State of the Art : image synthesis and virtual reality

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Abstract

This paper has two goals : first to present the computer graphics community's point of view on virtual reality, and next to describe some of the works realized by French computer graphics teams. We think that the point of view of the teams working in computer graphics is interesting because these teams have a particular knowledge of the possibilities and the limits of computers, in terms of computation but also in terms of visualization. Thus the recent breakthroughs in virtual reality were often realized by laboratories working on computer graphics.

1 Introduction

The term *virtual reality* designates the set of activities in which a part of the world upon which man acts, is replaced by a calculated module. The interest of virtual reality is to enable sensorial contact with an inaccessible world. This inaccessibility may have several types of causes : temporal causes (if the aim is to access an object that does not exist any more, or does not exist yet) geographical causes (if the aim is to access objects that are faraway or at different scales : the scale of a molecule or the scale of the universe). Virtual reality also enables to modify our perception of current objects.

Very often, the term *virtual reality* does not designate the concept but the set of implemented technologies. This is the approach adopted in this paper. We think that virtual reality comprises three major research fields.

- First the field working on the modelling of the objects and the worlds that are to be explored ; Next the field working on the devices that enable to sense and to act upon the simulated objects and worlds. These devices are often described as *force-feedback* devices. The third field is dedicated to the control of the interactions between man and model via the interaction devices.

  Any virtual reality device must have a model of the objects and worlds that are to be discovered. Such a model must comprise a great number of characteristics. As a minimum, a geometrical model must be built, that is the set of surfaces defining the representation of the object. Currently the two main solutions are geometric modellers and reconstruction. Moreover, if the aim is to be able to act on the object, then the reactions to external actions must also be modelled. This is dynamic modelling.

- A second research field consists in designing and realizing devices enabling man to apprehend virtual models. In particular, it is necessary to define visual display devices. Several solutions are possible, complete immersion thanks to headsets, stereoscopic representation, etc. It is also necessary to take into account haptic interactions, that is the interactions with the user's hand. This includes tactile perception as well as the possibility to act. This very active research field is now identified by the force-feedback thematic. For auditive perception, headphones are used for a long time now. On the other hand taste and smell have not yet been tackled.

- The third research field, which is probably the field that has been explored the least, consists in the study and control of the interactions between man and the virtual environment. Today in most applications, the model of the reality that is virtualized is very simple. The interaction peripherals are also very rudimentary. In order to act on a virtual object, it is necessary to detect the collisions between this object and the model which represents the peripheral in the virtual environment, and to deduce the tactile and visual reactions. The whole process must be realized with a frequency sufficient for interaction with man. Thus it is still very difficult to design virtual reality devices that be relevant work tools.

After this global presentation, we will stress on three major subjects on which works the computer graphics community and which are central in the development of virtual reality. These three subjects are modelling, visualization, and all that is connected to interactions and interfaces. Next we will introduce the notion of complete virtual reality platform enabling man to interact with complex worlds. These platforms have several objectives : interactive dynamic simulation and experimentation.

2 Modelling and interactive simulation

We currently dispose of the geometric models of a great number of objects. The formats of these objects are very various depending on the application field for which they have been designed. However, thanks to Internet, the VRML model is becoming a standard. In its version 2, there starts to be interaction models (manipulation, animation). However it offers only a very limited interactivity. VRML does absolutely not offer complex interaction with objects because only the geometry is defined. This means that other models are necessary, in particular in order to account for the objects' dynamic characteristics (dynamic models of motion) and for the scenes' heterogeneity (dynamic environment modelling).

2.1 The study of the dynamic models of motion

These works tackle the problems related to the modelling and the control of physical systems, but also to the different types of interaction which may be involved in a simulation (guiding, collision, contact, ...). Very much in the same way as in the field of photo-realistic image synthesis, the development of interactive physical models has become considerable. Indeed these models appear to be, at the same time, excellent processes for the production of complex kinematics, and excellent tools for the description and simulation of interaction, between different objects, as well as between the objects and human operators. Physical models can model deformations and state changes in physical objects (fracture, hardening, fluidification etc) due to the action of other simulated objects or due to the action of the human operator.

Several models are used and evaluated on the basis of the phenomenon which is to be modelled and the desired interaction with the operator : particle models, finite-elements, articulated solids in deformable environment. These models must be able to visually render the displacements, deformations and transformations, but also to determine the forces that must be returned to the operator via motors.

The necessity to evaluate the mechanical and physical relevance of the proposed models does imply a collaboration with the mechanics community. However, the interaction issue, that is the presence of sensorial action and reaction with virtual objects with time constraints raises a certain number of extremely new modelling problems. This is why the works connected to these problems are still in their infancy. Moreover, the synthesis of natural motion requires to account for other types of complex phenomena such as bio-mechanical or neurophysiological phenomena.

2.2 The study of the modelling of dynamic environments

The simulation of behaviour entities is based on models of interaction between entities, but also on the perception of the environment in which they move.

The geometrical and physical characteristics of the environment are not sufficient in order to account for the interaction of the behaviour entity with its environment. It is necessary to add some information on the organization of space and on the characterization of the objects which compose this space. (topological and semantic levels). Behavioural animation aims to tackle a new dimension : the animation of complex scenes in a multi-agent context. Current research aims to endow each of the scene's entity with a certain autonomy and to control them with high-level directives.

Simulations are composed of a set of dynamic objects whose motions depend on the various types of interactions that may take place. In order to manage the decisional complexity, it is necessary to jointly process the continuous and discrete aspects, and to co-ordinate concurrent behaviours and to manage the organizational structure. In addition to the geometric representation of the environment, it is necessary to provide each entity with a symbolic model of its environment, in order to produce complex behaviour. A scenario may also be specified in order to transmit directives which aim to coordinate the animation.

As a corollary of research questions on the interactive modelling of objects and phenomena, the realization of interactive simulations raises implementation and optimization problems, which are specific to this field. In particular one can mention the rapid calculation of interactions between different objects or between an object and the manipulation tools : collision and rapid contact, collision and prolonged contact. Generally these computations are very expensive and when implemented without the necessary studies, they are incompatible with the aim of real interaction between the virtual world and the real world. Finally, the very term of ”virtual reality” implies a possible comparison with the non-virtual reality. This is a very important problem when virtual reality is used for the learning of manual tasks requiring dexterity such as the surgical gesture. The basic problem that is raised here is the comparison between the measurements on real objects (a human organ or a real tool for example) or real gestures and the observations on simulated objects. Besides the elaboration of a new measurement process enabling to bridge the gap between the real world and the models in the virtual worlds, this issue marks out the way for a the possibility to use interactive simulation as an identification tool for the characteristics of real objects.

3 Visualization

The only method enabling the display of synthetic images in interactive conditions is the projective rendering of planar facets. A quality rendering is possible by approximating the shape of the object with a great number of facets, by using several light sources, specular effects and Gouraud shading, texture mapping (possibly with filtering in order to anti-alias the texture) and over-sampling in order to anti-alias the object boundaries. Moreover it is possible to render a few effects such as fog, transparency, and the cast shadows of certain objects. All these possibilities are offered in the OpenGL library. Thanks to the proliferation of 3D video games, the hardware capable of displaying a very great number of facets with OpenGL are very rapidly becoming widespread. They are often called ”3D acceleration cards”. However the quality of the produced images cannot be considered as realistic. It ensues from this the following research themes :

- the dynamic reduction of the number of faces ;
- quality images, the use of pre-calculations, real-time rendering of specular effects ;
- dynamic facettization of deformable models.

Visualization algorithms follow two approaches :

1. The simulation of visualization and measure instruments (e.g. simulation of echographic examinations) in order to model the observation of the real world by instruments. This can be called the modelling of the measure instrument ; For instance, in the case of the echographic examination, the ray-tracing technique can be used in order to simulate the surface echos. Next the internal organs’ texture can be rendered by 3D texture mapping.

2. The clothing of mechanical models in order to discouple the mechanical model and the geometrical model. This may appear to be difficult in the case of large deformations and transformations of the virtual object during the manipulation.

4 Interactions and interfaces

The manipulation of virtual objects is often limited to a kinematic manipulation by the generation of an evolution function drawn on the screen. The introduction of external gestural sensors in order to produce this evolution function was a start for a radical change in the interaction with virtual objects.

Now several cases can be distinguished :

- The study of the conditions of gestural interaction with a virtual world and the study of the systems which implement this interaction ;
- the study of new man-machine interfaces taking into account multi-modality and multi-sensoriality, and joining symbolic and sensorial queries ;
- the elaboration of virtual multi-user environments.

The most sophisticated and accomplished instance of gestural manipulation of virtual objects is the force feedback manipulation. With such an interaction, an animator may ”conduct” his actors and objects very much in the same way as does a sculptor or a surgeon : he can perceive their behaviour in a physical and proprioceptive manner. Thus such ”conducting” is done with full physical knowledge of the material nature and characteristics of the objects. Thus the motions can be finer and the dynamic phrasings more expressive. These tools are rapidly becoming widespread in the research centers and laboratories that develop real-time simulation platforms for the learning of multisensorial dexter or even virtuosic tasks. Typical examples are platforms dedicated to the learning of surgical gestures, the driving of building site vehicles, or artistic creation. In this case, the generation of motion must be not only real-time but also synchronous. And since the models necessary for these applications are among the most complex models, these applications are the spearhead of the technologies of the years to come, in the field of interactive dynamic simulation.

In the context of the study of new man-machine interfaces, 3D presentation metaphors enable to transform computers in communication tools in the framework of synchronous cooperative work. More precisely, we develop a new interface which exploits an animated and interactive 3D presentation which enables the user to have a global perception of the current activity. The interlocutors are represented as clones. We work on their animation and on the possibilities to to collectively interact in a virtual space (via the clones) in order to facilitate communications and exchanges. We currently work on the integration of private conversations in the virtual environment and on the representation of private and public spaces.

Finally the elaboration of multi-user virtual environments extends the field to cooperative work and raises new questions on :

1. the analysis of the task itself : what are the communication vectors between users which enable cooperation ? Are they visual vectors, sound vectors, language vectors or body vectors ?
2. the realization of remote multimodal interaction and the updating of the shared virtual worlds from this type of interaction.

5 Integration

The field of virtual reality would not exist if the different components of modelling, simulation and interaction between worlds are not integrated in a unique interactive modelling and simulation platform which, would enable to accomplish a specific task, ranging from decision support and the learning of manual acitivites to production (teleoperation or the production of sounds and images).

The notion of dynamic simulation platform comes in two types of devices :

- generic animation platforms : their construction is based, on the one hand on the notion of modeller, a generic and powerful description language enabling to model the greatest variety of effects, and on the other hand on the notion of heterogeneous platform comprising a varied set of functionalities and model types : these platforms are dedicated to audiovisual production or to the prediction of complex systems' behaviour such as transport.
- interactive simulators which integrate in a real-time configuration :
    1. a certain number of models dedicated to a task (surgical task, vehicle driving, etc);
    2. real-time visual representations ;
    3. gestural interaction devices ;
    4. an educational program for the learning of manipulation tasks ; This is a new category of simulators which is rapidly expanding.

6 Qualitative and quantitative confrontation with reality

In principle, simulators and interactive simulation platforms enable to carry out a great number of simulations in a short time. Therefore between the observation of the real phenomenon by sensors in situ, and the real laboratory mock-up or the real experimentation prototype, a new device is inserted : the numerical prototype.

Thus the development of dynamic phenomena simulators enables to envisage the numerical visual prototype as a stage in the process of physical experimentation and opens a new field : the field of virtual experimentation. This new field raises two new questions :

- the handling of a great number of virtual physical experimentations and the appearance of a new concept : experiment data bases which generalize, among others, the notion of topographic plotting in geology and the notion of atlas in surgery.

  item dynamic parameter identification, especially when the situations and phenomena to evaluate cannot be reproduced, when the objects or actors are modified during the experiment or when they cannot be directly accessed (remote objects or protected objects).

The indispensible condition is the qualitative and quantitative calibration of these numerical prototypes with measurements realized in situ. An important consequence of the development of virtual prototypes and of their use in virtual experimentation beds will be that the number of experiments that it will be possible to carry out in a given time will increase and will allow to elaborate hypotheses more rapidly, but also to make parametric estimations on the real target phenomena.

7 Conclusion

One of the birth places of virtual reality is the field of computer graphics and image synthesis. Indeed Evans & Sutherland's Sketchpad system in the mid sixties was the first to implement the innovative concept of virtual reality and the coupling between the visual display of a virtual object and the gestural action on this object. This gesture which was called the ”graphical gesture” for a long time, was the incentive basis of the evolution of interfaces and of the notion of interactivity. Since that time a great number of scientific paths have been covered and currently lead to the notion of virtual reality platform, or, in less condensed terms to ”interactive multisensorial simulator platforms”. The different stages of this evolution were :

1. the development of more and more advanced object models in terms of their interaction with light, their spatial and dynamic behaviour, but also in terms of their mutual interactions and the interaction with the human user.

2. the development of optimization processes in geometrical or physical modelling and which enable to achieve computations times which are compatible with on-line human action and decision ;

3. the evolution of computer architectures towards the realization of these simulation platforms, which are true numerical prototypes of a reality.

4. the study of the introduction of man in computation systems for decision support and production, with his dexterity and his communication and cooperative capacities.

The computer graphics laboratories whose web site addresses are given in our bibliography have often preceded this evolution, in particular in the innovations of force feedback devices in physical models but also in the modelling of complex scenes and biomechanical models. Besides the deepening of current works and the resolution of the new scientific and technical issues raised by, what can be considered as a new scientific and technical field, everything points to a shift in the centers of interest in research : the fact of disposing of numerical platforms integrating man, leads to new scientific challenges, in particular in the evaluation, the observation and the scientific knowledge of tasks which have always been empirical. This leads to new knowledge, not only on natural phenomena and objects but also on man himself.

Bibliography

The reader is invited to refer to the following web sites which contain the major part of the works and texts proposed by the French computer graphics research community on the theme of virtual reality.

1. The GDR - ALP site on http://www.lifl.fr/˜devienne/alp.html

   The *Animation, simulation, and dynamic systems* workshop
   The *Rendering and visualization* workshop
   The *Geometric modelling* workshop
   The *Discrete geometry* workshop

2. The web site of the *French Computer Graphics Association* (AFIG) on

   http://www-afig.gamsau.archi.fr/
   http://www-lil.univ-littoral.fr/ renaud/AFIG/

3. The web sites of the French research laboratories working on virtual reality

   http://www.lifl.fr/
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