Image-space Based Collision Detection in Cloth Simulation on Walking Humans

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Abstract: *This paper describes a technique for cloth-body collision detection applicable to simulation of apparel on walking humans. It is based on image-space interference tests but employs a new approach with layers of depth maps to resolve the problem arising from overlapping body parts. The modern workstations' graphics hardware is used to generate the depth maps of the body as well as to interpolate the normal vectors and velocities of each body vertex. The latter information is necessary for proper collision response. Images showing the result of applying this technique are given at the end of the paper.*
Key words: *Collision Detection, Image-based Approach, Cloth Simulation, Mass-spring system.*

INTRODUCTION

The main objective of this work is to develop an efficient technique for cloth-body collision detection applicable to simulation of apparel on walking humans. Collision detection is the bottle-neck in today's cloth simulation in computer graphics. Dealing with collisions is the most time consuming stage of the simulation process due to the following two reasons. On one hand the achievement of virtual realism requires highly detailed object surfaces (the model of human and the apparel in our case) which results in a significant increase in the computational demands of all aspects of the simulation. On the other hand, in this particular case all elements of the clothing are usually situated near or on the same surface of the body which is a precondition for multiple collisions in dynamic scenarios.

The underlying idea of this technique is to profit from the speed of the image-space based approach and at the same time to overcome its problems with overlapping parts by introducing layers of depth maps.

The rest of the paper is organized as follows. The next section reviews previous work on collision detection in cloth simulation. Section 3 briefly describes the utilized cloth model and gives basic idea about the way a simulation is carried out. Section 4 presents the improved technique for collision detection. Section 5 gives results of the experiment and Section 6 concludes the paper and gives ideas about future work.

PREVIOUS WORK ON COLLISION DETECTION

Intensive work on collision detection for the purposes of cloth simulation has been done by the Computer Graphics community in the past 15 years. This resulted in a variety of collision detection approaches which could be divided in two major groups – based on geometrical interference tests in object-space and based on depth map interference tests in image-space. In general the collision detection problem in 3D is a geometrical problem and initially it was considered and studied as such. A common feature of all object-space based techniques worthy to be considered is the utilization of hierarchical structure(s) for reducing the complexity of the problem. Klein et al [5] and Mezger et al [6] proposed the use of two bounding volume hierarchies (one for each object of interest) combined with an extended set of heuristics. Cordier et al [3] employed a cylinder approximation scheme for the limbs for speed-up followed by additional steps to preserve realism. A robust approach for collision detection and response based on axis-aligned bounding boxes is presented by Bridson et al [2] but it is very expensive computationally and thus not suitable for real-time applications.

A common drawback of all object-space based techniques, when used for dynamic simulations and/or simulation of deformable objects, is the necessity of frequent hierarchy updates [4]. The updates are computationally expensive hence simulation speed degrades. In addition the interference tests in object-space are complicated by nature too.

Inspired by the advances in graphics hardware and accelerated buffer to main-memory transfer speeds, during the last several years new techniques based on image-space were developed. They use the graphics hardware to render the scene and then perform tests for interference between objects based on the depth map of the image. These approaches are very efficient and they have one important feature. Their computational cost for collision testing is independent of the level of detail of the "target" object(s) in the scene (the model of human in our case). Initially image-space based collision detection was used to detect interference between solids [1, 4] but later on it was also employed in cloth modelling [7].

MASS-SPRING CLOTH MODELLING

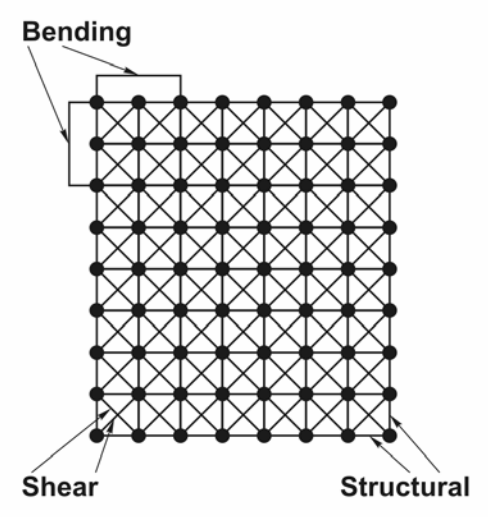


Figure 1. Mass-spring model of cloth with different types of springs shown

Mass-spring cloth modelling is a well-suited approach for fast simulations of fabrics due to its computational efficiency. That is why a mass-spring model of cloth was utilized in this work. It represents a mesh of $l \times n$ mass points, each of them being linked with its neighbours by three different types of massless springs of natural length greater than zero (Figure 1). There are two types of forces associated with such systems. Internal forces which originate form the tension of the springs and external forces acting on the system which vary depending on the simulations we wish to carry out. Successive positions of the mass points in the model could be obtained through numerical integration over time of the fundamental equations of Newtonian dynamics using Euler's method. Detailed information is given in [7].

LAYERED IMAGE-SPACE BASED COLLISION DETECTION

The technique is an implementation of the idea to make use of the basic image-space approach and extend it to handle overlapping parts via layers of depth maps. The basic image-space based technique is borrowed from the work of Vassilev et al presented in [7].

Generation of depth maps – the basic approach.

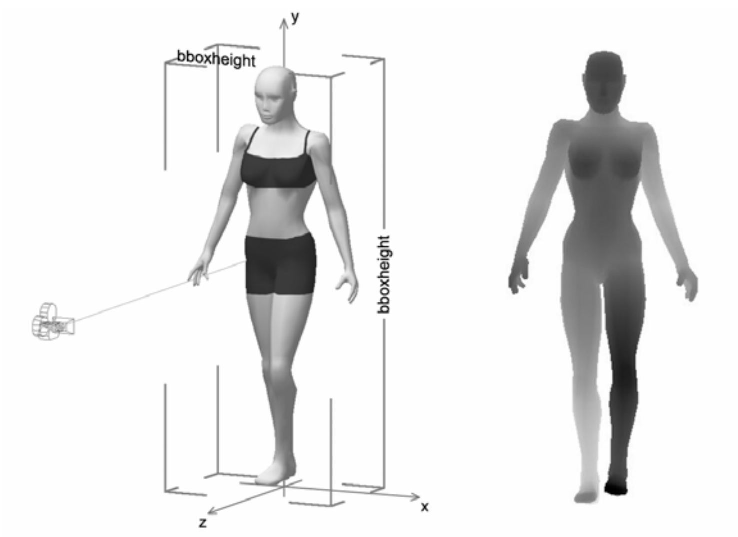


Figure 2. Front depth map acquisition setup and the respective depth map

Two depth maps are created at each animation step – respectively for the front and the back of the body. They are acquired via two off-screen renderings from the point of view of two orthogonal cameras at the centre of the front and the back face of the body's bounding box (BB). The cameras point at the centre of the BB. The setup for front map acquisition and the respective depth map are shown in Figure 2. The depth values are floating-point values ranging from 0.0 to 1.0. A value of 0.0 represents a point at the near clipping plane (the darker shades in Figure 2) whereas 1.0 stands for a point at the far clipping plane (the brighter shades).

The drawback of the basic approach manifests itself when there are overlapping body parts from the point of view of the cameras. The overlapping results in loss of essential depth information which is necessary for comparison with specific parts of the garment. Since this is a common situation in the animation of walking humans (limbs cover the torso or other limbs) the basic approach is not applicable. A display of the problem could be seen in Table 1 (the image in the middle) in the results section of the paper.

Layers of depth maps

We introduce layers of depth maps to resolve the drawback of the basic technique. A prerequisite for this approach is decomposition of the human model – in our case to a torso (with a head) and limbs. It has to be clarified that we are bound to the concept of "walking humans" and according to this some simplifications are made. They exclude the handling of self-overlapping body parts and cross-overlapping of two parts (arms as an example). Likewise we assume the torso is not overlapping the legs and vice versa.

At each animation step we determine the presence of overlapping areas that require layers of depth maps. Since exact tests are computationally expensive, we perform that task by simplified geometric computations involving body parts' BB. The penalty of this simplification is the false positive overlapping result in some situations. It has to be noted that additional considerations related to specifics of the human body are necessary for that approach to work. As an example in a typical woman's body the width of the hip is equal or wider than the shoulders. Thus, if using one BB for the entire torso and simple BB tests the results for overlapping with the arms would have been always positive regardless of the real situation.

Initially, in case of trousers in the scene a simple comparison between the legs' BB is performed (not necessary for skirts and dresses). The BB are compared in XY plane (see Figure 2 for coordinate system orientation) and if overlapping is detected the order is determined by the Z values. A test for the arms against the torso, the legs and each other follows. The nature of the test with the torso and the legs depends on the shape of the arm's BB in XY plane. Three cases are considered – the shape is a pronounced rectangle along the Y axis, a pronounced rectangle along the X axis or a square or close to a square. The latter two are straightforward to handle because the arm is either positioned away from the torso or overlaps it considerably. The former case, however, is more complicated because the arm is in close proximity to the torso. The test is performed with the aid of some additional information – namely the coordinates of the two ends of the hip-line, determined during the processing of the torso's triangles, and the coordinates of the

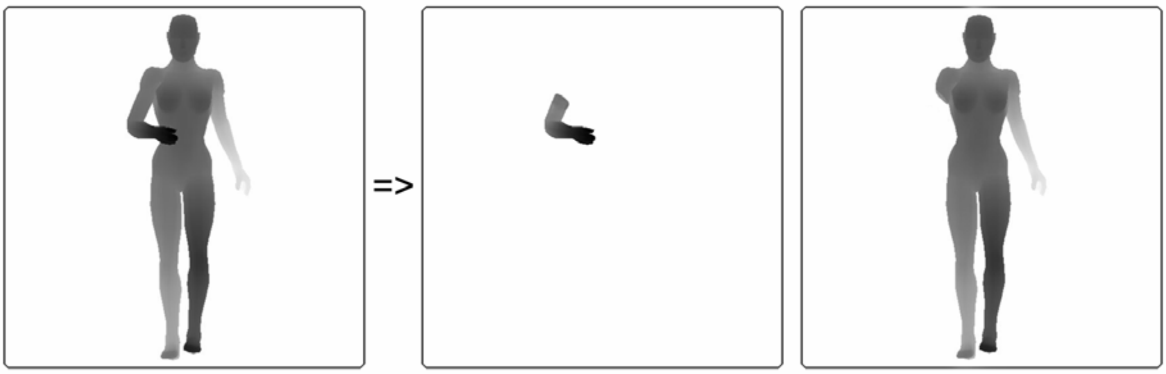


Figure 3. Two depth map layers for resolving the overlapping of the body by the right arm

point with endmost X value towards the torso for each hand. The latter is obtained via analysis of the triangles in the lower 25% of the arm's BB (according to human body's arm proportions). The test for overlapping is performed simultaneously with that analysis, thus not necessarily all arm rectangles are examined. The arm – leg overlapping test is performed via BB and if necessary the acquired coordinates of the "closest" hand point are also used. The testing concludes with check-up for overlapping between the arms which is a complex task because of the elbows' freedom of movement. Although not precise at all a simple BB comparison is used, with the drawback of many possible false positive results. However, in our case of walking figures this is acceptable because positions of the arms, causing such errors, occur on rare occasions.

If there is no overlapping the basic technique is used, otherwise layers of depth maps are generated. If more than one overlapping is detected an analysis is carried out, with the aim to reduce the number of necessary depth maps. As an example if both arms overlap the torso but not each other, then two depth maps are sufficient – one for the torso and the legs and one for the arms. Figure 3 shows two front depth map layers generated as a result of the overlapping of the torso by the right arm.

Testing for collisions

After the depth maps have been computed, testing for collisions is quite simple and made in two steps. First the x and y world coordinates of the mass-point of interest from the cloth surface are converted to X and Y map coordinates and then a depth value comparison is performed. The equations for conversion of the coordinates are as follows:

$$Y = \frac{y * mapsize}{bboxheight}, \quad X_{back} = \left(1 - \frac{x + \frac{bboxheight}{2}}{bboxheight}\right) mapsize, \quad X_{front} = \left(\frac{x + \frac{bboxheight}{2}}{bboxheight}\right) mapsize, \qquad (1)$$

where *mapsize* is the resolution of the depth maps.

All three coordinates in equations (1) are obtained through calculations involving the height of the mannequin's BB. This might look strange at first sight, but it is due to the choice of left and right camera clipping planes (along the x axis - see Figure 2). We set them to $-\frac{bboxheight}{2}$ and $\frac{bboxheight}{2}$ respectively, which results in a square viewport and prevents non-uniform scaling of the model in our implementation.

It has to be mentioned that the calculation of the map coordinates is simplified in contrast with the general case of projection in screen coordinates as a result of the use of orthogonal projections and the positions of the cameras. In the general case an additional step of projecting the point is needed which involves complicated computations with the projection and modelview matrices.

If a collision occurred, the normal and velocity vectors are retrieved from the respective maps indexed by the same coordinates (X, Y) used for the interference test. These vectors are necessary to compute a collision response.

In case of an animation step with more than one layer of depth maps, the map with closest Z value to the specific cloth point of interest is used. This strategy works because initially the garment is properly applied to the model of human and because of the fact that the body parts have certain "thickness". This consideration further simplifies things. Otherwise, it would be necessary to maintain additional information about the correspondence between garment patterns and depth maps.

Generation of normal and velocity maps, collision response.

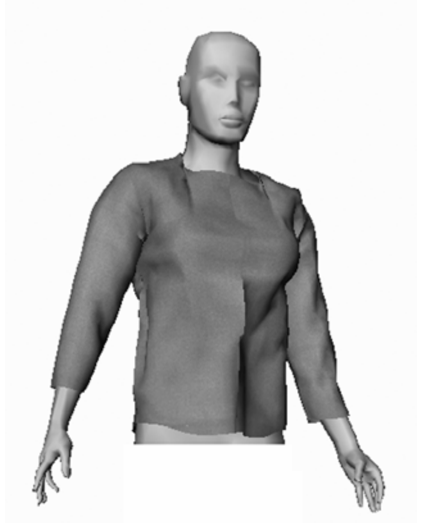
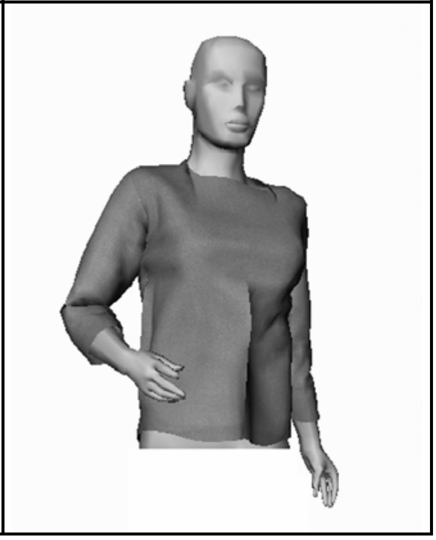
Since this work has no contribution to that topic, and because of space limitations it will not be discussed. A detailed description could be found in [7].

RESULTS

The algorithm of the technique was implemented under Windows with Microsoft Visual C++, using the OpenInventor™ library for rendering the 3D images. The experiments were conducted on a PC with Intel Pentium 4® CPU, 2.8 GHz and ATI Mobility Radeon graphics hardware.

Although possible no use of pre-computed data was made to universalize the technique. At each animation step the respective human model position was loaded from a VRML-like text file.

Table 1. Visual results of the experiment

Initial state	**Basic IS approach**	**Layer based IS approach**
		

Tests were carried out with a mannequin consisting of 4410 faces (triangles) with a total number of 2207 vertices and a shirt consisting of 6 patterns with a total number of 2436 mass points. Initially the shirt was properly applied on the body and then an animation sequence was simulated with and without the layers of depth maps feature. Visual results are given in Table 1. From left to right the images represent an initial state after applying the garment, a state when right arm – body overlapping occurs for the basic image-space (IS) approach and the same state (the same animation frame) for the layer based approach. The image in the middle clearly demonstrates the drawback of the basic approach, whereas there is no distortion in the garment using layers of depth maps.

Table 2. Performance data

		Frame 12	Frame 13	*Frame 14*	*Frame 15*
Basic tech-nique	Time for body animation and acquisition of the maps, (ms)	453	432	453	453
	Time for cloth simulation (after the body animation step), (ms)	172	173	172	172
Layered tech-nique	Time for body animation and acquisition of the maps, (ms)	532	532	641	641
	Time for cloth simulation (after the body animation step), (ms)	172	172	187	187

The performance data for four sequential frames is given in Table 2. Frame 14 is the first frame in which an overlapping occurred.

The performance data is divided in two – time spent in body animation and maps acquisition, and time spent in consequent cloth simulation (including collision detection and response) needed for the garment to follow the movement of the body. The first two rows of data represent the results from the basic technique while the last two the results from the layer based technique.

From Table 2 it could be seen that, when there is no need of additional layers, there is an increase only in the first time indicator of the new approach. This is due to the overheads for body parts handling and testing for overlapping. The increase in the first time indicator is much more noticeable when overlapping is detected whereas the second one increases slightly. The former is due to the creation of additional maps (depth, normals and velocities) while the latter is a result of the decision making which depth map to use for a particular cloth point.

CONCLUSIONS AND FUTURE WORK

An efficient technique for cloth-body collision detection applicable to simulation of apparel on walking humans has been presented. It employs the image-space based approach for collision detection and expands it to be capable of handling objects with overlapping parts. The results show that the collision response is performed properly.

The technique is not universal and it can't handle self-overlapping or cross-overlapping object parts. One possible solution is to further subdivide the object but this would increase the number of required layers of maps. In case of high resolution maps the performance would be seriously degraded.

Another problem is encountered when there are long objects in the scene positioned along the direction of view of the two orthogonal cameras. With the presence of such objects the collision response in its current form is completely inadequate.

The current system does not implement cloth-cloth collision detection and response. Future work will explore the possibilities of applying an image-space based approach to cloth-cloth collisions too.

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