INF574 - Projet of Cloth Simulation

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1 Problem Description

Cloth simulation is one of the most difficult aspects of computer graphics. it is a deceptively simple real-world item, but in fact presents very complex internal and environmental interactions.

The simulation of cloth requires more than the implementation of a simple dynamic system designed only for simple cloth objects. Many issues need to be resolved, concerning the accuracy and computational efficiency, robustness, stability, collision detection and response, and constraint handling.

2 Mains method ideas

The simulator described in the article represents the tissue as a triangular mesh and it is based in the common point of all approaches: physically-based cloth simulation formulated as a time-varying partial differential equation which, after discretization, is numerically solved as an ordinary differential equation:

$$\frac{\partial^2 \mathbf{x}}{\partial t^2} = \mathbf{M}^{-1}(-\frac{\partial E}{\partial \mathbf{x}} + \mathbf{F})(1)$$

x = geometric state M = mass of the cloth E = cloth's internal energy F = others forces

Since the beginning, research on clothing simulation has generally relied on explicit numerical integration to advance simulation. The greatest differential of the method described in the article we studied is that it uses implicit integration to solve this equation and advance the simulation instead of explicit integration as it is generally done in clothing simulation research.

The article claims that the biggest advantage of this difference is that it generates a simulator that can handle larger time steps while remaining stable, robust, and faster than the others methods. In addition, it allows a simple and unified treatment of damping forces and a running time that is more insensitive to the properties of the tissue.

In a simpler way, the algorithm can be described as follows: it models the cloth as a group of particles (the vertices of the mesh) each one having properties like mass, position, velocity, etc. At each iteration, the forces over all particles are calculated and used to create a linear system that comes from equation 1, using implicit integration. This linear system is then solved iteratively by a modified conjugate gradient method to find the next state of the particles (position and velocity).

The forces considered by the simulator described in the article are: stretching, shearing and bending for the main inner forces, 3 damping forces (each one corresponding to one of the 3 first forces cited before), and other forces like weight and forces generated to handle contacts.

3 Implementation

The first step that we took in order to be able to implement the idea of the article was to create the data structure that would represent the cloth. We created a triangular mesh, as described in the paper, and represented the cloth as group of particles, each one containing the main information necessary to represent them.

Then, we implemented a system solver which would be the responsible of constructing the linear system and solving it with the modified conjugate gradient method at each iteration of the animation.

One thing that is indicated in the article is the idea of representing sparse matrices (that are very present in the linear system to be solved) as an array of linked lists to really take advantage of their sparsity, and using this to make the products between matrices and vectors. We did not really understand how to do this, so our manner of doing this was actually store in each particle only the necessary information that we could use in the linear solver to reconstruct these sparse matrices in order to be able to make products with them.

Once this had been done, it was time to start putting the actual forces in action. Concerning the implementation of the forces, the article is well explained on how to compute the main 6 forces (stretching, shearing, bending and its respective damping forces) but there were some mathematical details that we had some trouble to figure out, like how to derive some matrices in a way that would work, make sense and we would be actually able to implement.

Regarding the other forces related for instance with contact handling between the cloth and itself or the cloth and another objects, we understood the general idea presented in the paper, but the instructions about how to actually calculate this forces were far less clear.

For example, the manner of detecting the contacts is cited as a form of a reference, we tried to read a little of the book referenced to try to understand how to do this detection but we weren't really able to apply the method in our simulator.

In addition to this, the idea of handling the contact of the cloth with another objects in the article is based on constraining the directions in which the particle is allowed to move. It is a simple idea and we understood the method, but to actually apply these constraints it is necessary to know the axes in which the particle is constrained and these can be almost arbitrary, with the only rule that they must be orthogonal in the case of two constrained axes, for instance. So what we did not understand was how to determine these axes in order to apply the constraints.

As a result of all this, the only two possible constraint states that we managed to apply to our particles were completely constrained or not constrained at all. Due to the difficulty in implementing the contact detection, we did not implement the contact handling of the cloth with itself either.

In the end, we managed to implement part of the idea of the paper, namely: the stretch force and the shearing force.

4 Results

Here you can see some illustrations of our final results. It is very different from those shown in the paper as expected since we left out some forces present in the original simulator such as the bending force and its related damping, and the forces related to contact and collisions handling.

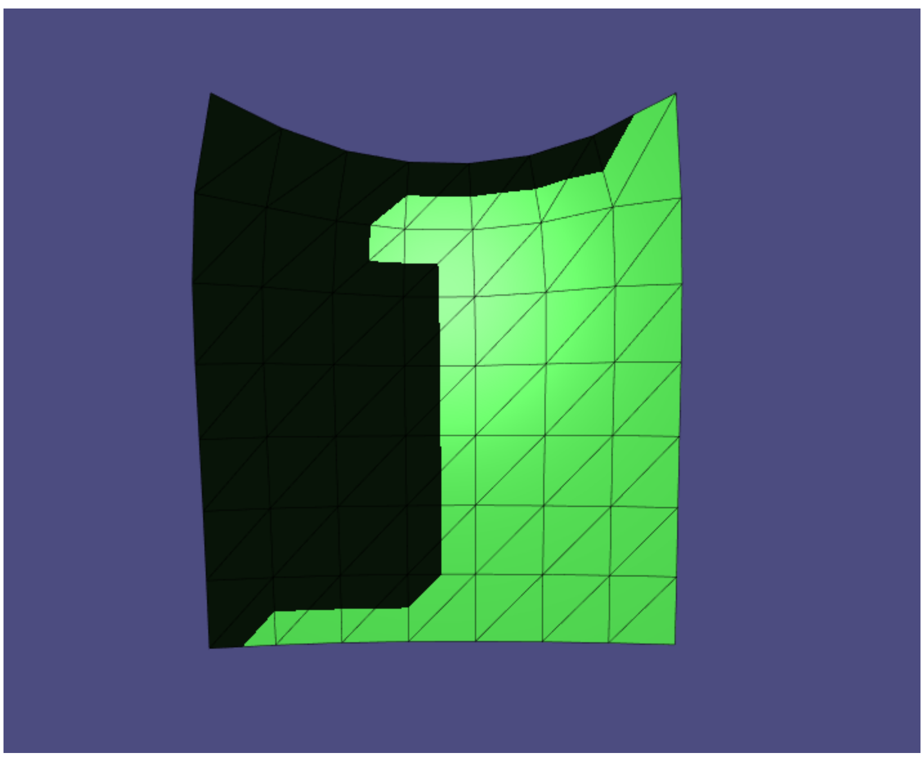

Figure 1: Results of the simulation (1).

The parameters used to calculate the forces, like the stiffness, are not explicitly cited in the paper, so we had to make some experiments with them to

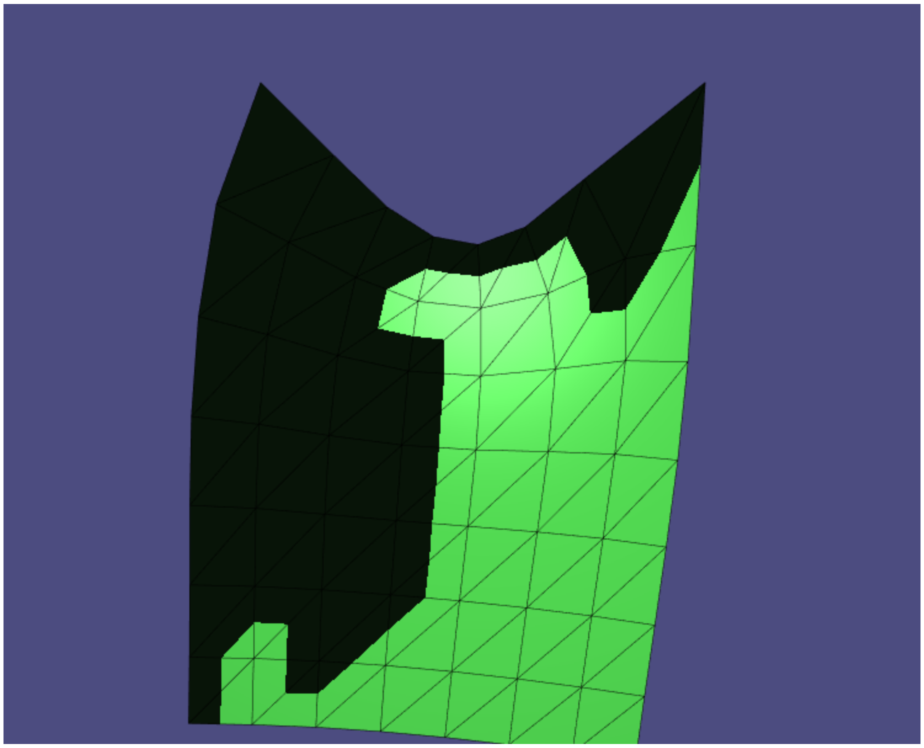

Figure 2: Results of the simulation (2).

try to achieve reasonable results. For instance, we had to put a very very large value for the stiffness so that it could handle the gravity in a satisfactory way, otherwise the cloth kept oscillating with enormous amplitude, pulled first by its weight and then by the stretch forces. The counter effect of this big parameter is that after some time, what we could see was an oscillating effect in the cloth that caused the illusion that it was under water, or under the effect of a less powerful gravity.

We noticed that the fact of not handling collisions is a big limitation of our implementation as it impacts a lot in the realism of the animation. Without this feature, we had experienced a lot of visual artifacts that are pretty bizarre to see in a cloth simulation, like triangles that move and intersect so much that they didn't even seemed to be attached to the same tissue (figures 3 and 4). As we added more forces to the simulator, this problem was a little resolved, but it was still one of the main causes of the non-realism of the animation.

Concerning this aspect, we believe that the bending force could also help to make a good difference, since it would stimulate the triangles to stay more "plane" with relation to each other by penalizing when the angles formed by the faces are too different from 180 degrees.

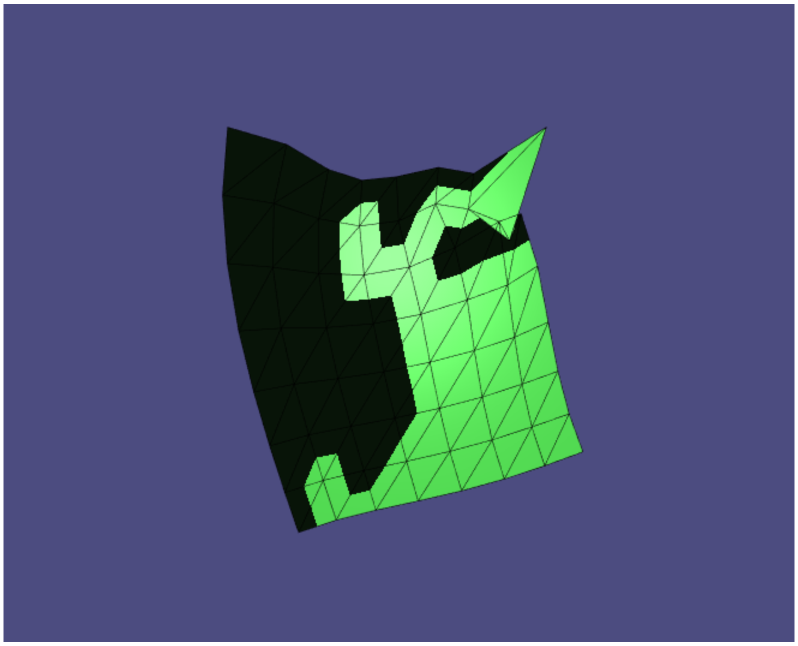

Figure 3: Some artifacts (1).

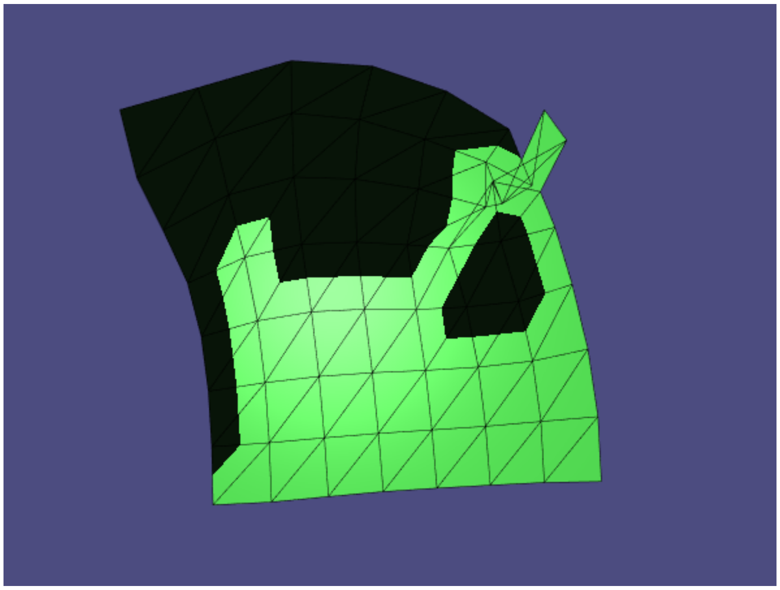

Figure 4: Some artifacts (2).

Another aspect that contributed to this less realistic result was the fact of not implementing the bending forces. We believe this is related with some of the artifacts that we saw in the simulation because the stretching forces, for instance, seemed to reinforce each other, without some kind of strong constraint to decrease their magnitude in a small interval of time. So after a period with the simulation turning we could still see some oscillating movement with reduced amplitude, but the cloth never got to its rest state, as we expected.

We tried to implement the damping forces related to the stretching and the shearing but, for some reason, when we did that the algorithm stopped being able to solve the linear system by the modified conjugate gradient method. It simply didn't finished the calculation anymore even in the first iteration and thus no animation was even shown. We didn't managed to solve this problem within the deadline of the project, so we preferred to keep it without the damping forces.

5 Conclusion

Cloth animation is indeed a very interesting subject and we would like to have been able to better implement the ideas present in the studied paper.

At first, we thought that the stretching force was the most important force of all and that in itself it would contribute a lot to realism, but as we can see, this is not exactly the case.

We conclude that each of the details presented in the article contributes with its amount of realism to the simulation, some more than others, but that in order to achieve a truly close-to-real animation, it is necessary to implement all or at least the vast majority of these features.

To improve our simulator we believe that it is essential to implement more forces (at least the bending force and damping forces), and try to better regulate the parameters to try to get the best out of the simulation.