ADJUSTING DEFORMATION METHODS FOR VIRTUAL REALITY SYSTEMS

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Abstract — *Virtual Reality Systems for training have been proposed and developed with the objective to simulate real situations and to allow the acquisition of specific abilities of critical procedures. Basically a Virtual Reality System (VRS) is a real-time system that presents interaction and immersion features to provide realism in the applications. In some of these systems, for example the ones used in medical area, the presence of virtual models that answer morphologically to interactions becomes necessary. These models are known as deformable objects. This work presents an analysis of the methods for modeling deformable objects, identifying their most appropriate application in VRS. In this analysis, factors related to the quality of the images, methods for collision detection between objects and computational performance is considered.*

Index Terms — *Deformable objects, Methods of Deformation, Systems of Virtual Reality.*

INTRODUCTION

Virtual Reality Systems are computational systems used to generate virtual worlds that present immersion, interactivity and real-time properties [1]. The combination of all these factors is responsible for the realism in different applications. These applications reach the most varied scientific areas with the objective to allow acquisition of practical in the execution of critical procedures.

In many applications the presence of virtual models that present interactive modifications in their structure becomes necessary, since objects with these features are present in real environments. Objects of virtual environments that present deformations when touched are known as deformable objects. The methods used for modeling these objects are known as Deformation Methods.

There are some methods for modeling deformable objects. These methods can be divided in two categories: geometric methods and physical methods. The geometric methods are only based on mathematics and for this reason present a low computational cost and deformations with limited realism. By the other side, physical methods consider some complex physical principles in addition of the mathematics. The physical methods can offer realistic deformations but demands a higher computational cost [2].

To increase realism in VRS by the use of deformable models is necessary an analysis to identify the most appropriate deformation method to be used. This analysis will verify the advantages and disadvantages of each method according to the system application. Besides that, the visual quality of the deformations, the collision detection method and computational cost must be considered in this analysis. The choice made from that analysis' results make possible the adequate implementation of the deformable objects, condition decisive to determine level of realism of the systems.

VIRTUAL REALITY

Virtual Reality (VR) is a recent research area that unites knowledge of many areas such as electronics, computer science, robotics, physics etc. The objective of VR is to offer real-time systems that integrate aspects of immersion and interactivity to simulate realistic environments [3].

The quality of the VR experience is crucial and it must stimulate the user in a creative and productive way. It means that the virtual environment needs to react in a coherent form to the movements of the user, and make the experience realistic [1]. For this reason it is important the presence of models that offer visual answer to the interactions in an equivalent way to its real similar.

DEFORMABLE METHODS

Deformable objects are computer generate models that can present deformations in time as a reaction of a contact with them. In some cases the deformations include physical aspects of the material of which the model are constituted [2].

Several methods have been developed to modeling of deformable objects. The mathematical theory used as base for them represents a union of Approach Theory, Geometry and Physics. Geometry is used to represent the shape of the object, the Physics imposes restrictions about the behavior in the space along the time and Approach Theory offers theoretical support to adapt the models in its

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dimensions/measures and become possible the computational implementation of them [4].

Deformable methods can be classified as geometric methods (non-physical) and physical methods, and their application is based on requirements from the VRS where the model will be used.

Geometric Methods (Non-Physical Methods)

Geometric Methods use geometry' foundations in their modeling process. In these methods, objects or the space around them are modified due to manipulations exerted on their vertex and control points [5]. Generally, these techniques present a low computational cost due to the concepts they are based on. They are adequate to systems that do not demand high levels of realism [2]. Amongst the geometric methods two can be highlighted: Splines and Free-Form Deformation (FFD).

- <u>Splines</u>

Splines method works on the modeling of segments of curves from a process based in the Bézier method. It presents some improvements as local control and higher smoothness in the drawing of curves [6].

There are several types of Splines but, in general they work on the form: Let be $P_0, P_1, P_2, P_3..., Pn$ points in the R^3, P_iP_{i+1} segments with $i=0,1,2...,n-1$ are considered polygon lines. By linear interpolation for each $t \in [0,1]$, one P_i' point is defined in each P_iP_{i+1} segment through

$$P_i' = tP_i + (1-t)P_{i+1} \tag{1}$$

to form new polygon lines from the $P_0', P_1', P_2', ..., P_{n-1}'$ points. After n steps, a polygon named as control polygon is generated and from it is obtained a P_0^n point. This point is the value of $P(t)$, a polynomial function with parameter t and degree n, that defines the segment of curve to be formed. Taking an integer k of $2 \le k \le n+1$ and (x_n) an finite increasing sequence called knot vector composed by $n+k+1$ real numbers, the function $P(t): [0,1] \to R^3$ is defined by,

$$P(t) = \sum_{i=1}^{n+1} P_i N_{ik}(t)\ ,\ t_{min} \le t \le t_{max} \tag{2}$$

where N_{ik} is a polynomial function defined in successive steps and represented by,

$$N_{ik}(t) = \begin{cases} 0, & if\ t \in [x_i, x_{i+1}] \\ 1, & if\ t \notin [x_i, x_{i+1}] \end{cases} \tag{3}$$

The knot vectors can be expressed on different manner and could be uniform or not. These variations cause severe changes in the format of N_{ik} basic functions and modify the influence area of the control points. Due this fact, there is a collection of Splines where the most popular are the B-Splines, the rational B-Splines, the non-uniform rational B-Splines (NURBS) and the Cubic B-Splines [7].

A Spline model is formed by the assembled of several Splines curves. The movement of the control polygons from the different curves that generates the model allows its deformation. It does not give an intuitive control of the movements to the user and, consequently, does not provide realism to the model. This method is quite used in computer aided geometric design (CAGD), mainly in systems that require computational efficiency.

- <u>Free-Form Deformation</u>

Free-Form Deformation (FFD) method acts directly on the vertex of the objects that need to be deformed. In this method the object to be deformed is embedded in a standard geometric lattice of control points, such as a cube. Soon after, the points of the lattice are connected through functions to the points of the object. The initial form of FFD was introduced by Sederberg and Parry [8] and used the trivariate Bernstein polynomials:

$$B_{in}(t) = \binom{n}{i} t^i (1-t)^{n-1} \tag{4}$$

The space inside the lattice is deformed when the control points of it are manipulated, what also deform the object contained in the lattice. In other words, this deformation method works deforming the space where the objects is contained. For a better refinement of the object deformation is necessary a great amount of control points that will turn more difficult its manipulation as well as it will increase the processing cost [2][8].

FFD has been used in association with other deformation methods and also to modeling complex forms from their geometric primitives. FFD are more intuitive than deformations based on Splines and they can be applied in different graphical representations.

Physical Methods

Physically based methods can model objects by the restriction of its movements according to the physics and dynamics involved in interactions with them. Thus, internal and external forces are considered during the simulation what provides more realistic behaviors to the objects [6]. These methods use computational technology with physical principles to develop realistic simulations that demand high fidelity in the deformation of objects.

Most of the techniques used for physical objects modeling is reduced to two general categories: Mass-Spring Systems and Finite Elements Methods (FEM).

- Mass-Spring Systems

In a mass-spring systems object geometry is represent by a three-dimensional structure (lattice) composed by n mass points connected by springs what forms a regular polygon on its surface. Each mass point is the mapping of a specific point on the object surface. For this reason, a mass point displacement will describe an object deformation. The mechanical properties of the object are described by data stored in the mass points and springs. That is made through the association of mass, damping and stiffness to the mass points and springs [9].

In dynamic mass-spring systems, Newton's Second Law ($F=ma$) governs the motion of each mass point in function of the time what generates a second order differential equation. The motion of the whole body is calculated by the concatenation of the motion equations of all mass points in the lattice. It generates a differential expression formed by mass (M), damping(C) and stiffness (K) matrices:

$$Md^2x/dt^2 + Cdx/dt + Kx = f \qquad (5)$$

where f is a three-dimensional vector of the sum of external forces acting on the points and x is a three-dimensional position vector formed by the concatenation of the position vector of all the mass points.

The expression (5) can be solved through a variety of numerical integration methods to obtain the position and velocity values of each point in function of time and to determine the model deformation [2].

This method can be used for soft deformations modeling as well as for deformations related to the human organism. The approximation of the differential equations solutions offers images with satisfactory quality of realism with a time of processing that doesn't commit the properties of real-time of the VRS.

- Finite Elements Methods

Finite Elements Methods (FEM) combine concepts of Mechanical Continuum with finite elements methods for numerical approximation [2]. The continuum properties govern the deformation process that will be developed. Thus, FEM discretize these properties and allow the computational implementation of the method.

The continuum model of a deformable object considers the equilibrium state that can be influenced by external forces. This equilibrium state in dynamic systems is calculated through the potential energy (Π), determined by the strain (Λ) and work (W) applied to the object:

$$\Pi = \Lambda - W \qquad (6)$$

An object reaches equilibrium when its potential energy is minimum. The strain and work are expressed in terms of the object deformation, which is represented by a function of the material displacement over the object. This physical process is mathematically represented by a differential equation that is approximated by the finite elements method.

FEM divide the object continuum into reduced discreet points (finite elements) and approximate the equilibrium function for each one of them. The model is represented by the join equilibrium equations that are expressed by several calculations inherent to the strains and works generated by the system.

The use of FEM has been limited in VRS due to the continuous re-calculation of the equilibrium equations for each manipulation what commits the real-time necessary for this kind of application [2].

DEFORMATION METHODS IN VRS

Implementations of deformable methods in VRS is a process that require the combination of different types of knowledge:

- Computer Graphics, to the visualization and manipulation of the virtual models presented into three-dimensional environments;
- Physics, that models behavior features of objects and environments properties where the objects are inserted;
- Mathematics, that provides the mathematical descriptions of the physical mechanisms, of the generated models and all other foundations used in the development of these types of systems, besides the optimization of the systems;
- Specific knowledge of the scientific area of VRS application to provide the data and necessary information about the objects features and environments that composes the virtual worlds to be generated.

This association allows the conception of realistic systems and provides solutions for several applications and specific problems. However, a meticulous analysis of the deformation methods must be accomplished to identify its benefits in the VRS and do not compromise the real-time of the application.

In a VRS a deformation is related to interactions with and between objects and also to movements and forces applied during these interactions. A deformation will occur only when a contact exists and a collision detection method must be used to identify the contact position and its properties. This fact make the implementation of the collision detention algorithm a critical factor because its bad use can compromise the real-time feature of VRS [10]. In these systems, collision test routine uses the interactions to identify contacts and calculate possible deformations. Due to this, the collision test routine is continuously processed.

Figure 1 presents a diagram to illustrate how collision detection and deformation routines are related in a VRS. During the system execution, when an interaction occurs the collision detection routine is called to verify if there is contact between objects of the scene. When a contact happens, the properties of the collision are provided to the deformation model to process the deformation of the 3D model.

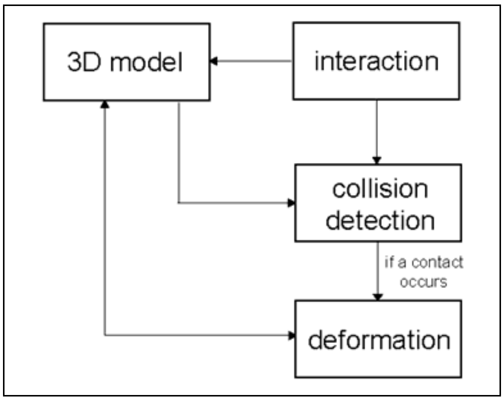

FIGURE. 1
INTEGRATION OF COLLISION DETECTION AND DEFORMATION IN A INTERACTIVE VRS.

CONSIDERATIONS ABOUT DEFORMATIONS METHODS IN VRS APPLICATIONS

The quality of deformation provided by each deformation method must be combined to the performance expected by the applications. The correct combination of these factors is possible with the previous planning and study of the process to be simulated. It is important to identify the possibilities that each one of the deformation methods can offer and how to adapt them to different VRS.

Because geometric methods for deformation are independent from material characteristics and external forces from the environment where the object is inserted, they are not very realists. By the other side, they can be quite useful in systems that prioritize the visual rendering and do not depends on high levels of details in the objects deformations. CAD (Computer Aided Design) systems are one example of these systems. They make an extensive use of Splines methods and request relatively simple mathematical foundations, as functions, distances and lineal transformations to allow the modeling of complex objects by the composition of curves. When compared to the Spline method, FFD provides a higher and more powerful level of control about the deformations. Besides its use for generation of models in systems of geometric modeling, Free-Form Deformation method has also been used in association with other methods for deformation, as mass-spring methods for elaboration of complex animations.

In Physical methods, the quality of the deformations is higher when compared to deformations based on geometric methods. In Physical methods, the computational cost requests care due the quantity of calculations to be executed in each cycle of the VRS. In this context, mathematical techniques for approximation are used to optimize results and then promote the non-commitment of the VRS real-time. In general, VRS that incorporate a physical method of deformation for objects present realistic deformations due incorporate inherent characteristics of the material that compose the objects and environments in that they are inserted. The Mass-Spring method is relatively fast and easy to construct and allows realistic simulations for varied objects, including viscous and elastic tissues usually applied in medical simulations [11]. This method has been used in facial animations to model the smooth human facial expressions. The objects can be animated at rates not reached with FEM and present visual realism and low processing cost that does not commit the real-time properties of the VRS. The use of Finite Elements methods in real-time systems is limited due to the computational requirements demanded by the same. This occurs because FEM require complex calculations for each point of an object to determine the deformation of the whole object at each user interaction. In spite of this, the use of deformation based on Mechanical Continuum provides objects with accurate physical properties when compared to objects deformed by other methods.

The application of a specific deformation method in a graphical system cannot be discussed in an independent way. The advantages and disadvantages that each one presents need to be discussed in relation to the specific application. It means that the method will depends on the graphical quality related to the physical properties of the object and the performance of the system. The most important is to maintain the real-time feature of the application when deformable objects are present in a VRS.

Because VRS are interactive applications, a collision detection method must be present to activate the deformation when a contact occurs between two objects. So, an ideal deformable method must guarantee real-time and graphical quality when running together with a collision detection model. The purpose of the application must serve as base during the choice of the deformation method to allow the balance between cost and benefits and to avoid any delay in the final result.

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