing a prescribed set of movements, while its topological structure can be used for searching in database. Our system also allows arbitrary camera configuration. Moreover, the whole scheme avoids the problem of merging of reconstructed surface patches from different views as in [Wang and Aggarwal 1989]. The proposed garment CAD system also provides a pattern print out function.

In the next section, implementation of cloth modeling is given. Virtual body construction is explained in Section 3. In Section 4, how to place the cloth on the body is then described. We follow with all details about pattern making for printing in Section 5. Finally, experimental results and conclusions are given successively in Section 6 and 7.

2. Cloth modeling

Although in the real world cloth is considered as a kind of rigid object, in CG, cloth is represented by a deformable model, since it is made of soft woven material having flexibility with an ability to change its shape without tear. These major characteristics of cloth are considered as a set of parameters of cloth modeling. In addition, natural force and reaction are computed for its realistic motion representation.

2.1 Mass-spring model

Among several methods [Ng and Grimsdale 1997; Volevich et al. 1997], mass-spring model is mainly used for describing cloth dynamics because of its suitability for real time application. Mass-spring model treats cloth as a grid of nodes at which mass of the cloth is assumed to be concentrated. This grid is the connection of a series of linear springs designed to resist forces pulling the fabric apart. Various types and structures of springs has been proposed while each method gives different results and draw backs [Breen et al. 1994; Carignan et al. 1992, Eberhardt et al. 1996, Ng et al. 1995, Terzopoulos et al. 1987]. In this

research, in order to trade between accuracy and speed, we use a mass-spring model having three types of springs [Lander 1999] to maintain the cloth shape as shown in Figure 2:

- **Structural Spring:** these springs connect each node with its four adjacent non-diagonal neighbors, serving to keep the cloth in a sheet.
- **Shear Spring:** these springs connect each node with its four adjacent diagonal neighbors, opposing shearing deformation.
- **Bend Spring:** these springs connect each node with the two horizontally and diagonally neighbors. This type of springs has little impact unless the points are non-coplanar, in which case the springs serve to restrict the bending of the sheet.

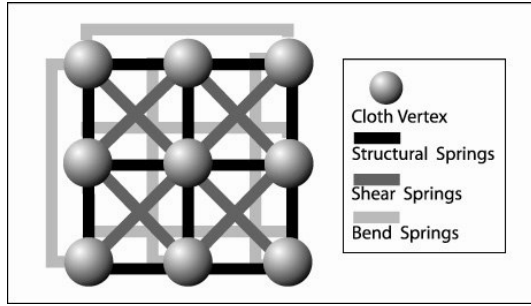


Figure 1: Mass-spring model structure.

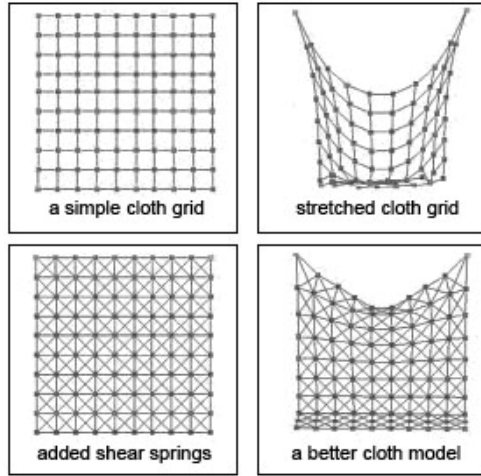


Figure 2: Real-time deformation results of cloth without non-shear spring (upper) and with shear spring (lower).

2.2 Cloth movement

The movement of cloth is caused by forces that applied to each node of model. Since each node has a mass, the gravity force will make it move down to the ground. The position of each node, at any time t , can be derived through the Newton's second law of motion:

$$\begin{aligned}
 f &= ma \\
 a &= \frac{dv}{dt} = \dot{v} = \ddot{x} = \frac{f}{m} \\
 v &= \frac{dx}{dt} = \dot{x}
 \end{aligned}
 \tag{1}$$

There are two main forces that applied to each node. The first one is gravity force g , which can be calculated from the basic Newton's law by substitute a with g .

$$F = mg \tag{2}$$

The other force is the spring force, which can be calculated from the formula where k is spring constant and s is displacement from equilibrium position.

$$F = k\Delta s \tag{3}$$

All the above formulations make it possible to compute the force $f_{ij}(t)$ applied to each node n_{ij} at any time t :

$$a_{ij}(t + \Delta t) = \frac{1}{m_{ij}} f_{ij}(t) \tag{4}$$

The positions and velocities of the nodes are computed based on Runge kutta integration as following [Ng et al. 1997]:

$$\begin{aligned}
 k_1 &= hf(x_0, t_0) \\
 k_2 &= hf(x_0 + \frac{k_1}{2}, t_0 + \frac{h}{2}) \\
 k_3 &= hf(x_0 + \frac{k_2}{2}, t_0 + \frac{h}{2}) \\
 k_4 &= hf(x_0 + k_3, t_0 + h) \\
 x(t_0 + h) &= x_0 + \frac{1}{6}k_1 + \frac{1}{3}k_2 + \frac{1}{3}k_3 + \frac{1}{6}k_4
 \end{aligned}
 \tag{5}$$

3. Virtual body

Parts of body needed to be considered are shown in Figure 3 referred to the study of body measurement [Narong 2004]. All measured values for 3D human model needed for the construction is shown in Figure 4. Human body cross-sections are computed from these measured values and represented as cross-sectional contours. Then, the body's surface is constructed after interpolation of in-between contours.

3.1 Contour construction

Let I be such a closed set that $I=[0, 1]$. Let C be a finite set. Each element of C is a continuous mapping from I to R^3 and is called the contour of human body. In this system a contour c is defined as a closed curve that satisfies the following conditions:

- A contour c is a closed curve. i.e., $c(0) = c(1)$ must be satisfied.
- A contour c does not intersect itself.
- A contour c does not intersect any other contour of the human body.
- Contours of the human body are oriented in the same direction.

Each contour's perimeter corresponds to each body's perimeter. The equation of each contour is derived from the formula below [Lockwood 1932]:

$$p \approx \pi[3(a+b) - \sqrt{(a+3b)(3a+b)}] \tag{6}$$

when a and b are computed from shorter radius and longer radius

of human perimeter consequently. From the equation 6, all points on the curve of a contour are calculated and stored with their corresponding angles between them and \vec{x} axis, that is (1,0,0).



Figure 3: Model for dress making

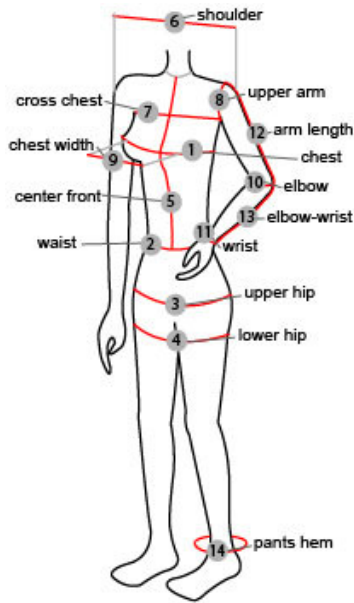


Figure 4: Body measurement

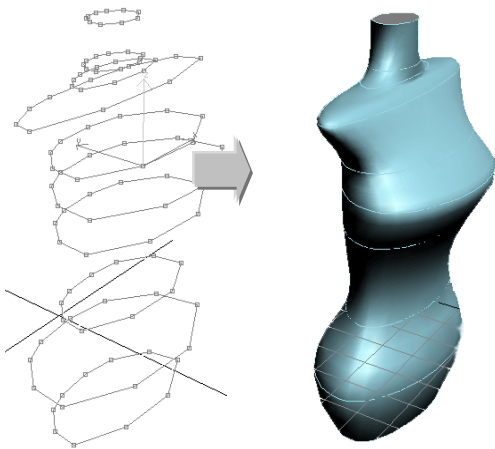


Figure 5: Virtual body construction

3.2 Interpolation

Interpolation between contours starts from mapping a couple of two contours. One contour is called the upper contour and the other is called the lower contour. Each point on the upper contour is mapped to a closest point on the lower contour. After the correspondence between the upper contour and the lower contour is determined, the contour between them will be interpolated. In this research, Natural Cubic Spline method [Micula 1999] is used to interpolate points to construct the other contours.

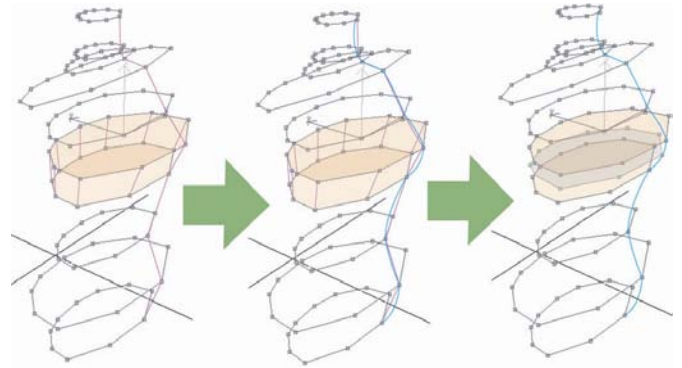


Figure 6: Contour interpolation

Suppose that $\{(x_k, y_k)\}_{k=0}^n$ are $n+1$ points, where $a = x_0 < x_1 < \dots < x_n = b$. The n cubic polynomial $S_k(x)$ with coefficients $s_{k,0}, s_{k,1}, s_{k,2}$, and $s_{k,3}$ has to satisfy the properties:

$$S_k(x) = s_{k,0} + s_{k,1}(x-x_k) + s_{k,2}(x-x_k)^2 + s_{k,3}(x-x_k)^3 \quad (7)$$

for $x \in [x_k, x_{k+1}]$ and $k = 0, 1, \dots, n$

- The spline passes through each data point.

$$S_k(x_k) = y_k \text{ for } k = 0, 1, \dots, n \quad (8)$$

- The spline forms a continuous function over.

$$S_k(x_{k+1}) = S_{k+1}(x_{k+1}) \text{ for } k = 0, 1, \dots, n \quad (9)$$

- The spline forms a smooth function.

$$S'_k(x_{k+1}) = S'_{k+1}(x_{k+1}) \text{ for } k = 0, 1, \dots, n \quad (10)$$

- The second derivative is continuous.

$$S''_k(x_{k+1}) = S''_{k+1}(x_{k+1}) \text{ for } k = 0, 1, \dots, n \quad (11)$$

The natural cubic spline has zero second derivative on one or both of its boundary.

3.3 Surface construction

Three adjacent points on the model are formed as a triangular-shape mesh. When triangular patches are created, the triangulation method must satisfy the following condition:

- If two nodes of the same contour are to be defined as the vertices of the same triangle, they must neighbor each other on the contour's perimeter.
- No more than two vertices of any triangle may be recruited from the same contour.

The surface can be simply constructed when all points are covered with meshes. Additionally, to make smooth body surface, normal vector of each point has to be averaged with normal vectors of the other points around it.

4. Placing cloth on the virtual body

The major task of placing the generated cloth on the body is to compute the attached position between cloth vertices and the virtual body. This process includes collision detection to avoid intersection between the patterns and the surface of virtual body. A fast and precise the collision detection in real time can be shown in this Section. The time complexity of the system also includes computational time for seaming the patterns together.

4.1 Collision Detection

In general, each cloth node should move down to the ground because of the gravity force. If any node touches or collides with the body, its direction of movement will change corresponding to the body's surface; nevertheless, the gravity force still be applied. The simplest collision detection idea involves checking possible collisions between all pairs between cloth and the human model. An important task is to distinguish between inside and outside position of each surface which affect to the surface collision response.

Data of the virtual body are stored in an array of 3- dimensional points sorted by their heights (z -axis). The collision is happened when a cloth node is on or in the body; therefore, to detect collision, each cloth node has to be examined whether it is intersected with the pair of two contours corresponding to its height. After all nodes are checked, if there is an intersection, the two corresponding contours are considered. The in-between contour of these two contours at the same height (z value) of the node is then constructed. Next, a collision checker line is cast from the center of the contour to the node. If the collision checker line intersects the in-between contour before the node, the collision is then found, and vice versa.

This technique use the human contours as a bounding volume for collision detection which can reduce the computational time from $O(nm)$ to $O(cn)$ when n is number of cloth nodes, m is number of nodes in human model and c is number of contours which is quite small (≈ 10 in our system).

4.2 Collision Response

When a collision between a node and body surface is found, a recalculation of the node position and its velocity is happened. This step is done according to the mechanical conservation law, consistent with a perfectly inelastic collision.

4.2.1 Velocity correction

Let collision line be a line orthogonal to the surface at the intersection position. After the collision is found, the colliding

node's velocity is reversed along the collision line, and then the tangential velocity is decreased due to friction force. The reversed velocity of colliding node v_D can be expressed by equation (12).

$$v_D^+ = -v_{Dk}^- + v_{Dl}^- - \mu N \quad (12)$$

where v_D^+ is the node's velocity after the collision, v_{Dk}^- is the component of velocity of v_n along the direction k' normal to the surface before the collision, v_{Dl}^- is the component of velocity tangent to the surface, and μN is the friction force, where μ is friction coefficient, and N is normal force.

4.2.2 Position correction

Although, the position of the collided node can be set to the position of intersection point, this method sometimes gives an unexpected result such as non-continuous movement of the cloth. More reasonable approach by keeping the position before the collision occurs has been proposed [Volino et al. 2005].

4.3 Seaming

Seaming lines are pairs of garment edges that need to be sewn together. The seaming pairs have to be predefined by users or designers. The seaming process is started when elastic forces are applied along the seaming lines to join them together, and finished when all seaming pairs have converged to the collision distance [Volino et al. 2000]. The wider the collision distance is, the shorter time the simulation will take; however, if the collision distance is too wide, the garment might not look real.

5. Pattern making for printing

In this research, basic patterns for making cloth are predefined. After the user body measurements are calculated, the predefined basic patterns are resized to the fit the user size. Lastly, the system provides several garment pattern models according to the basic principle for separating and rotating patterns [Sornprintr 2004] which corresponding to the real dresses.

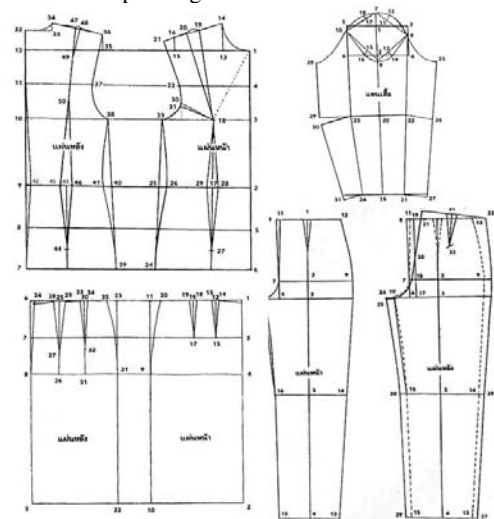


Figure 7: Basic pattern.

5.1 Cellular structured space modeling

The method for modeling pattern structure here is to use cellular structured space modeling [Charussuriyong and Kanongchiyong 2005]. Cellular structured space modeling is a method for constructing an object based on theory of structure in algebraic topology [Hatcher 2002] which can be used to classify an object into equivalence class as a disjoint union of the subsets of the object representing a mathematical invariant, while other geometrical modeling methods do not provide such information which is not trivial for classification process.

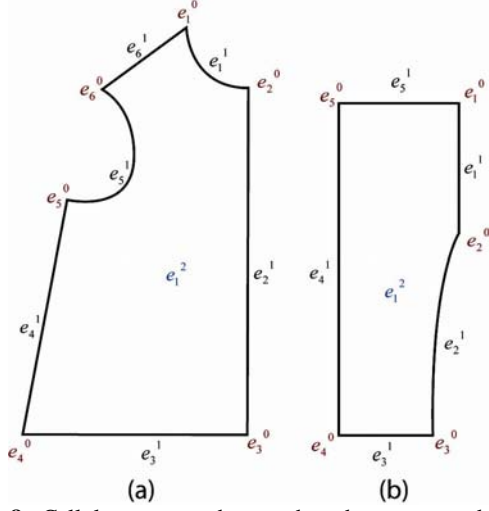


Figure 8: Cellular-structured space-based pattern model; (a) a body's pattern (b) a sleeve's pattern

First, each pattern X is defined as a topological space composing of a sequence of cells X^p , which are subspaces of X , and then a continuous attaching function F is used for mapping n -dimensional open ball to X . Second, we compose the outline of a pattern X^1 , starting from set X^0 consisting of points, 0-cell, at each corner of the pattern shape. X_0 is then attached lines, 1-cells forming a structure of the pattern. Finally, a cloth surface X_2 can be attached via an attaching function. The model of a body's pattern shown in figure 8(a) is described as following:

$$X^0 = \{e_1^0, e_2^0, e_3^0, e_4^0, e_5^0, e_6^0\} \quad (13)$$

Then we attach 1-dimension balls $\sqcup_i B_i^1$ representing lines between points to X^0 via attaching function

$$f : \sqcup_i \delta B_i^1 \rightarrow X^0 \quad (14)$$

when $\sqcup_i B_i^1 = B_1^1 \sqcup B_2^1 \sqcup B_3^1 \sqcup B_4^1 \sqcup B_5^1 \sqcup B_6^1$ and

$$X^1 = X^0 \sqcup_f (\sqcup_i B_i^1) = X^0 \sqcup (\sqcup_i e_i^1) \quad (15)$$

where $i = 1, 2, 3, 4, 5, 6$

$$\begin{aligned} f_1 : \delta B_1^1 &\rightarrow \{e_1^0, e_2^0\} \\ f_2 : \delta B_2^1 &\rightarrow \{e_2^0, e_3^0\} \\ f_3 : \delta B_3^1 &\rightarrow \{e_3^0, e_4^0\} \\ f_4 : \delta B_4^1 &\rightarrow \{e_4^0, e_5^0\} \\ f_5 : \delta B_5^1 &\rightarrow \{e_5^0, e_6^0\} \\ f_6 : \delta B_6^1 &\rightarrow \{e_6^0, e_1^0\} \end{aligned} \quad (16)$$

We extend our model by attaching the cloth surface B_1^2 to X^1 via attaching function $g : \sqcup_i \delta B_1^2 \rightarrow X^1$. Then, we get a model for the pattern in Figure 5a as describing below:

$$X^2 = X^1 \sqcup_g (\sqcup_i B_i^2) = X^1 \sqcup (\sqcup_i e_i^2) \quad (17)$$

where $i = 1, 2, 3, 4, 5, 6$, and

$$g : \delta B_1^2 \rightarrow \{e_1^1, e_2^1, e_3^1, e_4^1, e_5^1, e_6^1\} \quad (18)$$

Finally, we can define a model for a garment or a dress by combining all patterns X_i^2 together. We set every pair of connecting points to be equivalent to each other. For seaming the two patterns shown in Figure 8, we set point e_{A6}^0 and point e_{A5}^0 of the body's pattern (X_1^2) to point e_{B5}^0 and point e_{B1}^0 of the sleeve pattern (X_2^2) as in equation (19) and (20).

$$e_{A6}^0 = e_{B5}^0 \quad (19)$$

$$e_{A5}^0 = e_{B1}^0 \quad (20)$$

Each attaching function of the connecting patterns is set to be equivalent to each corresponding functions ($F_{A6} \cong F_{B5}$ and $F_{A5} \cong F_{B1}$), so we also have $e_{A5}^1 = e_{B5}^1$ corresponding to the attached seaming line.

6. Experimental Results

To validate the proposed algorithm, the simulation and collision detection code are implemented in C++ with OpenGL on Pentium(R) M 1,400 MHz, RAM 512 MB. Our garment CAD system provides 3 main functions as following:

6.1 Human Body Reconstruction

Our system allows users to reconstruct a virtual human-like 3D model based on their shapes. These inputs can be measured by any tailor measuring tools. Finally, the shape of the human model is constructed in real-time (> 50 fps) with smooth and continued surface.

6.2 Cloth Simulation

All simulations can display in real-time (>50 fps) after users select their designs. First, the mass-spring model is generated based on the pre-estimated parameters as shown in Figure 9. Figure 10 shows how to place the pieces of cloth on the virtual while collision detection algorithm is computing. In Figure 11, a synthetic drape skirt using our cloth model is shown.

6.3 Synthesis of Dress Human

Our system can easily be extended to a more complex garment model because of the well defined structure using cellular structured modeling. Each pattern can be seamed to form a garment by attaching the points on its seaming lines to other patterns like in Figure 9. Our system provides more than 100 designs of garments that can be preview quickly. Colors and textures of the cloths are also changeable. Finally, the generated garment pattern model can be resized or transformed in order to print out as a ready-to-cut pattern as shown in Figure 12.

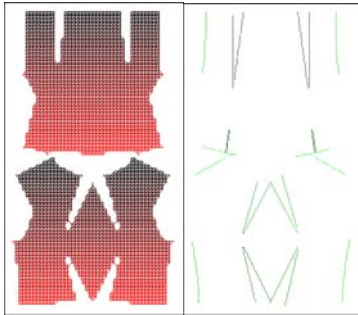


Figure 9: Implemented mass-spring model pattern and its seaming lines

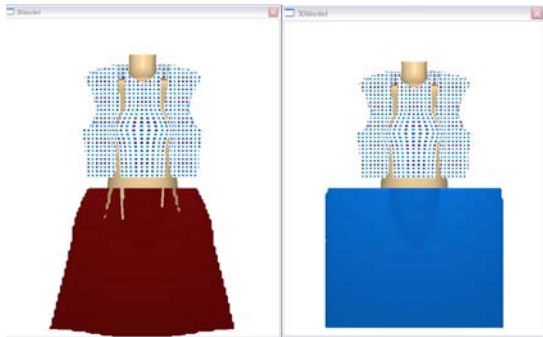


Figure 10: The cloth when simulation starts.

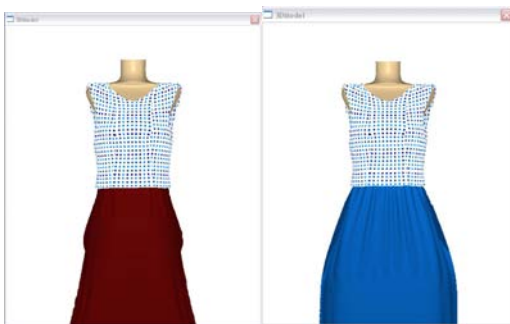


Figure 11: The cloth when simulation ends.

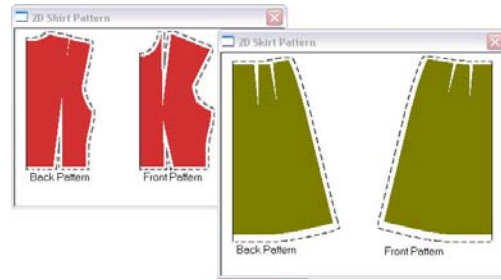


Figure 12: 2D patterns.

This garment CAD system can help users to design and make pattern for garment with low cost of production. The virtual bodies will be changed corresponding to body measurements which are the general measured parameters of any tailor measurement. Patterns and designs of cloth can be selected, and then the program will show real-time simulation (>50 fps) of placing cloth on the body which can work on any home PC. At last, the 2D ready-to-cut patterns can be printed.

7. Conclusions

This research presents an adaptive method to apply cloth simulation for designing and making cloth. This method uses mass-spring model to represent cloth with user-defined parameters. 3D human model is constructed using contours corresponding to perimeters of human shape while some previous methods require extra expensive input device like 3D scanner. Generated cloth is then placed on the constructed human model after the collision detection between cloth and human model using contour-based bounding structure which gives less computational time when compared with the general collision detection algorithm. The proposed system also allows users to view the selected garment on the virtual body interactively unlike static and unmovable model methods [Kakadiaris et al. 1996]. Furthermore, our garment CAD system can works in real-time with low computational cost while most previous systems require high cost graphic workstation [Gross et al. 2004; Spanlang et al. 2003]. Moreover, our garment CAD also proposed a new method for modeling garment pattern based on cellular structured space which provides the structural information for model retrieval. Real pattern printing feature is also available in this system.

In the future, we plan develop more features allowing users to edit free form patterns. More selections of fabrics and garment patterns are also challenged. This can include a variety of body poses and more realistic human modeling which can improve the simulation. Pattern layout optimization for printing is also in progress.

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