# SIMULATION OF A DEFORMABLE HUMAN BODY FOR VIRTUAL TRY-ON

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***Abstract:*** *This paper presents a mass-spring model for real-time simulation of a deformable human body. A new type of springs that show collective behaviour was developed, which model the "matter" inside the object and make it approximately preserve its volume without the need of explicit volume computations during the simulation as it is done in conventional methods. Experiments on bodies with a different number of triangles show the low computational complexity, which is linear to the number of surface triangles. Results of applying the method in a system for virtual try-on of jeans are shown at the end of the paper.*

***Key words:*** *physical simulation, mass-spring system, volume preservation*

## INTRODUCTION

Cloth-simulation on virtual human bodies has been dealt with for the last couple of decades by many researchers in computer graphics and simulation [11, 16, 17]. Its main applications are in fashion design industry and in electronic commerce when customers shop for garments on the web and try them on in a virtual booth. The simulation is much more convincing and accurate if the human body is deformable and compresses when the garment is dressed, at least in the main contact areas. This deformation should be volume preserving, although the accuracy of preservation is not important. The objective is to achieve visually pleasing results rather than accuracy.

For years physical modelling and animation of deformable objects has been a problem of interest in the computer graphics society. Some of the first steps were initiated by Terzopoulos et al. [14, 15]. Their team described elastically and plastically deformable models and used the finite element method and energy minimisation techniques borrowed from mechanical engineering.

Volume preservation is of interest in geometric modelling [2, 7, 8, 12, 13], virtual reality surgery simulations [3-5, 10] and entertainment industry [1, 9]. Geometric constraints are applied to free form deformations (FFD) as described in [13] to allow constant volume of deformed objects. Rappoport et al. [12] applied an iterative Lagrange multiplier method, called Uzawa based volume preservation, to constrain deformations to preserve the volume of an object modified by FFDs. Aubert and Bechmann [2] use a similar approach to [12], claiming to be more flexible by introducing an independent deformation function. They compute the exact volume of the triangular surface in a similar way as proposed in [8]. To allow handling of curved surface solids Hirota et al. [7] use a multi level of detail approach employing FFDs. Chadwick [3] applied FFDs to change the appearance of muscles and fatty tissue by changing the FFD control points according to a multi layered character skeleton. Hookean springs are added to automatically simulate stretch and squash of muscles and tissue. Volume preservation is not attempted here. Chen and Zeltzer [4] implement a finite element method (FEM) to create a complete biomechanical model of muscle action for cartoon character animation. This approach is very accurate but due to its computational complexity very slow. Promayon et al. [10] approximate surfaces of volumes by mass-points linked to their neighbours. Volume preservation is achieved by constraining the model to its volume calculated using an approach similar to [8]. Nedel and Thalmann [9] described a mass-spring system for modelling real-time muscle deformation. They presented the muscle shape as a surface based model fitted to the boundary of medical image data. In order to control the muscle volume during deformation a new type of springs was introduced called “angular springs”. The muscle deforms under the impact of external forces, but only when they are applied on a preliminary defined line called “action line”, which represents the direction of the forces produced by the muscle on the bones. Aubel and Thalmann [1] extend [9] by introducing a new multi-layer model similar to [3]. "Action lines" are defined in a more general way using poly-lines.

The main objective of our work was to develop a fast mass-spring model for simulating volume-preservation deformable bodies. A mass-spring system was chosen because of its simplicity and low computational complexity. A new kind of springs was introduced called "support springs", which model the "matter" inside the object and make it preserve its volume.

## MASS-SPRING SYSTEM

A general mass-spring system consists of *n* mass points, each of them being linked to its neighbours by massless springs of natural length greater than zero. Let $\mathbf{p}_i(t)$, $\mathbf{v}_i(t)$, $\mathbf{a}_i(t)$, where $i$=1,…, *n*, be respectively the positions, velocities, and accelerations of the mass points at time *t*. The system is governed by the basic Newton's law $\mathbf{f}_i = m\,\mathbf{a}_i$, where *m* is the mass of each point and $\mathbf{f}_i$ is the sum of all forces applied at point $\mathbf{p}_i$. The force $\mathbf{f}_i$ can be divided in two categories. The **internal forces** are due to the tensions of the springs. The overall internal force applied at the point $\mathbf{p}_i$ is a result of the stiffness of all springs linking this point to its neighbours. The **external forces** can differ in nature depending on what type of simulation we wish to model. The most frequent ones are gravity and viscous damping.

The formulations make it possible to compute the force $\mathbf{f}_i\,(t)$ applied on point $\mathbf{p}_i$ at any time *t*. The fundamental equations of Newtonian dynamics can be integrated over time by a simple Euler method.

## IMPLEMENTATION OF A DEFORMABLE BODY

The main feature of the traditional mass-spring system is that it consists of individual springs, i.e. the response of each spring depends only on its own elongation and not on the elongation of other springs. The idea of this work was to create an ensemble of springs where the response of each member depends on the state of the whole team. In particular the algorithm generates a response that will preserve the volume of a deformable solid object.

Let *B* be a body, whose surface is triangulated, as shown in Figure 1. The deformable volume preservation body is constructed as follows. All surface vertices are connected to each other with regular springs, described in the previous chapter. These springs model the elastic membrane of the body and keep the triangles' surface approximately constant. In places where the body cannot compress, because of supporting bones, like the hips on the sides, the vertices are marked as static and they cannot move. All the other vertices on the surface are connected with equal rest-length springs, perpendicular to the surface, to an imaginary frame, which is inside the body. We call the collection of these springs support springs. They model the "filling" of the 3-D object. As mentioned earlier our approach does not aim accuracy, so the volume of the constructed body between the frame and the surface can be approximately computed as:

$$V = \sum_{i=1}^{ntr} S_i l_i \,, \qquad (1)$$

where *ntr* is the number of all triangles, $S_i$ is the area of the *i*-th triangle, $l_i$ is the length of the spring, connecting one of the vertices of the *i*-th triangle with the static frame.

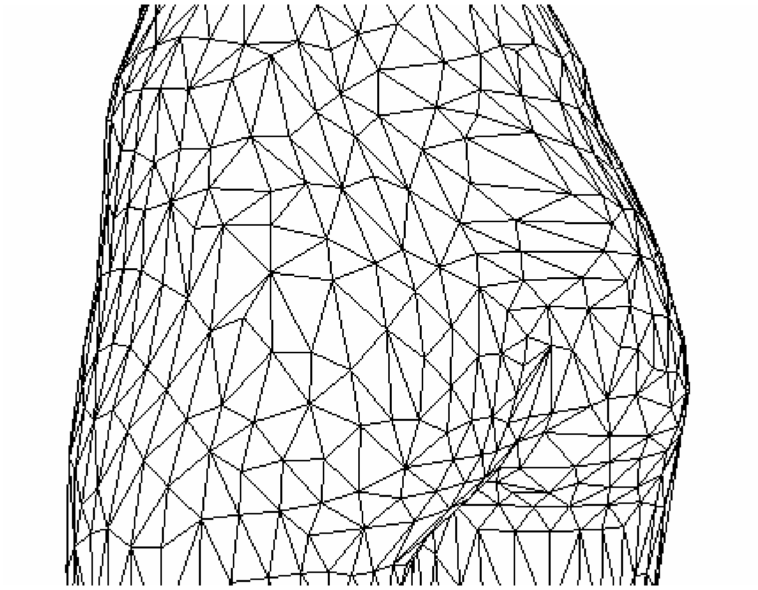

Figure 1. Human body with a triangulated surface

Let us make the following definitions. If $l_i^0$ is the natural (rest) length of the *i*-th support spring and $l_i(t)$ is the length of the same spring at time *t*, and S(*t*) and *V*(*t*) are the body surface and volume at time *t*, then the following lengths are defined:

$$\Delta l_{tot}(t) = (V(t) - V(0)) / S(t), \quad \Delta l_i(t) = l_i(t) - l_i^0 \tag{2}$$

The force acting on the surface vertex $\mathbf{p}_i$ at time *t* due to the *i*-th support spring is computed as

$$\mathbf{f}_i(t) = -K(\Delta l_{tot}(t) + C\Delta l_i(t))\,\mathbf{u}_i\,, \tag{3}$$

where *K* is the stiffness of the springs, $\mathbf{u}_i = (\mathbf{p}_i - \mathbf{c}_i)/l_i$ is a unit vector, $\mathbf{c}_i$ is a vertex on the frame, and *C* is a coefficient in (0, 1), which can be varied. As evident from Equation 3, the response of a support spring is a result from two different behaviours. The first one is the collective reaction, i.e. each spring opposes to the change in the volume, trying to preserve it constant. The second addend gives the individual behaviour of the spring. The coefficient *C* controls the proportion between the collective and individual behaviour. It can be varied, depending on the type of simulation. The bigger its value is, the stiffer the object, which requires larger forces to deform it.

Implementing the above-described approach directly has a couple of drawbacks. Firstly it is computationally expensive for objects with a large number of faces. Secondly, our tests showed that the volume preservation accuracy and the simulation quality depend very much on the spring stiffness *K* in equation 3. In order to get pleasing results, this coefficient must be in a very narrow interval, which unfortunately depends on the magnitude of applied forces. Otherwise the volume preservation accuracy gets low and for some values of *K* the simulation even becomes unstable.

This is why an approximation of equation 1 has been derived. Let $S_{AV}$ be the average triangle area. Dividing the two sides of equation 1 by $S_{AV}$ and rearranging the sum on all support springs instead of all triangles one can get

$$V / S_{AV} = \sum_{i=1}^{ntr} S_i / S_{AV} l_i = \sum_{i=1}^{ns} l_i \sum_{j=1}^{ni} S_j / S_{AV} \tag{4}$$

The sum $\sum_{j=1}^{ni} S_j / S_{AV}$ indicates that the *i*-th support spring participates in the volume calculation of $n_i$ truncated tetrahedrons. There is freedom in selecting one of the three edges for each truncated tetrahedron, so one can make sure that each edge is met at least once, i.e. $n_i>0$ for all $i=1, \ldots, ns$. If we substitute $c_i = \sum_{j=1}^{ni} S_j / S_{AV}$ we derive the following equations

$$l_{tot}(t) = \sum_{i=1}^{ns} c_i l_i(t), \qquad \Delta l_{tot}(t) = l_{tot}(t) - l_{tot}(0) \tag{5}$$

We consider that the coefficients $c_i$ do not change significantly over time and can be regarded as constants. So the only thing that needs to be computed during simulation is the length of each support spring. The technique tries to preserve the value $l_{tot}(t)$ constant, which is the weighted total length of all support springs.

The force acting on the surface vertex $\mathbf{p}_i$ at time $t$ due to the *i*-th support spring is computed as

$$\mathbf{f}_i(t) = -\, c_i K(\Delta l_{tot}(t) + C \Delta l_i(t))\, \mathbf{u}_i\ . \tag{6}$$

According to equation 6 the reaction force does not depend only on the changes of spring lengths but also on the coefficient $c_i$. This reflects the difference in the triangles face areas.

**RESULTS**

The algorithms were implemented on an AMD Duron PC, 1.3 GHz, 512 MB RAM, using the Open Inventor library for rendering the images. Volume preservation error tests were not done, because, as above mentioned, our aim is not to develop an accurate method for volume preservation deformation, but to just produce visually pleasing results.

The method for body deformation was implemented in a system for dressing virtual people [16]. In the first version of the system the human body was considered rigid and it was not deformed during the simulation. In order to enhance the realism and quality of fit, the approach, described in this paper, was incorporated in a system for virtual try-on of jeans. The areas of the belly and buttocks are automatically marked as deformable. This is possible because the body is obtained with a 3D scanner, which also outputs human body landmarks such as points on the shoulders, waist, hips, elbows, etc. The results are shown in Figure 2. The same size of jeans was tried on the same body, once on a rigid body (right) and then on a deformable body (left). While the jeans do not fit on the rigid body thanks to the body compression they fit on the deformable one. The results were confirmed by an actual try-on. These customers were asked to try the actual jeans on. The tests confirmed that the jeans fit, so the implementation of a deformable body increased the quality of fit. There were a few cases like this.

In order to check the algorithm complexity, we measured its speed for a different numbers of triangles on the surface. Results are given in Table 1. The times were measured using the profiling feature of Microsoft Visual C++ 6 and they are total times for computing the forces, integration of equations and rendering the image. As shown in the table the simulation still runs in real time for as many as 6728 triangles. Note that these times do not include the cloth simulation but just the body deformation!

Figure 2. Fit of jeans: left-with body deformation; right-with no deformation

Table 1. Times for deforming a body with a different number of triangles on the surface

| Number of Triangles | Time for 100 frames (s) | Time per frame (ms) | Frames per second |
|---|---|---|---|
| 1152 | 1.17 | 11.72 | 85.3 |
| 2592 | 1.82 | 18.24 | 54.8 |
| 4608 | 2.74 | 27.45 | 36.4 |
| 6728 | 3.67 | 36.74 | 27.2 |

## CONCLUSIONS AND FUTURE WORK

A mass-spring model for simulating a deformable human body has been developed. The technique is applicable for objects presented with their triangulated surfaces. It uses the so-called “support springs”, which act as an ensemble and their response depends on the change in the object's volume as well as on each individual spring. The technique has a very good speed and it runs in real time for objects with as many as 7000 triangles. This approach is very useful for simulating deformable human body parts in a virtual try-on system. The experiments showed that it improves the accuracy and quality of the fit. In the future the method can be applied to other parts of the human body. Applications of the technique in other fields will also be considered. Many thanks to Bodymetrics, Ltd., UK, who sponsored this work.

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