INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team i3D

3D Interaction and Virtual Reality

Rhône-Alpes

THEME COG

Activity Report

2005

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1. Team

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2. Overall Objectives

2.1. Overall Objectives

The objective of the i3D research team is to contribute to making interaction in virtual worlds as simple and intuitive as in the real world.

To this end, three research axes are privileged:

- Interaction metaphors and paradigms
- Haptic feedbacks [1]
- Human factors study

Within these research axes, focus is put on:

- **Spatial approaches**: spatial input and output.
- **Immersive environments**: immersion of the user into the virtual world or immersion of the application into the user's real world.
- **Better exploitation of the user's various sensory channels** such as visual and haptic.

The research activities are based on both the **"Workbench"** and **"Video See-through HMD"**. These systems have been chosen for their complementarity and their potentialities in terms of interaction and their adequation to the main approaches mentioned above (see 3.3).

Research of the i3d group is organized around three themes:

- **The study of interaction metaphors and paradigms**. Tasks apparently as simple as displacement inside a virtual scene or catching and repositioning an object are still difficult to realize in a virtual world today. The objective of this theme is to study new paradigms and metaphors of interaction using the approaches quoted above.

[1] force or tactile feedback

- **The study of haptic feedbacks**. There are several ways to return a haptic feedback: *active haptic feedback* (requiring the use of a haptic feedback device), *pseudo-haptic feedback* [13], [12], *passive haptic feedback* (makes use of a prop), and *sensory substitution*. The objective of this theme is to study these different approaches in order to have a better characterization of haptic feedback according to the completed task.
- **Human factors study**. In addition to the two previous themes, the research group aims at carrying out experiments whenever possible. These experiments are either carried out to provide a basis for the research, such as psychophysic experiments on human perception or evaluation of existing techniques and peripherals, or evaluation of approaches developed in the group.

The i3D group wishes to emphasize the genericity of the proposed solutions. The results are developed with the objective to be integrated into various applications within different application fields. However, concerning applications, the group currently focuses on the most promising applications in term of industrial use for the Workbench:

- **Interactive exploration of complex data** such as data from scientific computation, fractal models or meshes.
- **Virtual prototyping**: virtual prototyping for industries such as automotive or aeronautic.

3. Scientific Foundations

3.1. Virtual Reality

Keywords: *Virtual reality*.

We begin by explaining the expression **virtual reality**. We are not going to propose a $n + 1^{th}$ definition. Instead, we propose to position Virtual Reality by reference to the image synthesis field which is older, better specified but which is nowadays too often confused with virtual reality.

Image synthesis gathers all the techniques leading to the production of images (fixed or animated) representing a numerical model, a scene or a virtual world. To simplify, one can say that image synthesis is a restitution of a virtual scene through a photo album (fixed image) or a film (animated images). Virtual reality makes it possible to enrich perception of the virtual scene by making it possible to the person to interact with this scene.

It is proposed to him/her to move from a passive role to an active role, to "live" the virtual experiment instead of being satisfied to view it. By taking again the preceding analogy, virtual reality can be compared with the visit of a country while going on the spot as opposed to the photo report or documentary film. However, contrary to the real case, where the photo report or the documentary film are quite distinct from living the experiment, in the virtual world there is a continuum between the graphic applications and virtual reality. It is mainly the position of this border which is prone to discussions.

A first brief reply is by consulting the various definitions of virtual reality. The concept most usually associated to the expression virtual reality is that of immersion. One speaks about virtual reality when the interaction is sufficiently realistic to get a feeling of immersion, communion, fusion between the person and the application. This concept of immersion remains quite subjective. Should we specify it ? Or isn't it rather prone to a slow evolution accompanying virtual reality research progress ? We choose this second solution and we will be satisfied to enumerate, in no particular order, some factors improving immersion such as stereoscopic visualization, visualization on large screens, head tracking, spatial interaction, superposition of virtual and real spaces, two-handed interaction, multi-sensory interaction, real time simulation. To summarize, we will say that the more numerous are these factors, the stronger is the feeling of immersion and the more justified is the **virtual reality** expression.

3.2. 3D Interaction

Keywords: *3D interaction*.

The importance of 3D interaction in virtual reality (see 3.1 for a description of virtual reality) coupled with the immaturity of the field, makes 3D interaction one of the most important **open problems** of virtual reality. In spite of its major importance, the human-application[2] interface is currently far from providing the same level of satisfaction as other computer graphics sub-domains [7].

In computer graphics, the race toward realism engaged over the last twenty years has led to impressive results where the virtual world is sometimes not easily discernible from the real one. Who did not hesitate while seeing certain images of complex scenes, with most realistic illumination effects ? Most of us have one day doubted while seeing an image or a sequence of images which he/she did not know how to classify: real or virtual ? At the inverse, this feeling of doubt is unlikely as soon as there is interaction. Conversely, it is often a feeling of faintness or awkwardness which dominates. Indeed, the processes of interaction with the virtual worlds are still often very poor. A large majority

of the systems is developed on 2D workstations. Even if using 3D configurations, the user interface is frequently inspired by 2D interfaces. The WIMP concept (Windows, Icons, Menu, and Pointing) is often used. As an example, operations as simple as navigation inside virtual 3D scenes, or the handling (displacement) of entities in a virtual 3D scene, are still open research problems. The relative poverty of the interaction with virtual worlds is even more poorly perceived because the real world, in which we live and which we are used to interacting with, is a very rich world. Any machine, with some complexity, (car, bicycle, television, telephone, musical instrument...) has its own mode of interaction adapted to the task to achieve.

On the other hand, some configurations and some recent approaches are very promising. These approaches are more specifically 3 dimensional or are proposing a better use of the various sensory channels.

In short, the current situation is as follows. One can identify:

- **a well identified need:** increasingly demanding users and a growing number of applications.
- **an unsatisfactory situation:** poor interfaces, primarily 2D, with a strong under-utilization of the human-application bandwidth.
- **strong potentialities:** very promising configurations and approaches to study or to conceive.

3.3. Virtual/Augmented/Mixed Reality Configurations, Workbench and See-Through HMD

Keywords: *CAVE*, *HMD*, *flat or cylindrical wall*, *immersion*, *see-through HMD*, *virtual/augmented/mixed reality*, *workbench*.

Until 2004, much of the research work and especially of the developments of the i3D group were dictated by the **Workbench** Virtual Reality configuration installed at the end of 1999. This year, the i3D group has acquired a complementary augmented reality configuration, the **Video See-Through HMD** This paragraph briefly describes these configurations and positions them within the set of other configurations of the same class.

Virtual reality has been identified for a while with head mounted displays. HMD (Head Mounted Display) isolate the user from his/her real environment and require the use of avatars.
Currently, projection-based virtual environments often take the place of HMDs. More recent, less invasive and offering better characteristics, these configurations take several forms. In this class, one finds the CAVE^{TM}, the flat or cylindrical walls and the Workbenchs. See [6] for a more detailed introduction of this class of configurations.
The CAVE^{TM} [3] [9] is probably the best known of these configurations. It is also the most expensive and the most complex to install and maintain. It appears as a room of approximatively 3 meters on each side with the virtual world retro-projected on 4 (three walls and the ground) to 6 (for some recent configurations) of the faces

[2]one will speak about human-application interface instead of human-machine interface, as one would tell in 2D, because the objective is to make the machine transparent and to give the impression to the user to interact directly with the application

[3]CAVE is a trademark of the university of Illinois

of the room. This configuration provides a good feeling of immersion thanks to the screens which "surround" the person, to stereoscopic visualization and to head tracking. This configuration is very well adapted to navigation inside large spaces (for example, a visit to a virtual scene such as architecture, an amusement park, or a driving simulation).

The wall is a large flat or cylindrical screen on which the virtual world is visualized generally with the assistance of 3 video projectors. The fact that people sit in front of the screen, without head tracking, makes this configuration more passive. It is a nice configuration for presenting projects to a group of approximately 20 persons, like projects reviews for example.

The Workbench (or Responsive Workbench^{TM}[4] [8], by reference to the first developed system [11], [10]) is the "lightest" configuration (see Figures 1). Often less known than the CAVE^{TM}, this configuration is, from many points of view, far from being less attractive. With a horizontal screen (plus, possibly, a second vertical one providing a wider field of view) which represents a tabletop, the Workbench makes it possible to visualize a virtual scene within the range of hands, in front of the observer. A video projector, after reflexion on one or more mirrors, retro-projects the image on the screen representing the surface of the table. 3D effects are provided thanks to stereoscopic visualization with shutter glasses. As with the CAVE^{TM}, head-tracking is provided.

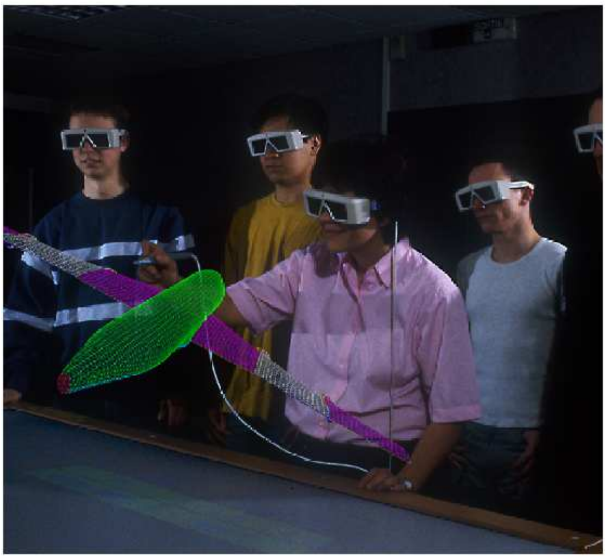

Figure 1. The INRIA Workbench (with special effects)

[4]"Responsive Workbench" is a trademark of GMD

The form of the Workbench predestines it with manual manipulations on a table. This configuration is also characterized by strong potential for interaction. Its head tracking feature allows a superposition of the visualization and the manipulation spaces (virtual and real spaces) and opens the way to simpler and more intuitive interactions. In addition, whereas a maximum immersion of the person into the virtual world was preached a long time, in particular with the HMDs, this configuration introduces the opposite approach, which is more comfortable: the immersion of the application into the user's (real) environment. This configuration is thus integrated into the users real world, providing him with very pleasant feelings, close to what he/she is used to when manipulating objects on a table in the real world. It is thus quite naturally that the applications of this configuration are those where the user observes and handles data or numerical mock-ups which rest in front of him, within the range of hands.

Projection-based configurations only allow a limited mixing of the real and the virtual worlds. The real world has to be in front of the virtual one. Optical see-through HMD overcome this limitation but introduces the inverse one, the virtual world has to be in front of the real one. The only VR/VA configuration allowing for a free mixing of the real and the virtual worlds is the video see-through HMD. The video see-through HMD is an HMD configuration with two small cameras positioned, one in front of each eye. The cameras are capturing the real world which is mixed together with the virtual one within the computer and then, the mixed world is displayed onto the HMD. Even if presently, the characteristics of see-through HMD in term of resolution, field of view etc... are too weak for some industrial applications, acquiring expertise on these configurations is of a great interest because they potentially allow unique applications.

4. Application Domains

4.1. Application Domains

In 3D interaction, applications are of a great interest. In addition to their significant role regarding industrial transfer, they are essential for our research. They make it possible to validate our work, to make the Workbench more known, and to cause new interaction problems therefore new research problems.
We are concentrating on applications for which the use of the Workbench (more recently, we also focus on applications for the see-through HMD) seems particularly promising to us. These applications are by order of importance:

- the visualization and analysis of complex data (geological data, fractal models, complex meshes, graphs...),
- virtual prototyping (assembling/disassembling...).

On the other hand, we do not set any constraint on the domain to which we apply our results.

5. Software

5.1. Panorama

In 2005, the migration from the SGI Onyx to a PC cluster has continued. On the software side, our software development effort was mainly dedicated to the continuation of the development of the Miniosg platform.

5.2. Miniosg

Participants: Mathias Lorente, Olivier Chenu, Michaël Ortega, Sabine Coquillart.

Due to the migration from SGI Onyx to PC clusters as well as new configurations like see-through head mounted displays, the development of a new software platform named Miniosg has started in 2004.

Three main guidelines have been followed:

- The development of the core of the platform
  According to the work done last year[5], OpenSG has been chosen as basis of our new virtual reality platform: miniosg. The main advantage of OpenSG resides in that visual rendering can be done over a cluster of PCs quite easily. So, our efforts have not been wasted in the synchronization of the scenegraph in a cluster environment.
  In order to simplify the usage of standard components, lights, cameras, geometries and other have been encapsulated in our own objects. These one are managed in OpenSG manner, i.e. using enhanced smart pointers. This way, a simple configuration system has been developed to set object properties.
  Other configuration parameters are also available through a configuration file. These allow to adjust client and server options and increase the flexibility of the virtual reality platform. Moreover, some work has been done to allow to launch the platform on multiple PCs in one command line.
- Connectivity with other library/peripherals
  To make the plateform available for the see-through HMDs, interactions between real and simulated worlds are essential.
  Tracking systems have been integrated to the platform. Currently, all tracking devices managed by the VRPN library can be used with miniosg. Here again, just some few parameters have to be defined in a configuration file to exploit trackers in simulated world.
  Some other developments have also been done. Specific devices (like the Spidar) can be used with miniosg not only as tracking system but also as force feedback system.
- OpenSG specific improvements
  Whereas specific developments have been done to achieve miniosg, other generic developments have also been done to improve OpenSG capabilities.
  For example, in order to increase the resolution of shadows, shadow volumes have been added to OpenSG. Some new constraints have been put on geometries but rendered shadows are more realistic.
- Conclusion
  Miniosg is currently used in different projects. It works not only on the Stringed Haptic Workbench but also on workstations and with the new video see-through HMD.
  This platform is configurable and evolutive enough to allow future researches. Moreover, miniosg does not depend on specific hardware and will work on future clusters of PCs.

[5]cf. Activity Report 2004: http://www.inria.fr/rapportsactivite/RA2004/i3d/i3d_tf.html

6. New Results

6.1. Panorama

This year has been marked by a continuation of the researches on the Stringed Haptic Workbench, and the first industrial application on this configuration. It has also been marked by the first studies on the Video See-Through HMDs.

6.2. Prop-Based Haptic Interaction with Co-Location and Immersion

Participants: Michaël Ortega, Sabine Coquillart.

In 2003, i3D introduced the Stringed Haptic Workbench [20]. This configuration developed in the framework of the PERF-RV RNTL project has also been used for the Geobench RNTL project, for scientific visualization. This year, the i3D efforts have been concentrated on the integration of tactile/grasp feedback on the Stringed Haptic Workbench. The Stringed Haptic Workbench is a unique configuration integrating together high quality immersive visualization, stereo, head-tracking, co-location and direct 6dof force feedback with a large manipulation space. The challenge is now to integrate realistic grasp/tactile feedback. Tactile feedback is of a great importance for many applications including assembling, training,... However, tactile devices are far from providing realistic feedback. In collaboration with PSA Peugeot-Citroën, i3d proposed to integrate props (tangible interfaces) into the Stringed Haptic Workbench. The integration of props in the Stringed Haptic Wokbench follows three major steps:

- Attaching the prop to the force feedback device. After some informal tests, the strings of the haptic device are attached on a plexiglas cross fixed on the prop.
- Introduction of mixed-prop concept. In order to improve the integration of the prop, it is split into a real and a physical part. Among other, it allows to reduce the occlusion problems between the prop and the virtual model.
- Use of real-time shadows. The addition of shadows greatly improves the realism of the interaction. Collisions are easier to anticipate, and the positions of the objects are easier to evaluate.

For more details, see [2].

6.3. Putty Application for the Automotive Industry

Participants: Michaël Ortega, Sabine Coquillart.

Several applications of the Prop-based Stringed Haptic Workbench have been considered. The first one developed is an automotive application for putty application. In the conception stage, car designers must ensure that an operator will be able to apply putty on metallic junctions of car body parts. Today, the only solution is to make a physical mockup. This method is expensive and slow. In collaboration with PSA Peugeot-Citroën, i3D proposed a solution making use of the Prop-based Stringed Haptic Workbench. The prop is the putty gun. It is attached to the Spidar stringed through a Plexiglas cross (see Figure 2 and 3). Informal evaluations highlighted the benefits of the proposed approach. The application is approved by PSA Peugeot Citroën representatives, and currently transferred at PSA Peugeot Citroën.

This work has been presented in [1] and [3].

6.4. Six Degree-of-Freedom Haptics

Participants: Michaël Ortega, Stéphane Redon, Sabine Coquillart.

i3D has developed a new algorithm for six degree-of-freedom (dof) haptic interaction with rigid bodies (see Figure 4). The algorithm combines continuous collision detection and constraint-based quasi-statics to generalize the well-known god-object method for haptic exploration of a rigid body with a three degree-of-freedom haptic device. The new algorithm preserves the desirable properties of the original god-object method:

- the god-object never penetrates the environment obstacles, which is known to improve the perceived stiffness of the haptic feedback [19];

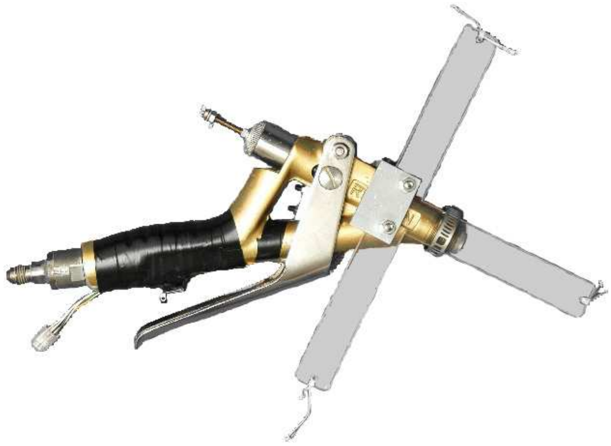

Figure 2. The putty gun

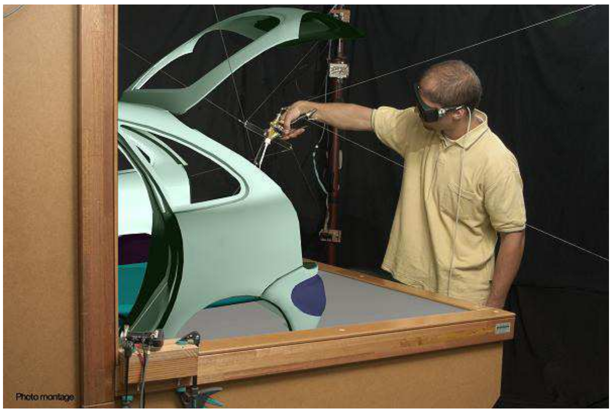

Figure 3. Putty Application on a Citroën Picasso car

- the constraint-based forces applied to the user are always orthogonal to the constraints, and do not suffer from the artifacts typically encountered in previous methods (*e.g.* forces felt at a distance, sticking, artificial friction). The new method contributes to enhance the realism of the haptic feedback, as it has been shown that an incorrect force direction perturbs the perceived orientation of the haptic surface [18].

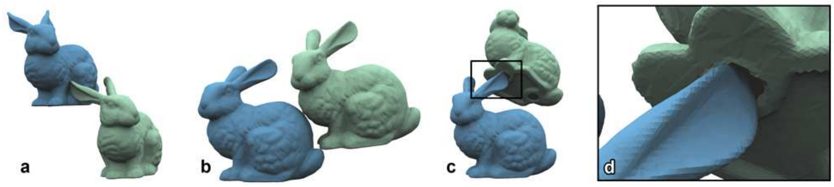

Figure 4. Haptic interaction with Stanford Bunnies. The new six degree-of-freedom haptics approach developed by i3D provides a user with high-quality haptic display of contacting rigid bodies. The user manipulates the green bunny. ***a:*** *the ear of the green bunny slides in a ridge of the blue bunny.* ***b:*** *continuous collision detection and constraint-based quasi-statics allows the manipulated object to precisely contact and slide on the obstacles.* ***c-d:*** *our method provides the user with the ability to precisely feel the contact between pairs of triangles, resulting in highly detailed haptic display of contacting rigid bodies.*

The new approach has been implemented on a 3.2 GHz Xeon biprocessor and successfully tested on complex benchmarks. The separation into asynchronous processes allows us to satisfy the different update rates required by the haptic and the visual displays. The constraint-based force applied to the user, which handles any number of simultaneous contact points, is typically computed within a few microseconds, while the update of the configuration of the rigid god-object is performed within a few milliseconds for rigid bodies containing up to tens of thousands of triangles. For more details see [14].

6.5. Stringed Haptic See-Through HMD

Participants: Olivier Chenu, Sabine Coquillart, Michaël Ortega.

Projection-based Virtual Reality configurations are very popular nowadays because they are comfortable, non intrusive and when head-tracking is available, they provide high immersion. However, with Projection-based VR configurations, mixing the real and the virtual world is not very flexible. The real has to stay in front of the virtual world. To our knowledge, the only configurations allowing any combination of virtual and real with co-location, stereo,... are video see-through HMDs. Potentially, video see-through HMDs allow any combination of virtual and real with correct occlusions. A correct mixing of the real and the virtual world is of importance for many applications. It is one of the reasons why the i3D group is starting to work with video see-through HMDs. Like for the Workbench, our objective is to develop a complete configuration integrating as many as possible sensory feedbacks and high performance algorithms. Our first study concerned the integration of force feedback. Similarly to the Stringed Haptic Workbench, the Spidar has been chosen for its lightness and low intrusivity. Based on the Haptic Gear work , a first prototype of a Stringed Haptic see-through HMD has been developed. This solution provides a large haptic space and allows a limited mobility (within a room for instance). See [4] for more details.

6.6. Passive Dissipative String-based Haptic Device: a Preliminary Study

Participants: Yuanhang Wang, Sabine Coquillart.

In the continuation of 2004 work on Self-constrained Haptic Device [15] (see also i3D 2004 activity report), a preliminary study about constructing an energetically passive and dissipative string based haptic device has been conducted. The idea is to utilize passive devices such as clutch or brake to replace the motor as actuator for the current Spidar system. A special class of brake is investigated and proposed as candidate to replace the motor. Such a system constructed based on the brake benefits directly from the inherent passivity of brake, stability is thus guaranteed. An emulation of the brake was done by modifying the hardware driver for the current Spidar system, in hope to provide a general feeling and a rough subjective comparison with the active system. Control of a passive Spidar would be a challenging task, due to the fact that the passive actuator is only able to apply forces in direction against its movement. Potential problems concerning control of passive Spidar and a literature review of known control algorithm are presented in [5].

6.7. Articulated-body Dynamics

Participant: Stéphane Redon.

Stephane Redon continues to investigate new algorithms for articulated-body quasi-statics and dynamics [17], [16]. A discrete collision detection module has been added to the adaptive articulated-body dynamics library [16]. The algorithm currently combines hierarchies of axis-aligned and oriented bounding boxes to cull away groups of triangles that are far from each other, before performing discrete triangle/triangle intersection tests.

7. Contracts and Grants with Industry

7.1. PSA Peugeot Citroën

Participants: Michaël Ortega, Sabine Coquillart, Stephane Redon.

PSA Peugeot Citroën and i3D are collaborating within a CIFRE contract.

7.2. INRIA

- **Siames Project**: Several collaborations are running with the Siames Project. As they all involve other partners, they are presented in the section on "National" or "International" actions.
- **Apache Project**: i3D is collaborating with the Apache project within the framework of the Geobench project. As this project involves other partners, it is presented in the section on "National" actions.

7.3. Regional

- i3D is working on Pseudo-haptic feedback with LPNC - Laboratoire de Psychologie et Neurocognition of Grenoble - within a Robea project called "Ecovia" (see 7.4).
- i3D is working with the ID lab. within an RNTL project called Geobench (see 7.4).
- PEGASUS project on Haptics evaluation in collaboration with TIMC and LPNC - Laboratoire de Psychologie et Neurocognition of Grenoble

7.4. National

- **Geobench** i3D, Apache, Mercury Inc., BRGM, CEA-DAM and the University of Orleans collaborate on the RNTL project "Geobench". Concerning i3D, the purpose of this project is to integrate the Spidar system into Amira with a PC cluster and to propose new interaction techniques making use of the Stringed Haptic Workbench configuration.
- **Ecovia** i3D, Siames, College de France and LPNC-Grenoble collaborate on the Robea project "Ecovia". The purpose of this project is to pursue previous researches on pseudo haptic feedback.

7.5. International

- Collaboration with Sato-Koike research group from the Tokyo Institute of Technology. Collaborations on the Spidar system.
- Within the Sixth European Framework Programme, i3D together with Siames in the core group of the "Intuition" Virtual Reality Network of Excellence. They are the INRIA representatives.
- i3D is starting a collaboration with EWHA-Korea on continuous collision detection and haptics.

8. Dissemination

8.1. Leadership within Scientific Community

- Sabine Coquillart is a member of the EUROGRAPHICS Executive Committee and of the EUROGRAPHICS Working Group and Workshop board.
- Sabine Coquillart is a member of the Editorial Board of the "Computer Graphics Forum" journal.
- Sabine Coquillart is a member of the Editorial Board of the journal of "Virtual Reality and Broadcasting".
- Sabine Coquillart is a member of the NWO (Dutch National Science Foundation) VIEW committee on Visualization and Virtual Reality.
- Sabine Coquillart is a member of the evaluation committee of the FP6- HAPTEX project.
- Sabine Coquillart is co-founder of the French Association on Virtual Reality and first chair.

8.2. Teaching

- **DEA I3 University Paris-Sud-Orsay**, Sabine Coquillart is teaching in the "Virtual Environments and Advanced Interfaces" module.
- **DEA VRMSC, University Evry and Versailles Saint-Quentin-en-Yvelines**, Sabine Coquillart is teaching in the "Virtual Reality" module.

8.3. Conference and Workshop Committees, Invited Conferences

- Sabine Coquillart has been a member of the International Program Committee of the following conferences: CGI05, GRAPHITE05, Haptex05, ICAT05, ISVC05, VRIC05, SCCG05, SMI05, WSCG05, IPT-EGVE05, Eurographics05, IEEE Virtual Reality05.
- Stéphane Redon has been a member of the International Program Committee of Pacific Graphics05.

See the list of references for a list of conferences where i3D presented papers.

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