INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team i3D

3D Interaction

Rhône-Alpes

THEME 3A

Table of contents

1. Team

Head of project-team
Sabine Coquillart [Research Director - INRIA]

Administrative assistant
Anne Pasteur [part time]

Technical staff
Olivier Chenu [Project technical staff - since October 1st, 2003]
Mathias Lorente [Junior technical staff - since September 1st, 2003]
Tangui Morvan [Project technical staff - until October 15th, 2003]
Nicolas Tarrin [Project technical staff]
Thomas Vincent [Project technical staff - since June 1st 2003]

Ph. D. student
Jean-Edouard Coste [CEA-DAM scholarship]
Jérôme Grosjean [Teaching assistant, Ecole Centrale Lyon - until October 30th 2003]
Alexis Paljic [INRIA/Ile de France scholarship]

Student intern
Olivier Chenu [DESS "Complementary Competences in Computer Sciences" - from May to September 2003]

2. Overall Objectives

The objective of the i3D research team is to contribute to make 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

The objective of the i3D research team is to contribute to make interaction in virtual worlds as simple and intuitive as in the real world. We focus 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** : visual, haptic, sound,...

The research activities are based on the **"Workbench"**, a system that was chosen for its potentialities in terms of interaction and its adequation to the main approaches mentionned 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.

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[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* [17][16], *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 it is possible. These experiments are either carried out to provide a basis for the research, such as psychophysics experiments on human perception or evaluation of existing techniques and peripherals, or to evaluate approaches that are developed in the group.

The i3D group wishes to emphasize the genericity of the proposed solutions. The results are developped 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**: data from scientific computation, fractal models, meshes,...
- **Virtual prototyping**: assembling/disassembling for the automotive and aeronautic industry and others.

3. Scientific Foundations

3.1. Virtual Reality

Key words: *Virtual reality*.

We begin by defining 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 nowaday 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 image, 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 criteria improving immersion: 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 criteria, the stronger is the feeling of immersion and the more justified is the **virtual reality** expression.

3.2. 3D Interaction

Key words: *3D interaction*, *HCI*.

The importance of 3D interaction in virtual reality (see 3.1 for a definition 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 [9].

In computer graphics, the race toward realism engaged for more than 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 ? On the other hand, this feeling of doubt is much 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 badly 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.
- **a 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 Reality Configurations and Workbench

Key words: *CAVE*, *flat or cylindrical wall*, *workbench*, *HMD*, *immersion*.

Much of the research work and especially of the developments of the i3D group are dictated by the **Workbench** installed at the end of 1999. This paragraph briefly describes this configuration and positions it within the set of other configurations of the same class.

Virtual reality has been identified for a while with head mounted displays. In this class, one finds HMD (Head Mounted Display) which isolate the user from his/her real environment and require the use of avatars. One finds also see-through HMD which have the advantage of allowing to see the real world by transparency but whose characteristics in term of resolution, field of view... are often too weak for the majority of the industrial applications.

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 [8] for a more detailed introduction of this class of configurations.

The CAVE^{TM}[3] [11] is probably the best known of these configurations. It is also the most expensive one and the most complex to install and maintain. It appears as a room of approximatively 3 meters on each side

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[2] one will speak about human-application interface instead of human-machine interface, as one would tell in 2D, because the objective is now 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

with the virtual world retro-projected on 4 (three walls and the ground) to 6 (for some recent configurations) of the faces 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 (visit of virtual scenes: architecture, amusement park, driving simulation,...).

The wall is a large flat or cylindrical screen on which the virtual world is visualized with generally 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 approximatively 20 persons, like projects reviews for example.

The Workbench (or Responsive Workbench^{TM}[4] [10], by reference to the first developed system [15][14]) is the "lightest" configuration (see Figures 1, 2, 3). 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 for the CAVE^{TM}, head-tracking is provided.

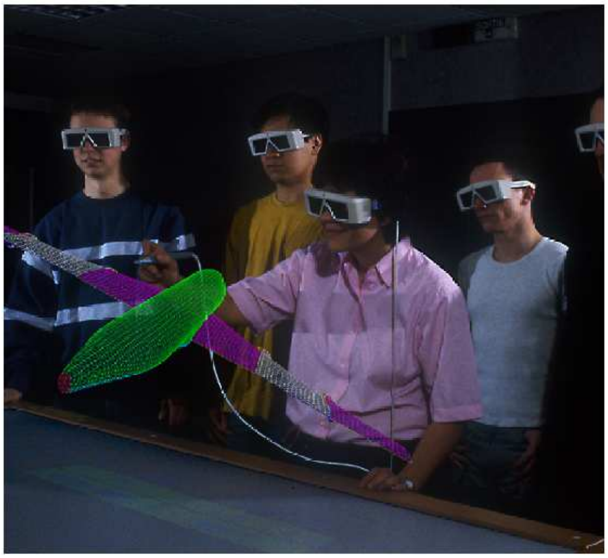

Figure 1. The INRIA Workbench (with special FX)

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[4] "Reponsive Workbench" is a tademark of GMD

In addition to its form which predestines it with manual manipulations on a table, this configuration is characterized by strong potentialities in term of interactivity. 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 mockups which rest in front of him, within the range of hands.

4. 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 privileging applications for which the use of the Workbench 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...) and 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 the continuity of previous years, in 2003, our software development effort continued mainly in the following directions:

- The software platform for force feedback on the workbench has been reconsidered and improved.
- The developpment of Minifly (see previous years report) has been continued with an integration with the software platform for force feedback.
- A few demos demonstrating the MiniFly platform with force feedback on the workbench have been developped

In addition, two new development activities have started this year, both part of a RNTL project.

- In the frame of the Geobench RNTL project, the force feedback platform has been integrated with Amira, a scientific visualization software.
- In the frame of the Inventor Immersif RNTL project, several interaction techniques have been integrated to Open Inventor, a commercialized 3D graphics API.

5.2. Force Feedback Platform

Participants: Nicolas Tarrin, Thomas Vincent, Sabine Coquillart.

In parallel with the research work on the "Stringed Haptic Workbench" (see 6.2) an effort has been undertaken to improve the software part of this project. The first objective was to increase the modularity of the platform in order to get independant modules which can be freely connected or integrated into other platforms.

The proposed solution is composed of three modules: the *driver* which contains the driver of the haptic device, the *simulation* module which provides collision detection and constraint management (the home made

CONTACT Toolkit library [18] has been integrated), and the *virtual coupling* module. Various visualization modules can be connected to the platform (see 5.3 and 5.5) using a communication layer.

Each module can be used on its own or freely connected to others. Other modules can also be integrated into the platform.

5.3. Minifly and the Force Feedback Platform

Participants: Nicolas Tarrin, Sabine Coquillart.

The design and the developments done on the force feedback platform have first been validated with MiniFly, the visualization platform previously developed by the i3D research group. Minifly has been connected to the force feedback platform using a communication layer. A specific module has been added to Minifly to allow data exchange data with the platform.

This module update the "visual scene" according to the "haptic scene". Objects loaded in the simulation module are sent to Minifly and displayed in real time on the workbench. The position of the SPIDAR, the force feedback system (see 6.2), is also displayed and updated in real time on the workbench. We also experimented sending the trackers position from Minifly to the force feedback platform to test different interactions (see 5.4).

5.4. Force Feedback Platform Demonstrators

Participants: Nicolas Tarrin, Tangui Morvan, Sabine Coquillart.

In the frame of the Perf-RV project, three demonstrators have been developed to make non formal evaluation of the Stringed Haptic Workbench and to test the feasibility of particular tasks. These demonstrators all use the combination of the force feedback platform and Minifly.

- Cube
  The "Cube" demonstration consists in allowing a user to touch a cube with the finger. The real and the virtual spaces are superposed, thus allowing a direct manipulation. The hardware interface is a finger cap attached to the SPIDAR strings where the user puts the tip of one of his fingers.
- Driving wheel
  A second demonstrator has been made in collaboration with Renault. It uses a driving wheel model that allows us to test the software platform with a more complex dataset (10000 polygons). This demonstrator has shown that the speed of each module was sufficient to provide a good quality of force feedback. See Figure 2.

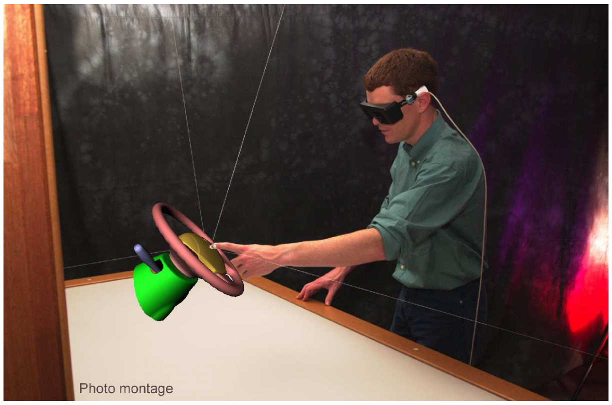

Figure 2. Driving wheel demonstrator, with special FX, ©data copyright Renault

Like for the cube example, a direct manipulation, where the user is touching the surface to inspect it has been implemented. More formal evaluations have to be made, but this demonstration shows that it should be possible to haptically feel small details of a surface.

- Window Winder Motor
  The "Window Winder Motor" demonstrator is making use of Renault data. It is more precisely designed to test a precise task in the automotive industry. This task is the assembling/diassembling of a window winder motor in a car door. The motor is manipulated using a tracked stylus and has to be mounted into the car door through openings in that door. Information given by the stylus is used to provide 6 degree of freedom (dof) input, but the force feedback is still 3 dof. That is to say that the rotations of the motor depend both on the rotation given by the user and on the collision of the motor with the door parts. See Figure 3.

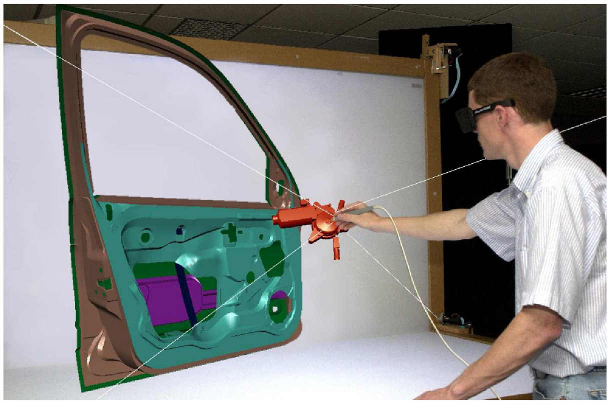

Figure 3. Window winder motor demonstrator ©data copyright Renault

This demonstrator shows that it is sometimes (not in all cases) more difficult to manipulate an object using 6dof input and 3 dof output than with only 3dof in / 3dof out. More work has to be done to evaluate in which cases a 6dof in / 3dof out manipulation is more appropriate than a 3dof in / 3dof out manipulation. It is also in our future work to test a 6dof in / 6dof out solution.

5.5. Integration of Force Feedback into Amira

Participants: Nicolas Tarrin, Thomas Vincent, Sabine Coquillart.

In the frame of the Geobench project, the Stringed Haptic Workbench configuration is used in the domain of scientific visualization. Scientific visualization requires very specific visualization tools, to be able to display and to analyze complex datasets. Such software already exist. Amira, TGS's scientific visualization software, is one of those. Our collaboration with TGS allowed us to develop a module inside Amira to connect Amira to the force feedback platform. This module lies on the communication layer we developed.

Two interaction tools have been implemented.

- The first one allows to "feel" the visualized data. Forces are computed from the SPIDAR position and from the dataset that is visualized using some parameters like density. Several ways of computing and returning these forces are currently under study.
- The second interaction allows to touch isosurfaces. In this case, the collision detection and constraint management modules of the force feedback platform are used to compute the returned force.

5.6. Industrial Transfert of Research Results on interaction tools

Participants: Tangui Morvan, Olivier Chenu, Sabine Coquillart.

Within the frame of the Inventor Immersif RNTL project, three interaction paradigms developed recently by the i3D group have been ported and integrated in OpenInventor, a commonly used 3D graphics API.

The ported interaction tools are: the Metric Cursor [19][20], the Command and Control Cube [12], and QuickWriteVR [13].

In addition, a demonstration application making use of these tools has been developped. It is a scientific visualization application of meterological data.

6. New Results

6.1. Panorama

This year, i3D research results concern mainly haptic feedbacks. Both active haptic feedback and pseudo-haptic feedback have been investigated.

6.2. The Stringed Haptic Workbench

Participants: Nicolas Tarrin, Sabine Coquillart.

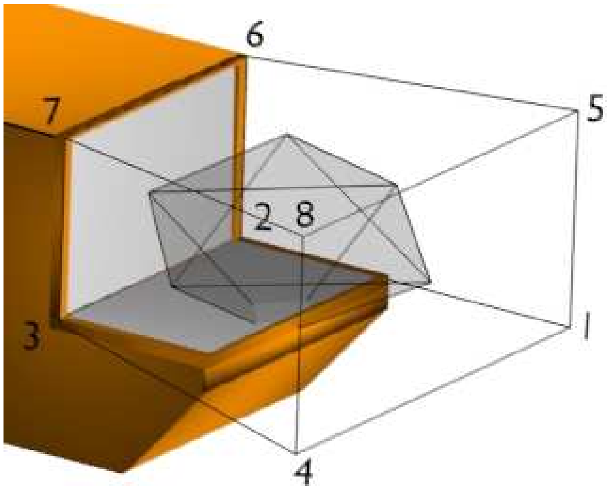

Figure 4. Motors positioning

This work is the prolongation of last year research on providing force feedback on a two screen workbench using a SPIDAR (a string based force feedback device developed by the Tokyo Institute of Technology). Our previous work showed that the SPIDAR strings are not perturbing the stereoscopic visualization. However, the SPIDAR configuration had to be geometrically adapted to the workbench configuration. One of our main concerns was to provide force feedback within a sufficiently large space. More precisely, we wanted to fill as fully as possible the workbench manipulation space - whose size is $1m^3$ - with the SPIDAR manipulation space (the space where the SPIDAR returns forces in every direction), also called SPIDAR space. We have chosen an 8-motor SPIDAR configuration that potentially provides force feedback on 3 dof on 2 different points or 6 dof on one handle. Only the 3 dof on force feedback on one point configuration has been tested for the moment. Usually, the SPIDAR is presented on a cubic frame, but the SPIDAR space is tunable by moving the motors on different a different frame shape. Fitting the SPIDAR space to the workbench manipulation space has been done by placing the motors as shown on Figure 4.

The resulting SPIDAR space size is approximately $1m^3$, which is far larger than the 0.18 m^3 of the PhanTOM^{TM} 3.0[5] (the most commonly used force feedback device) space. The size of the workbench manipulation space not covered by this SPIDAR space is 0.37 m^3. Figure 5 shows the hardware installation, with the strings highlighted. Tests confirm that strings are extremely discreet and are quickly forgotten while manipulating.

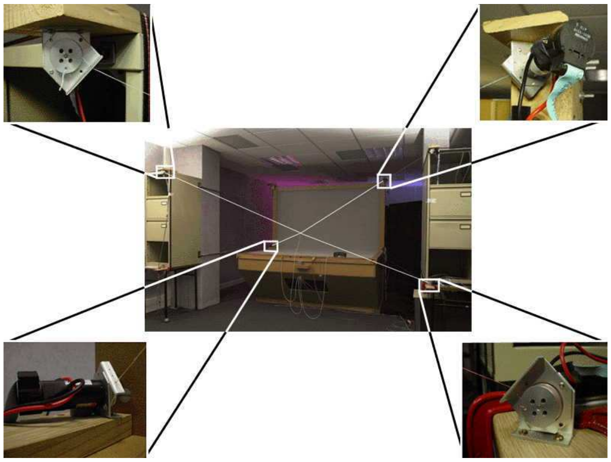

Figure 5. Installation overview

Another advantage of this configuration compared to other haptic workbench solutions is that the hardware design of this system is safe. Mobile parts of the SPIDAR are so light (a few grams) that even in the worst situations, they cannot damage the screens. User safety is also improved for the same reason. In addition, the maximum returned force is limited by the string's resistance. If ever too strong a force is applied, the strings just snap, and the remaining parts wind around their motor pulleys. Replacing broken strings is a fast and cheap operation.

The Stringed Haptic Workbench is a flexible configuration that potentially allows the use of different interaction techniques. Three demonstrators using the Stringed Haptic Workbench have been developped (see 5.4). This work has been published and presented in [5] and [6].

6.3. Pseudo-Haptic Torque Feedback

Participants: Alexis Paljic, Sabine Coquillart.

In previous work we investigated whether pseudo-haptic feedback is suitable for simulating torque feedback. An experiment was conducted to evaluate this feedback and involved compliance discrimination between real torsion springs and pseudo-haptic simulated torsion springs.

Results show that torque haptic feedback was successfully simulated, with a difference in performance between device types.

The concept of pseudo haptic feedback requires that the passive device resists to user-applied forces, thus it must have mechanical properties that allows this behavior. This can be implemented either by using an isometric device (with infinite stiffness and no displacement) or by using an elastic device (with a finite internal stiffness and displacement during manipulation). The nature of the device is an important issue which has been addressed this year.

The experiment conducted this year consists in using an elastic device which enables us to compare isometric and elastic devices with a between subjects repeated-measures design. Isometric (former experiment)

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[5] PhanTOM is a trademark of Sensable Technologies Inc.

and elastic (new experiment) devices have been built. They use a force sensor in order to allow a measurement of user applied forces.

Experimental results show that users are able to discriminate pseudo-haptic simulated torsion springs and real springs. Results for perception resolution (JND) show better performance when using an elastic input device (6.75%) compared to an isometric one (21.2%). The elastic device yields a better resolution but a higher subjective distortion of perception compared to the isometric device.

The maximum applied torque seems not to depend on the simulated stiffness; moreover, it seems almost constant over the different simulated springs. This result shows that the successful discrimination between real and pseudo-haptic simulated springs does not directly rely on actual forces, nor on actual mechanical work, but relies more on a haptic illusion.

An ANOVA (ANalysis Of VAriance) on answer time with repeated measures has been carried out. There is a significant two-way interaction between device type and presented virtual stiffness. Answer time seems not to be affected by variations of virtual stiffness with the isometric device, but it is affected with the elastic device: the smaller the difference between real and virtual springs, the longer the answer time. On the basis of applied torque measurements, we propose the hypothesis that a cue called "perceived mechanical work" is used during the discrimination. As for answer time, it seems that the difficulty of the discrimination increases when the difference between the real and the virtual springs decreases for the elastic device. This phenomenon resembles the real situation, whereas difficulty seems constant over the comparisons for the isometric device. This could be characteristic of a more realistic feedback for the elastic device.

This work has been done in collaboration with Jean-Marie Burkhardt (Paris V University and INRIA-Eiffel group) and published in [4].

7. Contracts and Grants with Industry

7.1. EADS - Renault - PSA Peugeot Citroën

Participants: Stéphane Redon, Abderrahmane Kheddar, Sabine Coquillart.

The CONTACT Toolkit libraries have been furnished to EADS, Renault and PSA Peugeot Citroën for tests and evaluations.

7.2. INRIA

- **Eiffel Project** : Eiffel skill on human factors are of a great interest for the i3D research group. Several collaborations leading to publications have been conducted together with Jean-Marie Burkhardt.
- **Siames Project** : Several collaborations are running with the Siames Project. As they all involve other partners, they are presented in the section on "National" actions.

7.3. Régional

- i3D is working on Pseudo-haptic feedback with LPNC - Laboratoire de Psychologie et Neurocognition - 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).

7.4. National

- **VTHD++** As a follow up of the RNRT project VTHD, i3D and Siames take part of the VTHD++ project. The purpose of this project is to develop collaborative solutions upon Siames' OpenMask platform.
- **Perf-RV** Siames and i3D are also working together with other partners on an RNTL platform project called Perf-RV. i3D is part of two actions: one on virtual prototyping together with EADS, Dassault and CEA, and the other one on collaborative interaction, together with Siames, Limsi, LaBRI and Renault. More than fifteen partners are involved.
- **Inventor Immersif** i3D collaborate with TGS and IFP on the RNTL project "Inventor Immersif". The purpose of this project is to develop an immersive version of Open Inventor and to integrate some interaction tools.
- **Geobench** i3D, Apache, TGS, BRGM, CEA 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 Workbench-Spidar 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 researchs on pseudo haptic feedback.
- **CNRS Specific Initiative on "Virtual Reality and Cognition"** i3D takes part in CNRS Specific Initiative on "Virtual Reality and Cognition".
- **CNRS Specific Initiative on "Haptics"** i3D takes part in CNRS Specific Initiative on "Haptics".
- **CNRS Specific Initiative on "Collision Detection"** i3D takes part in CNRS Specific Initiative on "Collision Detection".

7.5. International

- Collaboration with **Sato-Koike** research group from the Tokyo Institute of Technology. Collaborations on the Spidar system (see 6.2).
- Within the Sixth European Framework Programme, i3D together with Siames are in the core group of the "Intuition" Virtual Reality Network of Excellence.

9. Dissemination

9.1. 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 Guest Editor for vol. 65, number 4 of the journal Graphical Models, July 2003.

9.2. 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.
- **Ecole Centrale Lyon**, Jérôme Grosjean has been Teaching Assistant in 2002-2003.

9.3. Conference and Workshop Committees, Invited Conferences

- Sabine Coquillart has been a member of the International Program Committee of the following conferences : AFRIGRAPH'03, CGI'03, GI'03, GRAPHITE'03, Graphicon'03, IPT-EGVE'03, VRIC'2003, SCCG'2003, WSCG'2003, Eurographics'2003, IEEE Virtual Reality'2003.
- Sabine Coquillart is co-chair of the 2004 Eurogaphics Symposium on Virtual Environments organized in Grenoble.

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

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Miscellaneous

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