Fast Virtual Garment Dressing on Posed Human Model

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Abstract: Due to the multiplicity of the implementation, virtual garment simulation requires the capacity of dressing a sewn garment onto various posed human models in a real time. In this paper, a three-step method has been proposed to accelerate the dress-up procedure. The virtual garment is first dressed onto a human model in a standing pose to record a distance map between the garment shell and the human model. And then the distance map is employed to generate a coarse match when the pose of the human model has been changed. Finally, a fine-tuned 3D configuration without surface penetration is generated after a draping/relaxation scheme. Experimental results suggest this method is a useful and fast treatment for dressing sewn virtual garment on various posed human models.

Keywords: virtual garment, distance map, mesh conforming, draping, global relaxation

(a) Default pose (b) Mesh conforming (c) Penetration recovery (d) Draping & relaxation

Figure 1 Illustration of cloth/pose synchronization solved by our method

1. Introduction

The state-of-the-art technology has made cloth simulation a very important topic in both the academic investigation and the industrial implementation (movies, games, online shopping, etc). A common avenue for 3D garment dressing is through virtual sewing and draping: the garment patterns with various boundary shapes are placed around the human body and are seamed by either the sewing force or the sewing springs. Further, the sewn garment is draped along the surface of the human body under the gravity and the other external forces such as air flow and friction. However, this is not always a straightway when dressing the human model with a sewn garment under various poses. For instance, in an environment of simulating sports-wear, the user may want to investigate the performance of a simulated garment under different movements to reach the maximum of evaluation. It is inconvenient to decompose the garment into patterns and to re-sew these patterns in every pose.

In this paper, we propose a three-step method to address this kind of issue. The first step is to register the distance between each garment vertex and the closest vertex selected from the human model, which actually generated a “distance map” that represents the current residual space between the garment shell and the human body. For the cloth/

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pose synchronization, it is believed that the transition of the body pose indicates the transformation of this residual space. Therefore, in the second step, the "distance map" is employed to determine the new position of each garment vertex when the pose has been changed. The third step is to resolve the penetration introduced by the pose transition to reach the final 3D configuration of the virtual garment. The super elongation and compression produced by the pose transition is rectified in terms of a vertex position adjustment and a strain control scheme.

Throughout the literatures, little previous research had been done specifically on dressing a sewn garment onto posed human models. The most related work is Cordier and Magnenat-Thalmann's technique of dressing animated virtual humans [23]. They subdivided the cloth layer into stretchy parts and loose parts for their hybrid approach of garment animation. The garment layer was actually partitioned into several moving regions with different constraints driven by the movements of the skeleton, which required careful segmentation of the cloth layer and complex computation for the semi-geometrical and semi-physical draping.

Our approach on cloth/pose synchronization is based on the common techniques from cloth modelling and collision resolving. The target of cloth modeling is to develop a physics-based method to simulate the dynamics of cloth in animation. Many cloth models had been proposed in the past two and a half decades. The most general approach was to treat the fabric as a two-dimensional elastic model [1, 4-13]. More broad surveys on this topic can be found in [2, 3, 19].

Another major concern of cloth/pose synchronization is to solve the collisions generated in the pose transition, as shown in Figure 1 A robust remedy of collisions should not only rely on preventing surface intersections from occurring, but also requires being able to "repair" those intersections whenever they occur. Vassilev et al [22] proposed an image-based collision detection and response scheme to perform the interference tests, which is a hardware accelerated collision remedy. Zhang et al [24] presented a coherence-based method to detect collisions between the garment and the human model. Collisions can be rapidly detected by tracking the movement of the most likely intersected geometric elements based on the property of coherence. Bridson et al. [15] proposed a continuous collision detection scheme to avoid crossovers entirely and guaranteed that the cloth was free of intersections at the end of a time step if it was free of intersections before. Volino et al. [16, 17] used a statistical approach to determine which parts of the cloth need to be corrected. These history-dependant approaches worked well for unconstrained cloth. Unfortunately, when garment models were dressed onto animated avatar, they might be forced into a tangled state despite the efforts of collision handling schemes. To overcome this issue, Baraff et al [14] proposed a history-free intersection handling method through a Global Intersection Analysis (GIA). Recently, Volino and Magnenat-Thalmann [18] proposed another history-free method for resolving intersections based on minimization of the intersection paths.

2. Algorithms

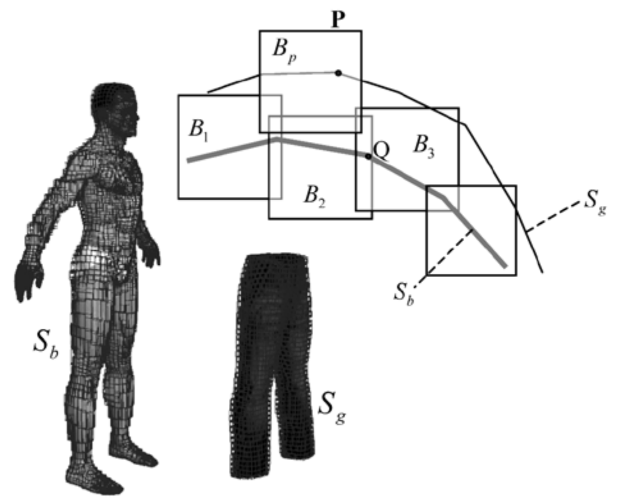

Figure 2 Searching the shortest distance via AABB acceleration.

2.1 Distance map

The cloth model employed in our approach is a mass-spring system solved by an implicit integrator (backward Euler integration) [7]. For the clearance of explanation, we use S_b to represent the 3D surface of the human body, and S_g to represent the 3D surface of the virtual garment. To synchronize S_g with S_b, we

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need to record the distance between S_g and S_b under the default pose:

Step A. Build an AABB (Axis Aligned Bounding Box) tree [21] for both the human body (denoted as $S_{b\text{-}AABB}$) and the garment shell (denoted as $S_{g\text{-}AABB}$). Figure 2 illustrates the leaf nodes of the AABB tree.

Step B. For each garment $\{\mathbf{P} \mid \mathbf{P} \in S_g\}$ vertex , find out the nearest body vertex $\mathbf{Q}$ that meets the following criteria:

$$\{\mathbf{Q} \mid \mathbf{Q} \in S_b, \|\mathbf{PQ}\| = MIN(\mathbf{P},\mathbf{Q})\}. \quad (1)$$

say $\|\mathbf{PQ}\|$ is the shortest distance between $\mathbf{P}$ and $\mathbf{Q}$. The searching of $\mathbf{Q}$ can be accelerated by recursively looping through the AABB tree, which is a typical top-down bi-tree. For a leaf node B_p of S_{g-AABB} that contains $\mathbf{P}$, if there is intersection between B_p and any of the leaf nodes of S_{b-AABB} , the nearest body vertex $\mathbf{Q}$ will be determined by comparing the distance between $\mathbf{P}$ and the vertices contained in these bounding boxes of S_{b-AABB} (B1, B2 and B3), as shown in Figure 2 In this way, each garment vertex will have a corresponding body vertex $\mathbf{Q}$, including the index of $\mathbf{Q}$ and the normal at $\mathbf{Q}$.

2.2 Mesh conforming

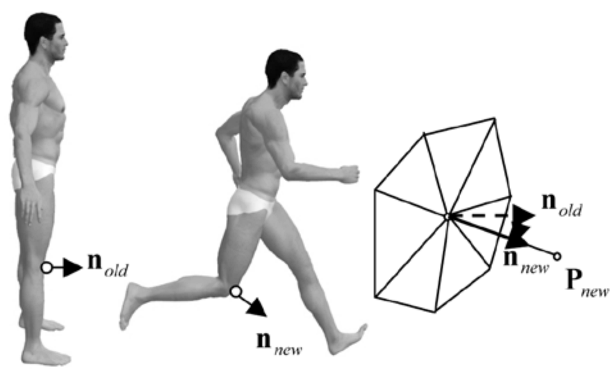

Figure 3 computing the new position of cloth vertex based on the recorded distance.

When the pose of the human body has been changed, the mesh of the garment layer should be conformed to the surface of the human body under the new pose. With the pre-recorded distance map, the new candidate position of the garment vertex is calculated by:

$$\mathbf{P}_{new} = \mathbf{Q}' + \mathbf{R} \cdot \|\mathbf{PQ}\| \quad (2)$$

where $\mathbf{Q}'$ is the new position of the corresponding body vertex (with the same index in the array of body vertices) under the new pose, and $\mathbf{R}$ is the rotation matrix defined by the rotation from $\mathbf{n}_{old}$ to $\mathbf{n}_{new}$.

Actually, the mesh at this stage is relatively coarse since the edge (springs) of each triangle could be either elongated or compressed. To smooth the unevenness, a position adjustment scheme is employed. From our observation, 2 to 3 times of iteration is necessary. More details of the position adjustment are given in section 2.4.

2.3 Penetration recovery

The abovementioned mesh conforming will not prevent the penetration from happening. Therefore, a robust and reliable penetration recovery procedure is inevitable. Different from the penetration recovery in most of the dynamic cloth simulation, our remedy is a fully geometrical approach to cope with the requirement of fast computation.

To determine whether a garment vertex locates inside or outside the human body, we need to find out the current nearest body vertex $\mathbf{Q}_{new}$ under the new pose ($\mathbf{Q}_{new}$ could be another body vertex with a different index in the array of the body vertices).

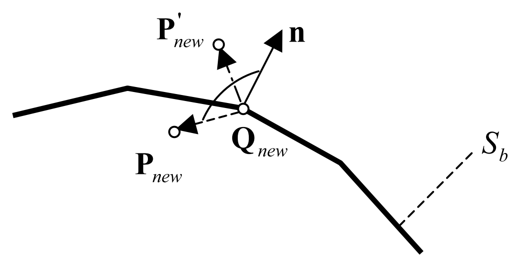

Figure 4 Locate the penetrated cloth vertex and pull it out of the S_b .

As shown in Figure 4, if $\mathbf{P}_{new}$ has moved into S_b , the angle between $\mathbf{n}$ and $\mathbf{P}_{new}\mathbf{Q}_{new}$ should be greater than 90 degree. This can be calculated by taking a dot product between $\mathbf{n}$ and $\mathbf{P}_{new}\mathbf{Q}_{new}$. If the result is smaller than zero, then the garment vertex $\mathbf{P}_{new}$ is inside the S_b . To bring it back to the outside of the S_b , the candidate $\mathbf{P}'_{new}$ is set to a position that takes the same length as $\mathbf{P}_{new}\mathbf{Q}_{new}$ but is perpendicular to $\mathbf{P}_{new}\mathbf{Q}_{new}$. This treatment promises that all the penetrated garment vertices will be taken back to the outside of the S_b . However, it also introduces unnecessary cusps that may destroy the continuity of the surface curvature, as shown in Figure 1c. To cure this, a draping procedure has been initiated with a strain control or relaxation procedure, as explained in section 2.4.

2.4 Surface smoothing

Both the mesh conforming and the penetration recovery can introduce extra edge extension or compression which may produce unevenness to the garment surface. To smooth the new generated surface, the length of each triangle edge (spring) should be constrained.

The position adjustment technique is first reported by Provot [12]. It is an arbitrary length resetting procedure. If the length change of a spring after one time-step of integration is larger than 1% compared to its rest-length, the two end points will be moved to such a position that the resultant length will be 1.01 times or 0.99 times of the rest-length, depending on whether it is elongated or compressed. This kind of position adjustment takes no responsible for preventing penetration from occurring. However, it is a direct and fast method to smooth the over-elongation or over-compression after several times of iteration. Figure 1b demonstrates the result of such treatment.

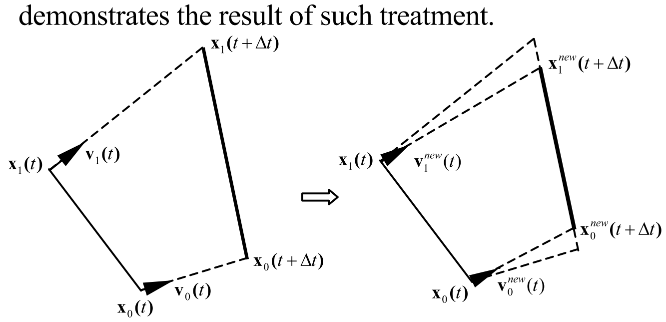

Figure 5 Strain control through initial velocity adjustment.

To overcome the cusps introduced by the penetration recovery, another kind of length resetting procedure is required when draping is initiated [15, 20]. As shown in Figure 5, at time t, we pre-calculate the position of the end points of the spring after Δt. Represented by Euler integration, for instance,

$$\mathbf{x}_0(t+\Delta t) = \mathbf{x}_0(t) + \mathbf{v}_0(t)\cdot\Delta t \tag{3}$$

$$\mathbf{x}_1(t+\Delta t) = \mathbf{x}_1(t) + \mathbf{v}_1(t)\cdot\Delta t \tag{4}$$

where x_0 and x_1 are the position vectors of the end points. At t+Δt, if the strain is greater than 1%, then the initial velocity of the two end points should be reset to prevent the future length of the spring from being either "over-elongated" or "over-compressed", which is,

$$\mathbf{v}_0^{new}(t) = [\mathbf{x}_0^{new}(t+\Delta t) - \mathbf{x}_0(t)]/\Delta t \tag{5}$$

$$\mathbf{v}_1^{new}(t) = [\mathbf{x}_1^{new}(t+\Delta t) - \mathbf{x}_1(t)]/\Delta t \tag{6}$$

where $\mathbf{x}_0^{new}(t+\Delta t)$ and $\mathbf{x}_1^{new}(t+\Delta t)$ are the new qualified position of these two end points. Usually, the collision response involves calculating the new velocity of a vertex or a triangle after colliding. Hence the initial velocity adjustment technique can be integrated into the collision response routine and to prevent the penetration area from re-entering the S_b . Figure 1d demonstrates the result of strain control.

Physically, the unevenness or cusps area indicates the aftermath of the unconstrained impulses. If we release the extra energy, the cusps should disappear. Therefore, changing the initial velocity of the particles is equivalent to take out the extra impulses. In our practice, 3 to 5 steps of iteration will dissipate the cusps to reach a more satisfied configuration of S_g .

3. Experimental Results and Discussion

Figure 6 Demonstration of single layer cloth/pose synchronization (running pose).

To evaluate the performance of our method, several synchronization tests have been conducted on a PC with an Intel(R) Duo core CPU (T5200, 1.6GHz) and 1G physical memory. Figure 6 illustrates the results. All the virtual garments are pre-sewn 3D objects with over 3,000 triangles, and the avatar is generated with 28,750 triangles from the 3D authorization software. The synchronization is solved less than 1s. The two left images are the front and back view when dressing a jean to a running pose, and the two right images are the results of dressing a T-shirt to the same running pose. As shown in Figure 6, the garment layer matches with the pose uniformly without any penetration.

To further investigate the effectiveness of our method, a multi-layered dressing has been performed. This is more likely in the real world where people may fully dressed in some kinds of physical exercise, such as shown in Figure 7 The technique of avoiding inter-layer penetration is reported in another paper [25].

Figure 7 Demonstration of multi-layered cloth synchronization (Chinese KongFu pose).

Benefit from the position adjustment and the strain control scheme, the size of the garment has been well maintained. The threshold of the length change for each garment spring is set to 1%. For a more flexible sportswear, this threshold can be loosely controlled. Though we have not proved the convergence of the position adjustment and the strain control procedure mathematically, from our observation, both methods can guarantee the convergence of the computation without “blowing” the integration. Since our method is to generate the 3D configuration of the garment shell under a very different pose in one frame, it is highly possible to use this method in a common animation sequence where each frame has little change comparing to the previous frame and the next frame, which implies the times of iteration may be less than what we currently reported.

Different from the work of Cordier et al [23], our method does not build a hierarchical bone structure for the garment model, which is commonly used in the skeleton-based cloth/pose synchronization. The skeleton-based method needs to register the affiliation between the garment parts and the bones. Once the avatar has been changed, the skeleton of the avatar must be reset before the registration. Unfortunately, most of the successful skeleton needs manual assignment by an experienced 3D artist, which limits the automation of the implementation. From this point of view, our method can be employed in a more versatile manner.

The capacity of fast cloth/pose synchronization has made our approach very useful in the sports-wear design, where both the beautification and the performance are highly valued. The designer can generate a 3D sports-wear under a default pose, and then test his design under various poses to evaluate the dynamic deformation and to make changes accordingly. Figure 8 demonstrates the result of using curvature map to evaluate the deformation of the design under movements. The colored curvature for each vertex is computed from the maximum angle between every two triangles who shared this vertex. As shown in Figure 8, the shading of the color indicates the ceases and wrinkles of the clothing during movement. Since our method can generate each frame of clothing animation rapidly, it is useful to review a series of color changes to evaluate which part of the design is highly deformed and to make necessary functional design accordingly.

Figure 8 Using curvature map of the garment to illustrate the deformation of the clothing.

4. Conclusion

In this paper, we proposed a fast and effective method to dress human body with pre-sewn virtual garment under different posture. This method requires neither the decomposition of the 3D garment, nor the segmentation of the 3D garment. It uses a distance map to conform the garment to the new body pose. The penetration remedy is based on a fully geometrical approach that can pull the penetrated area back to the correct side without any further compensation. The final configuration of the posed garment is generated after surface smoothing in terms of the position adjustment and the strain control scheme. To our knowledge, no previously established technique exists for simulating fully dressed virtual humans under various poses as what we reported. This method can be widely adopted in the animation of dressed avatar and other dressing simulations.

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