A 3D Virtual Show Room for Online Apparel Retail Shop

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***Abstract*—In recent decade, shopping online becomes a lifestyle. Virtual clothing is usually exploited to provide a realistic scenario of dressing for online clothes shoppers. It always starts with CAD (Computer Aided Design) patterns of a real garment. However, CAD patterns are not affordable for retail storekeeper since they are always copyrighted. In addition, they are mostly in some types of proprietary file format that cannot be read without expertise. In order to provide online apparel storekeepers an easy way to build a 3D clothing show room, we propose a plainly equipped 3D garment generation using 2D garment photos instead of 2D CAD patterns. All essentials for duplicating a garment in 3D are extracted from a photo. A magnet based interior nodes insertion method and Delaunay based Triangulation are used to produce uniform garment mesh. The back and front garment meshes are then automatically seamed around a virtual mannequin based on mass-spring model. The aim of the research is to develop a convenient and friendly virtual show room for people who are not able to gain 2D CAD patterns of real garments.**

I. INTRODUCTION

With Internet popularized, it has emerged as a compelling channel for retail. Online apparel store provides various presentation methods of apparel item for customers. Reference [1] is a traditional online clothing shop, it uses 2D photos of garments for presentation. LandsEnd.com [2] uses My Virtual Model to provide customer a virtual mannequin to dress on after a garment is selected. Nordstrom [3] uses 3D technology from California based 3Dshopping.com, which offers 360 degree viewing, enabling complete rotation of the apparel item. Many researchers in computer science keep working hard on producing realistic virtual garments for fashion designers and textile industries, see [4] and [5]. A virtual fitting room, showing the selected item in 3D view and allowing shoppers to be confident in their online purchases, will be essential to success for online apparel shops.

Most 3D technologies require realistic virtual clothing to cooperate with 2D CAD (Computer Aided Design) patterns of real garments. However, 2D CAD patterns are not open to general public since CAD/CAM is a professional tool for fashion designers and textile industries, and it is hard to perform for people not with expertise. Additionally, using CAD/CAM to produce a 3D garment model is a highly cost and time consuming job. Hence, most apparel storekeepers that sell ready-made clothes are not able to afford the cost of such 3D technologies.

Our work proposes an implementation of a simple and fast garment modeling procedure that provides an apposite feel for the garment's details. It starts with 2D garment photos, and ends up in 3D clothing. Image processing techniques, such as edge detection and feature points extraction, are exploited to extract garment silhouette from a 2D photo. A magnet based method is developed for inserting uniform nodes inside garment region. Using Delaunay Triangulation, the garment meshes are created. Mass-spring model is then applied for computing physical garment behavior. The back and front meshes are eventually seamed around a virtual human body. Texturing and smoothing the mesh is the last step of the process.

The whole methodology does not only aim to build a virtual dress room, where customers can view garments fitted onto their own virtual bodies, but also to apply to fashion design, where designers can view in 3D after scanning their hand work. The contributions of the research are described as below:

- A virtual fitting room is provided for online apparel retail shop to represent their clothing in 3D without CAD/CAM data.
- An integrated method is developed to extract a set of pre-defined feature points which represent the relationship of corresponding body segment.
- A magnet based method is developed to automatically insert uniform nodes inside garment region for generating uniform triangles.
- A pre-computed voxel-like approach is developed to fit the planar garment mesh to the virtual mannequin.
- An automatic sewing is developed for stitching front and back panels together.

Overall speaking, our aim is to develop a convenient and friendly virtual show room, where user can choose between many different types of garments and proceed to construct these garments on a virtual human. The paper is organized as follows: Section 2 gives works related to virtual clothing. Section 3 introduces our approaches of the entire process. Section 4 reports the experimental results. Finally, a conclusion is given in Section 5.

II. RELATED WORK

Modeling clothing and textiles has become a major topic in computer graphics research. Along the evolution of cloth simulation techniques, the focus was primarily aimed to address realism through the accurate reproduction of the mechanical features of fabric materials. A detailed survey on cloth modeling techniques can be found in the paper by Ng and Grimsadale [6]. Dimitris Protopsaltou and his colleagues proposed a body and garment creation method for an Internet based virtual fitting room in 2002 [7]. The research group then presented a Web application that provides powerful access to and manipulation of clothing to facilitate clothing design, pattern derivation, and sizing in 2003 [8]. Further, a strong impulse comes from clothing and fabric furniture industries, where CAD tools are increasingly demanded to assist the whole cloth design process. Techniques of cloth simulation mostly applied to apparel industry help fashion designer to sew CAD two-dimensional cloth pattern and show complete garment in three-dimension [5] [9]. [10] proposed a technique that can greatly improve the efficiency and the quality of pattern making in the garment industry.

The need of technologies of virtual clothes for fashion design, textile, and online apparel store has rapidly increased. However, those 3D technologies making realistic virtual clothing need to cooperate with 2D CAD patterns of real garments. They are not friendly to general user since 2D CAD patterns are often in some types of proprietary file format that cannot be read without expertise and the cost of building a virtual fitting room is also high. Thus, 3D technologies are difficult to promote to every online apparel shop.

[11], [12], and [13] explore sketching based methodologies for virtual clothing. The approach in [11] provides a 3D design tool to create garment patterns directly through 2D strokes. A prototype garment mesh surface is then constructed according to the features on a human model. The resultant mesh surface can be cut and flattened into 2D patterns to be manufactured. It is a convenient tool for fashion designers, but is difficult for people who do not have knowledge of fashion design. [12] and [13] present a method for simply and interactively creating basic garments for dressing virtual characters in applications like video games. The user draws an outline of the front or back of the garment, and the system makes reasonable geometric inferences about the overall shape of the garment. However, the resultant garment model looks unreal since the mesh surface is constructed through user sketches. Additionally, the resultant garment would not look right if the user is not good in drawing. The complexity of user interaction is always the main obstacle to the use of standard modeling systems. Hence, we propose an automatic method for reconstruction 3D garment model using 2D garment photos.

Furthermore, over the last several years, a lot of researches have focused on capturing the geometry and motion of garment. When working with garment capture, markers are typically painted on the surfaces. Early work on this topic focused on single sheets of cloth with existing textures [14]. They used unique line drawing as markers, and identified parameterization as one of the key aspects of cloth capture. The real-time system described in [15] introduces markers of constant color, resulting in significantly fewer correspondence errors than in [14]. Scholz et al. first proposed a solution to full garments capture with large areas of occlusion [16]. They suggested a special marker pattern composed of a matrix of colored dots, and used a simple thin-plate approach to fill any holes in the geometry. White et al. improved on these results by thoroughly analyzing the design of suitable marker patterns [17]. Besides, Bradley et al. proposed a marker-free approach to capturing garment motion [18]. It can capture the geometry and motion of unpatterned, off-the-shelf garments made from a range of different fabrics. However, such works of garment capturing can be complex and prohibitive for online apparel storekeepers. A simple and fast reconstruction of 3D dressing using garment photos is thus indeed needed.

Moreover, triangulation is the most widely used form of unstructured mesh generation, as any given arbitrary complex geometry can be more flexibly filled by triangular elements than by any other elements. Boris Delaunay invented Delaunay triangulations in 1934. Delaunay triangulations maximize the minimum angle of all angles of the triangles in the triangulation; they tend to avoid skinny triangles. Rebay presented an efficient unstructured mesh generation by means of Delaunay Triangulation and Bowyer-Watson Algorithm in 1993 [19]. Further, Narayan Panigrahi explored Delaunay Triangulation to tessellate 2D planar domain with holes in 2003 [20]. The work presented by Jonathan R. Shewchuk in 2007, generalizes constrained Delaunay triangulations (CDTs) to higher dimensions and describes constrained variants of regular triangulations [21]. The ideas in [21] seem to extend in a straightforward way to topological PLCs (piecewise linear complex) wherein open slits are modeled by topological holes in the domain. Unfortunately, it is difficult to describe these PLCs in simple geometric terms, because of the need to distinguish topologically distinct points that have the same coordinates. In our research, a simple and fast approach to automatically produce structured triangles inside the garment

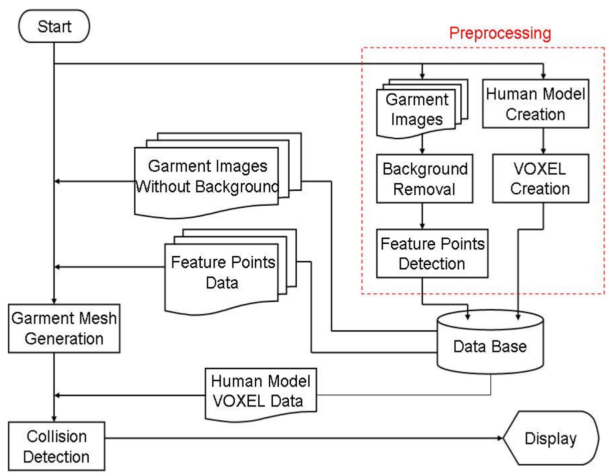

Fig. 1 The processing flow of reconstructing 3D garment mesh by inputting 2D photos. The red dotted rectangle represents the preprocessing stage.

mesh for corresponding texturing is required. Hence, Constrained Delaunay Triangulation algorithm is modified and applied to solve our problem.

III. APPROACHES

The proposed integrated approach is to generate a 3D garment mesh surface through two garment photos, one is taken from the front view and the other is from back. Fig.1 shows an overall processing flow. The red dotted rectangle covers the works done in preprocessing stage, including digital image processing and human model creation. On processing stage, garment is reconstructed around the virtual human body. The following sections describe approaches we proposed in details.

A. Features Points Extraction

The 2D garment photos are the input for producing 3D garment. However, photos may contain not only garment but also other irrelevant image. A 2D garment photo is divided into two regions: foreground which contains garment pixels, and background which contains other irrelevant pixels. We also assume that garment is flattened on a plain background and the lighting condition is well set while shooting. In our experiments, we choose black or white board as the background. A white (or black) background board is selected while the major color tone of the garment is dark (or bright). However, the color of background on the image may vary due to lighting effect. Therefore, background of the 2D photo has to be labeled before analyzing the physical features of garment.

To label background region, Sobel filter is firstly applied to the image to get an edged image. The result of performing Sobel filter shows how abruptly the image changes at that point, and thereby how likely the image represents an edge. The white pixel presents a point on an edge after applying Sobel filter. The reason we employed 3×3 Sobel operator is due to performance consideration. In order to make the width of each edge as one pixel, a thinning process [22] is then applied after performing Sobel filter. The original colored image is traversed to find a color which is never shown on the image, and set it as the background color. Next, go through each pixel of columns/rows from the origin of the 1-pixel edged image to find the first and the last white point for each column/row. Garment region is thus obtained. Pixels outside the garment region are painted using background color. Besides, the garment area may contain a region of brand label since it was flattened for shooting photo. In order to correctly extract garment features, brand label should not appear. Hence, the system provides a paint tool for user to redraw on the region of brand label using background color.

TABLE I
THE DEFINED CORRESPONDENCE BETWEEN FEATURE POINTS AND BODY SEGMENT [23]

Feature Point	Body segment
Neck (l,r)	Neck
Neck front	Neck
Neck back	Neck
Biceps (l,r)	Upper arm
Elbow (l,r)	Upper and lower arm
Wrist (l,r)	Lower arm, hands
Waist girth point	Lower torso
Hip (l,r)	Lower torso
Nipple (l,r)	Upper torso
Ankle inseam (l,r)	Lower leg, feet
Knee (l,r)	Lower and upper leg, lower torso

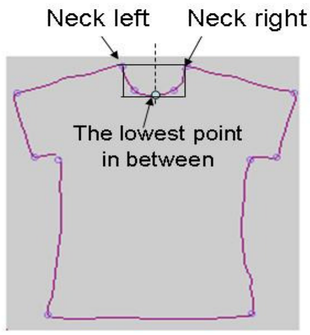

Fig. 2 Neck area is defined as the rectangle enclosed by the feature points of neck left, neck right and the lowest point in between.

After background is found, an algorithm using chain code is applied on the garment silhouette to find points of high curvature. We exploited the definition of correspondence between feature points and body segment (see Table I). It is the same as the definition in [23]. The silhouette of the garment can be obtained by setting all foreground parts as black. Then erosion [24] by a 3x3 structuring element is done on the silhouette image, resulting in a smaller silhouette. A 4-connective boundary of the clothing can then be obtained by subtracting the smaller silhouette from the original silhouette [24]. The boundary is then traversed through to get the chain code. It results in many continuous points that can pass through a given threshold. Therefore, for every group of continuous points, the one with the highest curvature is taken as a candidate of feature point. Sufficient candidates are obtained without being too abundant.

Templates are used to determine whether the candidate is actually one of the feature points. A template is a set of points, in which the relative positions of all feature points are predefined. The template is firstly scaled according to the ratio, and mapped to the clothing image. The candidate point closest to the template point within a given search region is taken as the feature point. In order to reduce the amount of templates, top is segmented into neckline and body according to the principle of garment design. There are several templates prepared for body segment according to the topology of top, such as vest and long-sleeved shirt. Three types of neckline templates are defined, round U-neckline, V-neckline and square neckline, which covers the majority of most necklines. We define the area enclosed by the feature points of neck left, neck right (obtained from before) and the lowest point in between neck left and neck right to be the neck area (Fig. 2). The selection of neckline template uses ratio of background

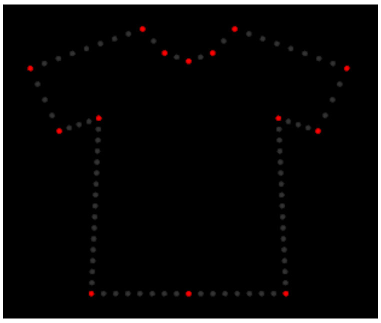

Fig. 3 The inserted nodes and the detected feature points form the garment boundary. Red points present feature points and gray points are the inserted points.

and foreground pixels in the neck area. If the ratio is close to one, we use the v-neckline template. If the ratio is close to zero (most pixels are background pixels), we use the square neckline. If the ratio is in between, the U-neckline is used. Again, candidates that have the shortest distance to the neckline template points are chosen as the feature points.

B. *Garment Surface Reconstruction*

A group of isolated feature points are gained after detecting garment features from photos. Afterwards, the surface of the input garment is reconstructed using those feature points. Delaunay Triangulation is a well known, simple and fast approach, which can produce structured triangles by connecting points. However, a convex polygon will be formed using Delaunay Triangulation. Hence, an efficient garment mesh triangulation is developed based on Delaunay Triangulation to produce garment surface which maintains the original shape of the garment.

According to the position of feature points in the image coordinate and image resolution, the transformation between image domain and numerical domain is defined. Hence, an initial triangular grid is obtained after connecting those feature points. In addition, for balancing and smoothing the garment mesh, uniform triangular elements inside the garment mesh are required. Intuitively, uniform nodes inside the garment region will produce uniform elements in the triangulation. Hence, a novel method for positioning uniform nodes inside garment region is developed based on the

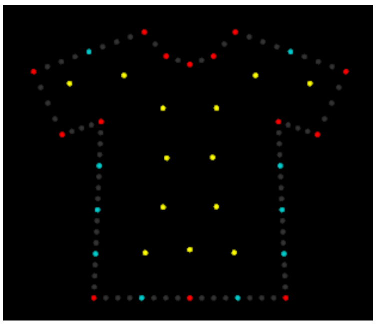

Fig. 4 Yellow nodes indicate the inserted interior nodes using magnet based method.

principles of magnetic motion. Normally, inhomogeneity induces magnetization. Opposite poles attract, like poles repel. Hence, a repulsive force (1) is exploited to simulate the magnetism model for remaining uniform nodes while insertion.

$$F_{\text{repulsive}} = G\frac{m_1 m_2}{r^2} \qquad (1)$$

where r is the distance between m_1 and m_2.

Firstly, some nodes are inserted in between the detected feature points by interpolation for building a magnetic wall on garment boundary (as shown in Fig. 3). The new nodes on the boundary are not used for triangulation, and all nodes on the boundary are not movable. Some interior nodes are then put into the garment region. The positions of the inserted interior nodes are dynamically changed while a new node comes in because of the effect of repulsive force between nodes. Each of the interior nodes eventually stays with uniform space of intervals. As shown in Fig. 4, red nodes on the boundary are the detected feature points, gray nodes in between the feature points are inserted by interpolation, and yellow nodes are the interior nodes having uniform distance. Finally, Delaunay Triangulation is used with detected feature points and the inserted interior nodes to gain an initial coarse garment surface. Fig 5 shows the triangulations with and without magnet based interior nodes insertion.

For balancing and smoothing the initial garment surface, some new nodes are inserted and some redundant nodes are removed according to the edge-ratio of each triangle. The edge-ratio is defined as the ratio between the length of the longest edge and the length of summing the other two edges,

(A) (B) (C)

Fig. 5 (B) is the original garment photo. (A)is the triangulated mesh without using magnet based interior nodes insertion; in contrast, (C) is the result with using magnet based interior nodes insertion.

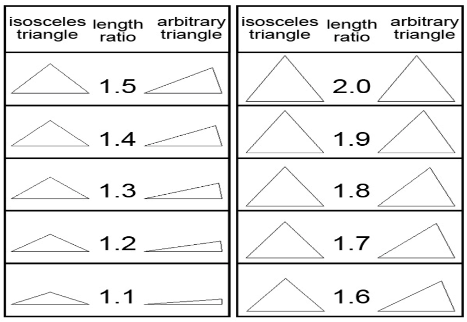

Fig. 6 With the same ratio, left triangles have the same length of the other two edges. Right triangles have one edge the same length as longest edge.

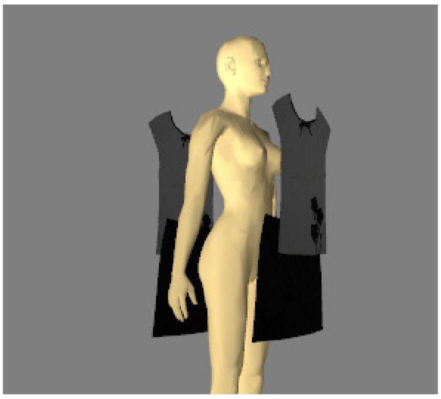

Fig. 7 The front garment mesh is eventually placed in front of the human model, while the back garment mesh is placed in back of the human model

as illustrated in Fig. 6. For triangles with edge-ratio below 1.3, which are flatter in shape, the node which is opposite to the longest edge of the triangle needs to be removed, and a new node is inserted at the midpoint of the longest edge. For triangles with edge ratio between 1.3 and 1.6, a new node is inserted on the longest edge of the triangle at the position of the midpoint. For triangles with edge ratio above 1.6, one new node is inserted for each edge at the position of each midpoint. For deleting redundant nodes, we traverse all nodes to search any two close neighbors and merge them. Delaunay Triangulation is then applied again to make those nodes inside garment region distributed evenly. Removing redundant triangles during triangulation is an important task to ensure those produced triangles stay in garment region. Hence, triangles with an edge outside garment region on the corresponding garment photo are removed.

C. *Virtual Dressing*

After planar garment surface is generated, a voxel-like approach is devised to fit the planar mesh onto a virtual mannequin. On the preprocessing stage, a virtual twin of the customer is firstly created in the 3D show room. In the implementation, eight primary measurements (height, bust girth, under-bust girth, waist girth, hip girth, inside leg length, arm length, and neck-base girth) are used to modify a generic human model to customized mannequin. A numbers of blocks of the same size, i.e. voxels, are then created around the virtual mannequin. Next, the garment triangulated surface is positioned nearby the virtual human according to the detected feature points. The 3D garment is then moved appositely based on interactive collision detection with voxels of the virtual mannequin. Eventually, the front garment mesh is placed in front of the human model, while the back garment mesh is placed in back of the human model (see Fig. 7).

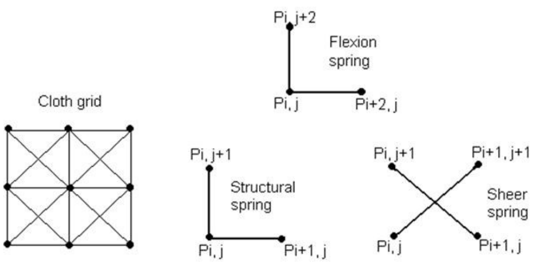

Fig. 8 Mass spring model structure

Sewing two garment panels is the next step. The information of seams is obtained while the feature points are determined using predefined templates. Nodes on the corresponding seam lines are automatically seamed together by the attractive force in between. Two corresponding sewing nodes are then progressive moving forward to each other till they meet. Mass-spring model (Fig. 8) is also used to simulate realistic clothing. As indicated in (2), the sum of forces between springs equal to the graviation, and the mass of node and k value of spring are used to represent different material of garment. Fig. 9 shows an example of dressed mannequin. The creases of the garment on the original image bring for a realistic appearance in 3D view.

$$F_{cloth} = mg = \sum_{i=0}^{t} (k_i \times \Delta l_i) \qquad (2)$$

where t is the number of springs in the cloth, $\triangle l_i$ is the length variation of each spring.

Fig. 9 A well dressed mannequine using the proposed approaches.

(A) (B) (C)

Fig. 10 (A) is the result of producing a 3D scoopneck-sleeveless top and a skirt. (B) show the meshes of a top with 1188 vertices, and a skirt with 954 vertices. (C) shows a girl with the top and skirt.

TABLE II
THE PERFORMANCE OF EACH INDIVIDUAL TASK OF RECONSTRUCTING A PAIR OF 3D GARMENTS WITH 1800 VERTICES

Task	Time cost (millisecond)
Compute positions of mass	2.366
Update positions of mass	3.502
Update overlapped region	0.484
Update spring force	0.449
Update normal	0.831
Rendering	10.117

IV. EXPERIMENTAL RESULTS

This section shows some results of virtual garment generation using the proposed approaches. The experiments are implemented on a PC running Windows XP with an AMD AM2 5200+ with 2GB of main memory. A virtual mannequin has to be loaded and voxeled in the preprocessing stage when every time starting the entire process. Several digital image processing techniques are utilized to gain the silhouette of the garment after a 2D photo is input. A modified triangulation method is then applied to generate triangular meshes of 3D garment surface. The garment is fit on the virtual twin with collision detection. The timing performance of each individual task is shown in Table II. Fig. 10 gives a result of producing a 3D scoop-neck-sleeveless top, which has 1188 vertices and 2206 triangles, and a 3D skirt, which has 954 vertices and 1754 triangles. Further, Fig. 11 shows a top of 974 vertices and a skirt of 746 vertices, and the processing time of 3D generation from 2D photos for each item of clothing is less than one second.


(A) (B) (C)

Fig. 11 (A) is the result of producing a 3D top and a skirt. (B) show the meshes of a top with 974 vertices, and a skirt with 746 vertices. (C) shows a girl with the top and skirt.

V. CONCLUSION

Our approaches provide a simple and fast way to directly produce garment surface in the 3D space through front and back garment photos. Background removal is firstly applied on the garment photos to extract garment region on the image. Chain code and templates are exploited to detect the predefined feature points of a garment. In order to generate uniform triangles for garment mesh, a magnet based approach is developed to insert uniform nodes inside garment region. Afterwards, a modified constrained Delaunay Triangulation is applied to generate the triangular mesh of garment surface. A voxel based approach is exploited to position the garment surface in front/back of the virtual human. With mass-spring model applied, people can view their apparel in realistic 3D view. Although the generated 3D garment is not as detailed as the one generated from CAD template, it still looks fine for general when customers surf online. It can be seen from experiments that the proposed methodology produces nice virtual clothes without complicated manipulation. Moreover, the shape of garment is retained by the detected feature points without requesting any CAD/CAM information. A virtual fitting room is therefore affordable for common retail storekeepers to increase online sales volume.

The whole methodology does not only aim to build a virtual dress room, where customers can view garments fitted onto their own virtual bodies, but also aims to apply to fashion design, where designers can view in 3D after scanning their hand work. Using the methodology users can build a particular 3D model easily with garment images and apply it to clothes collocation, apparel online shop, and 3D games model. In addition, using the proposed method with a personal digital wardrobe and the clothing styles cognition module [25], an Intelligent Dressing Advising System is eventually completed, which functions as a personal wearing advisor to help general users choose apposite clothing for occasions and provides 3D visualization of resultant garment pairs. Moreover, with smart phones and mobile networking, people are able to take garment pictures while shopping and get supports of whether to buy the garment immediately. It helps to make the most available out of each garment in our closet and without wasting a penny on an inappropriate garment.

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