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Generation of Flexible 3D Objects

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ABSTRACT

The objective of this research is to develop a tool for the generation of 3D objects modeled with flexible materials, with visco-elastic or inelastic characteristics, similar to the plasticine.
It is desirable to prioritize the simplicity of the interface with the user in the interactive deformation process of the object. To compute the deformations of object which is exposed to external forces, like elements with which the modeling will be simulated, what implies the process between the deformable object and rigid ones.

Keywords: computer graphic, 3D modeling, deformable objects, interfaces.

1. INTRODUCTION

Research in construction of deformable objects has increased during the past years [1, 2, 3, 8, 9, 13], simulation of this type of objects is needed in several areas of computer graphic:

In graphical animation: for the generation of movements of clothes [7], face expressions [5, 14, 16], movement of the human body, interactive video games, animation of cartoons, among others. The need to simulate the behaviour of tissues in virtual environments originated intense research to devise techniques for physically-based modeling of objects whose shape and topology can dynamically evolve. In training systems of surgeries to provide real rendering graphics with the human weave [3, 9], etc.

In interactive objects modeling: [18] where to design polyhedral objects of free 3D form is in general a hard task, the application of deformation techniques to some created object can be beneficial.

In the simulation of the behavior of materials with properties that allow the deformation (for example the plastic or elastic) to emphasize dynamic interaction with the surrounding like the simulation of a bouncing ball, or the collision of a car in race.

The process of deformable objects involves a complex combination of results that extend from considering mechanical parameters to solve great systems of differential equations, to detect collisions, to model reactions to the collisions, among others. These processes generate problems when the simulations must be executed in real time [3, 5, 10, 11, 12, 17].

On the other hand the design of polyhedral objects of free 3D form is in general an arduous task. The constructive geometric solid techniques are very useful in the context of industrial design, but they seem to be less flexible for applications with animation of characters or simulation of biological objects. Frequently the objects are modeled sampling of existing 3D objects and subsequent modifications. An alternative method is modeling through implicit surfaces [20, 22].

Generally the research in deformable models considers (depending on its application field) the exact and right prediction of the reaction of the object to the interaction with external forces and closed to the real time. The differences between an approach devoted to real time and one devoted to accuracy resides in: the different precision in the definition of the material properties while formulating the equations governing the deformations, the numerical technique adopted for the resolution of the equations, and the granularity of the object model used.

On the other hand, we found some systems that allow the design of 3D models [5] making possible a fast prototype in the first stages of design, favoring recreational or educative applications.

But it is little related to the modeling and simulation of 3D objects of viscous materials, like rubber or plasticine, which are used in the industry of films or animations of characters with the non-photorealistic appearance (npr) and where all the task of the modeling is totally manual,

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[23] the digital help is limited to the capture of photograms and its assembly.

The main motivation of this research is to provide a tool that could be used for this task.

2. ANTECEDENTS

Until the 90s, developed geometric models turned out particularly useful to model rigid and static objects, that is, whose form did not vary in time. It is for that reason that these models were not useful to represent physical properties of the objects.

This limitation caused an ample growth in the investigation field appearing the models called “models based on the physic”, that although more complexed than the net geometric models, offer a great realism when modeling natural phenomena. Their interaction with deformable objects will be limited to the specification of the forces, which this object will take and it will be the physic that will dictate the kinematic movements to low level of these objects.

In 1986 Sederberg, Parry and Watt [4] developed free form deformations models, *FFD.* This technique of deformation of free form (FDD) , submerges the object in a space that can be deformed, an analogy commonly used, is to consider that the object absorbed in an imaginary and transparent box of flexible plastic. When this structure is deformed the object in its interior will also be the same, since the objects are considered flexible, that is why they can be deformed with the plastic that covers them. The disadvantage that offers FFD model is that it does not allow enough control on the objects since the deformation must be made through the nodes of control of the parallelogram that defines the deformable space; in 1990 S. Coquillat [15] extended the model incorporating more types of meshes.

In 1987 Terzopoulos and others created deformable models of elastic synthetic objects and took the first step to the simulation of deformations [1, 2]. This first model used the physical properties innate of splines to incorporate physic to the generated objects by this type of surfaces.

In the development of simple interfaces for the modeling we found a job by Igarashi [7] that developed a system of modeling of free form based on a 3D sketch, where the user simply makes a 2D sketch with movements of the mouse and the system automatically generates a reasonable geometry 3D of free form with a novel method for inflation of polygons, in this work the objective was to explore the concept of *user interface of free form,* where it used rendering no-photorealistic (npr) interaction in order to avoid the user to worry about the details and is dedicated to a explorative task.

It takes transformation functions: to double, to extend and to twist the object but from the indications of target forms, preserving the polygonal topology of the connection, not of the accomplishment of a direct operation on the object to deform.

The main motivation of the technique of inflation of polygons is to have a less expensive computational alternative of modeling [6]. The technique of inflation of the polygon, can be useful in the stage of the design of a poliedral 3D model. Since in many aspects it is similar in reaction and intention to the modeling of implicit surfaces, it can be considered like an alternative to this modeling technique; it offers a definition of intuitive form via a skeleton located in space, and supports a great variety of attainable forms. It is a generalization of the operation of extrusion to increase polygons to polygonal prismatic objects. The initial configuration of the polygon and polygonal mesh that are topologic 2D structures absorbed in the 3D space.

3. MODEL and TECHNIQUES.

The **Deformable Objects** have two basic forms of reaction before the presence of external forces:
By means of *elastic deformations*, when the object is able to recover its original form, these forces are called internal forces and its magnitude is proportional to the level of deformation of the object, these forces will stop when the internal forces compensate the external ones giving a null total result. The deformation is linear when the deformation level is linearly proportional to the magnitude of the external forces that cause the deformation.
Another form of answer is by means of *inelastic deformations*, once deformed the object, this is not able to recover the original form. We found two types of them:
Viscous: when the speed of the deformation of the object is proportional to the magnitude of the external forces that are applied to it and …
Plastic: when the deformation of the object is independent of the magnitude of the external forces applied and the deformation is null until this magnitude does not surpass certain threshold.

The real solid objects that exhibit inelastic deformations do not present it pure but viscoelastic and elastoplastic form (combination of plastic and elastic)

The objects developed with **Deformable Models** can react in a way that is expected in the reality to the application of forces like the gravity, restrictions like the unions and fixations in the space, the means that surround them (viscous friction) or the contact with impenetrable objects. In addition, these models that incorporate the physical properties of the material can be defined in a dimension (lines and curves), two dimensions (surfaces) or three dimensions (solid objects).

The equations that govern the movement of a deformable body can be written by means of the Lagrange model.

Let c the material´s coordinates at the point of body. In a solid $c = [c_1, c_2, c_3]$, in a surface $c = [c_1, c_2]$.
The Euclidean 3D positions of the point inside the object are given by vectorial function, variable in the time $r(c,t)=[r_1(c,t), r_2(c,t), r_3(c,t)]$. The body in rest state is represented by $r_0(c)=[r_1^0(c), r_2^0(c), r_3^0(c)]$

$$\frac{\partial}{\partial t}\left(\mu\frac{\partial r}{\partial t}\right)+\gamma\frac{\partial r}{\partial t}+\frac{\delta \mathrm{E}(r)}{\delta r}=f(r,t) \qquad (1)$$

In Eq. (1), $r(c,t)$ is the position of the particle c in the moment t, $\mu(c)$ is the density of the body mass and $\gamma(c)$ is viscous friction factor in c, $f(r,t)$ represents the external forces which are applied on the deformable object, $\varepsilon(r)$ is a function that controls the instantaneus potencial energy of the body elastic deformation.

In order to define a potential energy of deformation that fulfills with conditions as to be zero for the model in its natural state of rest and that grows as the deformation of the model it increases, and that potential energy does not vary for rigid movements of model, are used differential geometrial concepts [1, 2].

Model based on the physics of Splines:

The use of the Spline elements, in computer graphics, had limited its purely geometric aspect, leaving aside the physical properties that they have contracted, Terzopoulos, in his models, emphasized this physical base to create models of sensible flexible surfaces to the application of external forces. As it is known, Splines is a technic interpolation that allows the generation of curves, surfaces and volumes from an set of point control, with them it is interpolated or approximated the form described by the points control by means of cubical functions and, therefore, have continuity of two orders, that is to say, curvature and tangent. An important characteristic of Splines is that its formulation is derived from the mathematical approach of the physical behavior of the tables that habitually are used in the construction of boats. In fact, it will be Splines, ones with which the elastic objects are constructed, that will confer an internal elastic energy to it, which will be null when the object reaches the original form (stay of rest). The application of an external force on this object will cause its deformation and, therefore, that the internal forces stop being null and they are against this deformation. The greater object becomes deformed according to its energy.

They are more complex than Mass-Spring model, but it allows greater control on the physical properties of the mesh. The disadvantages are the great number of parameters to fix for the simulation and the temporary and space cost to the resolution of the equations that govern the deformation.

The Mass Spring Model:

With the term Mass Spring System we intend a system formed by a set of *mass points* and a set of constraints between couple of points; each point is subjected to forces due to the status of the springs connected to it and to the potential external forces (gravity, user interaction etc.). The position of the mass points is calculated at each instant by integrating the equation of motion. It has to be taken into account that the system of equations arising from the previous definition cannot be simply integrated through the time, because points of unwanted local minima could be generated such that the simulation becomes unrealistic.

The deformable model based on simple T_2-Meshes is a deformable model of the mass-spring type that is characterized by the type of mesh that uses to carry out the deformation of the surface of the object, this mesh has a constant connectivity and therefore one simple discreet representation of the position nodes of the mesh, this property allows to simplify the deformable equations that govern the elastic behavior of models conferring greater speed in the calculation than in the rest of the algorithms to the same group of deformable models.
This type of model has the advantage that is easy programmable, very fast in the calculation of the deformation and needs the determination of a reduced number of parameters. The main problem is that these methods are very sensible to the values of the parameters so that an inadequate selection can cause that the equation is not stable or even that the solution does not converge.

Finite Elements Models FEM:

These are characterized by the decomposition of the dominion of the object in set of sub-dominions on which the calculation of the deformity of the object is applied. This way the calculation of the deformation of a complex object is transformed into an assembly of calculations of deformation of simpler geometric elements in which the object has been disturbed.

The main advantage of these models is that they allow to model the behavior of the objects as volumes (the previous ones allow it like surfaces), but the great disadvantage is the high temporary cost, for that reason they are limited to accelerate them to contemplate linear elastic models.

4. DEVELOPMENT:

The generation of artistic models made with deformable materials (plasticine) also requires great doses of skill and patience in the modeling process. In spite of the appearance of new techniques of animation by computer, the animation with characters and objects of plasticine may take weeks or even months to mould and to paint the objects.

Although much progress has been made over the years on 3D modeling systems, they are still difficult and tedious to use when creating freeform surfaces, for that reason also is necessary to study the interface with which the objects will be become deformed.

Our goal is the efficient development of structures and algorithms that can process models in compatible times for an interactive function. The fact is explored to make *local* deformations, limiting the calculations to the portions of the objects that experience significant deformations, it is necessary to detect an area of influence of the deformation and make some subdivision to handle the deformation, always trying to obtain the appearance npr of the plasticine designs.

Here, we were centered in two main problems:

- ☐ To compute the deformation of an object according to external forces,
- ☐ To handle the interaction between objects that become deformed and rigid objects, like the object with the tool that will mold it.

It is studied the fact that the deformations are made with some tools (for example when molding plasticine the fingers are used) that will have to be simulated, soon a study will be necessary on its interaction with the object to deform.

The successful deformation of a polygonal object requires the existence of enough numbers of polygons in it, since if the resolution is low the deformations could be in a degradation of the edges of the silhouette or in aliasing of edges, we explored criteria to extract a representation depending on the range of force intensities which can be applied to the object modeled, such that each part of the object is represented at the appropriate resolution.

The **Interface** allows the interaction between the deform model and the tool with which it will be molded, capturing these movements through mouse, to obtain the deformation is due to consider the application of a force made by the user. The characteristics of the forces are:

- The point of application or place of the mass on which it is exerted.
- The direction indicated by the air line of the resulting movement.
- The sense of the movement that produces.
- The intensity or power, that turns out to compare it with a force that considers the unit.

In this sense diverse techniques are studied with the objective to generate soft objects (or with capacity to become deformed itself) free 3D forms interactive, favoring the simplicity of modeling and incorporating the possibility of deforming the objects that are defined flexible simulating different types of materials.

To prototypal implementation is currently in development state.

Another important direction of the investigation is to conduct operations of modeling to create fold, to twist the model, etc. It is necessary to define the techniques for the development of a simple interface that it deals with the inevitable complexity of the support of these operations.

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