IN PARTNERSHIP WITH:
Institut national des sciences appliquées de Rennes
Université Rennes 1

Activity Report 2015

Project-Team HYBRID

3D interaction with virtual environments using body and mind

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Interaction and visualization

Table of contents

1. Members **1**
2. Overall Objectives **2**
3. Research Program **3**
3.1. Research Program 3
3.2. Research Axes 5
4. Application Domains **6**
5. Highlights of the Year **6**
6. New Software and Platforms **7**
6.1. OpenViBE 7
6.2. Statefinder 7
6.3. Pseudohaptik 7
6.4. Elastic_Images 8
6.5. #FIVE 8
6.6. #SEVEN 8
7. New Results **9**
7.1. 3D User Interfaces 9
7.1.1. Novel 3D Interactive Techniques 9
7.1.2. Understanding Human Perception in VR 10
7.1.3. Sports and Virtual Reality 10
7.1.4. Experiencing the Past in Virtual Reality 11
7.2. Physically-Based Simulation and Multisensory Feedback 13
7.2.1. Interactive Physically-Based Simulation 13
7.2.2. Multimodal Feedback 13
7.2.3. GPU-based Collision Detection in Virtual Environments 14
7.2.4. Medical Applications 15
7.3. Collaborative Virtual Environments 16
7.4. Brain-Computer Interfaces 18
7.4.1. Novel Usages of BCI 18
7.4.2. BCI Methodology and Techniques 19
8. Bilateral Contracts and Grants with Industry **20**
8.1. Bilateral Contracts with Industry 20
8.1.1. Mensia Technologies 20
8.1.2. MBA Multimedia 20
8.1.3. Polymorph Studio 21
8.2. Bilateral Grants with Industry 21
8.2.1. Technicolor 21
8.2.2. Realyz 21
8.2.3. VINCI 21
9. Partnerships and Cooperations **21**
9.1. Regional Initiatives 21
9.1.1. Labex Cominlabs S3PM 21
9.1.2. Labex HEMISFER 21
9.1.3. Labex SABRE 22
9.1.4. IRT b<>com 22
9.1.5. CNPAO Project 22
9.1.6. Imag'In CNRS IRMA 22
9.2. National Initiatives 22
9.2.1. ANR MANDARIN 22
9.2.2. ANR HOMO-TEXTILUS 23

9.2.3. FUI Previz 23
9.2.4. ADT MAN-IP 23
9.2.5. ADT OpenViBE-NT 23
9.2.6. Ilab CertiViBE 23
9.2.7. IPL BCI-LIFT 24
9.3. European Initiatives 24
9.4. International Research Visitors 25
10. Dissemination **25**
10.1. Promoting Scientific Activities 25
10.1.1. Scientific events organisation 25
10.1.1.1. General chair, scientific chair 25
10.1.1.2. Member of the organizing committees 25
10.1.2. Scientific events selection 25
10.1.2.1. Chair of the conference program committees 25
10.1.2.2. Member of the conference program committees 25
10.1.2.3. Reviewer 25
10.1.3. Journal 26
10.1.3.1. Member of the editorial boards 26
10.1.3.2. Reviewer - Reviewing activities 26
10.1.4. Invited talks 26
10.1.5. Leadership within the scientific community 26
10.1.6. Scientific expertise 26
10.1.7. Research administration 26
10.2. Teaching - Supervision - Juries 26
10.2.1. Supervision 27
10.2.2. Juries 28
10.2.2.1. Selection committees 28
10.2.2.2. PhD and HDR juries 28
10.3. Popularization 28
11. Bibliography **28**

Project-Team HYBRID

Creation of the Team: 2013 January 01, updated into Project-Team: 2013 July 01

Keywords:

Computer Science and Digital Science:

2.5. - Software engineering
5. - Interaction, multimedia and robotics
5.1. - Human-Computer Interaction
5.1.2. - Evaluation of interactive systems
5.1.3. - Haptic interfaces
5.1.4. - Brain-computer interfaces, physiological computing
5.1.5. - Body-based interfaces
5.1.7. - Multimodal interfaces
5.5.4. - Animation
5.6. - Virtual reality, augmented reality
6. - Modeling, simulation and control
6.2. - Scientific Computing, Numerical Analysis & Optimization
6.3. - Computation-data interaction

Other Research Topics and Application Domains:

1.3. - Neuroscience and cognitive science
2. - Health
2.4. - Therapies
2.5. - Handicap and personal assistances
2.6. - Biological and medical imaging
2.7.1. - Surgical devices
2.8. - Sports, performance, motor skills
5. - Industry of the future
5.1. - Factory of the future
5.2. - Design and manufacturing
5.8. - Learning and training
5.9. - Industrial maintenance
8.1. - Smart building/home
8.3. - Urbanism and urban planning
9.1. - Education
9.2. - Art
9.2.2. - Cinema, Television
9.2.3. - Video games
9.3. - Sports
9.5.6. - Archeology, History

1. Members

Research Scientists

Anatole Lécuyer [Team leader, Inria, Senior Researcher, HdR]
Fernando Argelaguet Sanz [Inria, Starting Research Position]

Faculty Members

Bruno Arnaldi [INSA Rennes, Professor, HdR]
Valérie Gouranton [INSA Rennes, Associate Professor]
Maud Marchal [INSA Rennes, Associate Professor, HdR]
Thi Thuong Huyen Nguyen [Univ. Rennes I, ATER, until Aug 2015]

Engineers

Emmanuel Badier [INSA Rennes, until Aug 2015]
Thomas Boggini [INSA Rennes, until Aug 2015]
Rozenn Bouville Berthelot [INSA Rennes, until Oct 2015]
Jérome Chabrol [Inria, from Oct 2015]
Charles Garraud [Inria, from Nov 2015]
Cédric Le Cam [INSA Rennes, until Oct 2015]
Jussi Tapio Lindgren [Inria]
Thomas Lopez [INSA Rennes, until Feb 2015]
Marsel Mano [Inria]
Florian Nouviale [INSA Rennes, SED Research Engineer 20%]

PhD Students

Merwan Achibet [Inria]
Lorraine Perronnet [Inria]
Jean-Baptiste Barreau [CNRS]
Guillaume Claude [INSA Rennes]
Guillaume Cortes [Realyz, from Nov 2015]
Antoine Costes [Technicolor, from Nov 2015]
Anne-Solène Dris-Kerdreux [Vinci, from Nov 2015]
Andéol Evain [Univ. Rennes I]
Jérémy Lacoche [Inst. de Recherche Technologique b<>com]
Morgan Le Chénéchal [Inst. de Recherche Technologique b<>com]
Benoît Le Gouis [INSA Rennes]
Gwendal Le Moulec [INSA Rennes, from Oct 2015]
Francois Lehericey [INSA Rennes]
Jonathan Mercier-Ganady [Inria, until Sep 2015]

Post-Doctoral Fellows

Kevin-Yoren Gaffary [Inria, from Oct 2015]
Adrien Girard [Inria]
Nataliya Kos'Myna [Inria, from Dec 2015]

Administrative Assistant

Nathalie Denis [Inria]

2. Overall Objectives

2.1. Introduction

Our research project belongs to the scientific field of Virtual Reality (VR) and 3D interaction with virtual environments. VR systems can be used in numerous applications such as for industry (virtual prototyping, assembly or maintenance operations, data visualization), entertainment (video games, theme parks), arts and design (interactive sketching or sculpture, CAD, architectural mock-ups), education and science (physical simulations, virtual classrooms), or medicine (surgical training, rehabilitation systems). A major change that we foresee in the next decade concerning the field of Virtual Reality relates to the emergence of new paradigms of interaction (input/output) with Virtual Environments (VE).

As for today, the most common way to interact with 3D content still remains by measuring user's motor activity, i.e., his/her gestures and physical motions when manipulating different kinds of input device. However, a recent trend consists in soliciting more movements and more physical engagement of the body of the user. We can notably stress the emergence of bimanual interaction, natural walking interfaces, and whole-body involvement. These new interaction schemes bring a new level of complexity in terms of generic physical simulation of potential interactions between the virtual body and the virtual surrounding, and a challenging "trade-off" between performance and realism. Moreover, research is also needed to characterize the influence of these new sensory cues on the resulting feelings of "presence" and immersion of the user.

Besides, a novel kind of user input has recently appeared in the field of virtual reality: the user's mental activity, which can be measured by means of a "Brain-Computer Interface" (BCI). Brain-Computer Interfaces are communication systems which measure user's electrical cerebral activity and translate it, in real-time, into an exploitable command. BCIs introduce a new way of interacting "by thought" with virtual environments. However, current BCI can only extract a small amount of mental states and hence a small number of mental commands. Thus, research is still needed here to extend the capacities of BCI, and to better exploit the few available mental states in virtual environments.

Our first motivation consists thus in designing novel "body-based" and "mind-based" controls of virtual environments and reaching, in both cases, more immersive and more efficient 3D interaction.

Furthermore, in current VR systems, motor activities and mental activities are always considered separately and exclusively. This reminds the well-known "body-mind dualism" which is at the heart of historical philosophical debates. In this context, our objective is to introduce novel "hybrid" interaction schemes in virtual reality, by considering motor and mental activities jointly, i.e., in a harmonious, complementary, and optimized way. Thus, we intend to explore novel paradigms of 3D interaction mixing body and mind inputs. Moreover, our approach becomes even more challenging when considering and connecting multiple users which implies multiple bodies and multiple brains collaborating and interacting in virtual reality.

Our second motivation consists thus in introducing a "hybrid approach" which will mix mental and motor activities of one or multiple users in virtual reality.

3. Research Program

3.1. Research Program

The scientific objective of Hybrid team is to improve 3D interaction of one or multiple users with virtual environments, by making full use of physical engagement of the body, and by incorporating the mental states by means of brain-computer interfaces. We intend to improve each component of this framework individually, but we also want to improve the subsequent combinations of these components.

The "hybrid" 3D interaction loop between one or multiple users and a virtual environment is depicted on Figure 1. Different kinds of 3D interaction situations are distinguished (red arrows, bottom): 1) body-based interaction, 2) mind-based interaction, 3) hybrid and/or 4) collaborative interaction (with at least two users). In each case, three scientific challenges arise which correspond to the three successive steps of the 3D interaction loop (blue squares, top): 1) the 3D interaction technique, 2) the modeling and simulation of the 3D scenario, and 3) the design of appropriate sensory feedback.

The 3D interaction loop involves various possible inputs from the user(s) and different kinds of output (or sensory feedback) from the simulated environment. Each user can involve his/her body and mind by means of corporal and/or brain-computer interfaces. A hybrid 3D interaction technique (1) mixes mental and motor inputs and translates them into a command for the virtual environment. The real-time simulation (2) of the virtual environment is taking into account these commands to change and update the state of the virtual world and virtual objects. The state changes are sent back to the user and perceived by means of different sensory feedbacks (e.g., visual, haptic and/or auditory) (3). The sensory feedbacks are closing the 3D interaction loop. Other users can also interact with the virtual environment using the same procedure, and can eventually "collaborate" by means of "collaborative interactive techniques" (4).

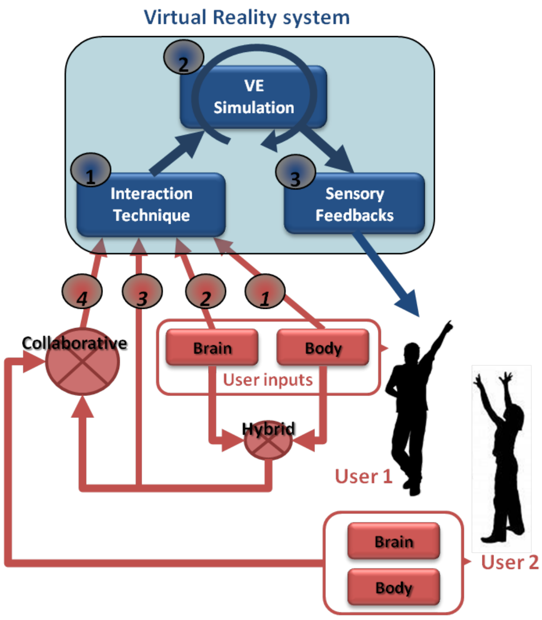

Figure 1. 3D hybrid interaction loop between one or multiple users and a virtual reality system. Top (in blue) three steps of 3D interaction with a virtual environment: (1-blue) interaction technique, (2-blue) simulation of the virtual environment, (3-blue) sensory feedbacks. Bottom (in red) different cases of interaction: (1-red) body-based, (2-red) mind-based, (3-red) hybrid, and (4-red) collaborative 3D interaction.

This description is stressing three major challenges which correspond to three mandatory steps when designing 3D interaction with virtual environments:

- **3D interaction techniques:** This first step consists in translating the actions or intentions of the user (inputs) into an explicit command for the virtual environment. In virtual reality, the classical tasks that require such kinds of user command were early categorized in four [42]: navigating the virtual world, selecting a virtual object, manipulating it, or controlling the application (entering text, activating options, etc). The addition of a third dimension, the use of stereoscopic rendering and the use of advanced VR interfaces make however inappropriate many techniques that proved efficient in 2D, and make it necessary to design specific interaction techniques and adapted tools. This challenge is here renewed by the various kinds of 3D interaction which are targeted. In our case, we consider various cases, with motor and/or cerebral inputs, and potentially multiple users.
- **Modeling and simulation of complex 3D scenarios:** This second step corresponds to the update of the state of the virtual environment, in real-time, in response to all the potential commands or actions sent by the user. The complexity of the data and phenomena involved in 3D scenarios is constantly increasing. It corresponds for instance to the multiple states of the entities present in the simulation (rigid, articulated, deformable, fluids, which can constitute both the user's virtual body and the different manipulated objects), and the multiple physical phenomena implied by natural human interactions (squeezing, breaking, melting, etc). The challenge consists here in modeling and simulating these complex 3D scenarios and meeting, at the same time, two strong constraints of virtual reality systems: performance (real-time and interactivity) and genericity (e.g., multi-resolution, multi-modal, multi-platform, etc).
- **Immersive sensory feedbacks:** This third step corresponds to the display of the multiple sensory feedbacks (output) coming from the various VR interfaces. These feedbacks enable the user to perceive the changes occurring in the virtual environment. They are closing the 3D interaction loop, making the user immersed, and potentially generating a subsequent feeling of presence. Among the various VR interfaces which have been developed so far we can stress two kinds of sensory feedback: visual feedback (3D stereoscopic images using projection-based systems such as CAVE systems or Head Mounted Displays); and haptic feedback (related to the sense of touch and to tactile or force-feedback devices). The Hybrid team has a strong expertize in haptic feedback, and in the design of haptic and "pseudo-haptic" rendering [44]. Note that a major trend in the community, which is strongly supported by the Hybrid team, relates to a "perception-based" approach, which aims at designing sensory feedbacks which are well in line with human perceptual capacities.

These three scientific challenges are addressed differently according to the context and the user inputs involved. We propose to consider three different contexts, which correspond to the three different research axes of the Hybrid research team, namely : 1) body-based interaction (motor input only), 2) mind-based interaction (cerebral input only), and then 3) hybrid and collaborative interaction (i.e., the mixing of body and brain inputs from one or multiple users).

3.2. Research Axes

The scientific activity of Hybrid team follows three main axes of research:

- **Body-based interaction in virtual reality.** Our first research axis concerns the design of immersive and effective "body-based" 3D interactions, i.e., relying on a physical engagement of the user's body. This trend is probably the most popular one in VR research at the moment. Most VR setups make use of tracking systems which measure specific positions or actions of the user in order to interact with a virtual environment. However, in recent years, novel options have emerged for measuring "full-body" movements or other, even less conventional, inputs (e.g. body equilibrium). In this first research axis we are thus concerned by the emergence of new kinds of "body-based interaction" with virtual environments. This implies the design of novel 3D user interfaces and novel 3D interactive techniques, novel simulation models and techniques, and novel sensory feedbacks for body-based interaction with virtual worlds. It involves real-time physical simulation of complex interactive phenomena, and the design of corresponding haptic and pseudo-haptic feedback.

- **Mind-based interaction in virtual reality.** Our second research axis concerns the design of immersive and effective “mind-based” 3D interactions in Virtual Reality. Mind-based interaction with virtual environments is making use of Brain-Computer Interface technology. This technology corresponds to the direct use of brain signals to send “mental commands” to an automated system such as a robot, a prosthesis, or a virtual environment. BCI is a rapidly growing area of research and several impressive prototypes are already available. However, the emergence of such a novel user input is also calling for novel and dedicated 3D user interfaces. This implies to study the extension of the mental vocabulary available for 3D interaction with VE, then the design of specific 3D interaction techniques "driven by the mind" and, last, the design of immersive sensory feedbacks that could help improving the learning of brain control in VR.
- **Hybrid and collaborative 3D interaction.** Our third research axis intends to study the combination of motor and mental inputs in VR, for one or multiple users. This concerns the design of mixed systems, with potentially collaborative scenarios involving multiple users, and thus, multiple bodies and multiple brains sharing the same VE. This research axis therefore involves two interdependent topics: 1) collaborative virtual environments, and 2) hybrid interaction. It should end up with collaborative virtual environments with multiple users, and shared systems with body and mind inputs.

4. Application Domains

4.1. Overview

The research program of Hybrid team aims at next generations of virtual reality and 3D user interfaces which could possibly address both the “body” and “mind” of the user. Novel interaction schemes are designed, for one or multiple users. We target better integrated systems and more compelling user experiences.

The applications of our research program correspond to the applications of virtual reality technologies which could benefit from the addition of novel body-based or mind-based interaction capabilities:

- **Industry**: with training systems, virtual prototyping, or scientific visualization;
- **Medicine**: with rehabilitation and reeducation systems, or surgical training simulators;
- **Entertainment**: with 3D web navigations, video games, or attractions in theme parks,
- **Construction**: with virtual mock-ups design and review, or historical/architectural visits.

5. Highlights of the Year

5.1. Highlights of the Year

Hybrid had 4 papers published at IEEE Virtual Reality Conference in 2015 : [19] [16] [18] [23].

Hybrid team was also strongly involved in IEEE Virtual Reality Conference, which took place for the first time in France in 2015 (Arles, March 23-27), with A. Lécuyer: Program Chair, F. Argelaguet and M. Marchal: Research Demos Chairs, F. Nouviale: Exhibit Chair, B. Arnaldi: Supporters Chair.

5.1.1. Awards

- Best PhD Thesis award from “Fondation Rennes 1” for former PhD student Fabien Danieau for his work "Contribution to the study of haptic feedback for improving the audiovisual experience" co-supervised with Technicolor company.
- Project PREVIZ received the “business” award in Trophies “Loading the future” (24/11, Nantes, Competitivity Cluster "Images et Réseaux").
- The algorithm developed by Lucas Royer (co-supervised by A. Krupa, M. Marchal and G. Dardenne) won the first place of the MICCAI Challenge on Liver Ultrasound Tracking.

6. New Software and Platforms

6.1. OpenViBE

KEYWORDS: Brain-Computer Interface, EEG, Neuroscience, Interaction, Health, Neurofeedback
FUNCTIONAL DESCRIPTION

OpenViBE is a free and open-source software platform devoted to the design, test and use of Brain-Computer Interfaces (BCI). The platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. The key features of OpenViBE software are its modularity, its high-performance, its portability, its multiple-users facilities and its connection with high-end/VR displays. The “designer” of the platform enables to build complete scenarios based on existing software modules using a dedicated graphical language and a simple Graphical User Interface (GUI). This software is available on the Inria Forge under the terms of the AGPL licence, and it was officially released in June 2009. Since then, the OpenViBE software has already been downloaded more than 40000 times, and it is used by numerous laboratories, projects, or individuals worldwide. More information, downloads, tutorials, videos, documentations are available on the OpenViBE website.

- Participants: Anatole Lécuyer, Jussi Tapio Lindgren, Jérôme Chabrol, Charles Garraud, and Marsel Mano
- Partners: Inria teams POTIOC, ATHENA and NEUROSYS
- Contact: Anatole Lécuyer
- URL: http://openvibe.inria.fr

6.2. Statefinder

KEYWORDS: Brain-Computer Interface, EEG, Neuroscience, Interaction, Health, Neurofeedback, Welfare
FUNCTIONAL DESCRIPTION Statefinder is a software for determining the mental state of a user based on EEG signals analysis. It notably enables to classify between different different mental states on-line, using a preliminary training phase during which the EEG signals corresponding to these different mental states were recorded. This software was designed and used during the PhD of Mr. Laurent George, in Hybrid team. It has been transferred to Mensia Technologies startup company.

- Participants: Anatole Lécuyer
- Contact: Anatole Lécuyer

6.3. Pseudohaptik

KEYWORDS: User Interfaces, 3D web, Pseudo-Haptic, Deph Perception
FUNCTIONAL DESCRIPTION

PSEUDOHAPTIK is a software which enables to simulate pseudo-haptic effects notably for web applications. Pseudo-haptic feedback enables to simulate haptic properties such as feeling the texture or relief of an image using visual effects synchronized with the motion of the user. This software has been notably transferred to MBA Multimédia and Polymorph companies.

- Participants: Anatole Lécuyer, Ferran Argelaguet Sanz and Maud Marchal
- Contact: Anatole Lécuyer
- URL: https://team.inria.fr/hybrid/w3d-project/

6.4. Elastic_Images

KEYWORDS: User Interfaces, Depth Perception, 3D web, Pseudo-Haptic
FUNCTIONAL DESCRIPTION

Elastic_Images is a software which enables to simulate pseudo-haptic effects related to the elasticity or stiffness of 2D images, notably for web application purpose. This software has been transferred to MBA Multimédia and Polymorph companies.

- Participants: Anatole Lécuyer, Ferran Argelaguet Sanz and Maud Marchal
- Contact: Anatole Lécuyer
- URL: https://team.inria.fr/hybrid/w3d-project/

6.5. #FIVE

KEYWORDS: Virtual Reality, Collaboration, 3D Interaction
FUNCTIONAL DESCRIPTION

#FIVE is a set of software modules for the design of interactive and collaborative virtual environments. The user can focus on domain-specific aspects of his/her application (e.g., industry, medicine, etc). The #FIVE modules can then be used in a vast range of domains based on virtual reality and requiring interactive environments and collaboration - such as in training simulators for example when connected to the #SEVEN engine (see section 6.6).

- Participants: Thomas Boggini, Valérie Gouranton, Bruno Arnaldi, Florian Nouviale
- Contact: Florian Nouviale
- URL: https://hal.archives-ouvertes.fr/IRISA/hal-01147734v1

6.6. #SEVEN

KEYWORDS: Virtual Reality, Training, Scenario, Petri Net
FUNCTIONAL DESCRIPTION

#SEVEN is a scenario engines that enables the execution of complex scenarios for driving Virtual Reality training applications. #SEVEN's scenarios are based on an enhanced Petri net model that can describe and solve intricate event sequence. #SEVEN comes with an editor capable of creating, editing and remotely controlling and running such scenarios. #SEVEN is implemented in C# and can be used as a standalone application or as a library. An integration with the Unity3D engine, compatible with MiddleVR, also exists.

- Participants: Guillaume Claude, Valérie Gouranton, Bruno Arnaldi, Florian Nouviale
- Contact: Florian Nouviale
- URL: https://hal.archives-ouvertes.fr/hal-01086237

7. New Results

7.1. 3D User Interfaces

7.1.1. Novel 3D Interactive Techniques

THING: Introducing a Tablet-based Interaction Technique for Controlling 3D Hand Models Merwan Achibet, Anatole Lécuyer and Maud Marchal

The hands of virtual characters are highly complex 3D models that can be tedious and time-consuming to animate with current methods. We introduced the *THING* [17], a novel tablet-based approach that leverages multi-touch interaction for a quick and precise control of a 3D hand's pose 2. The flexion/extension and abduction/adduction of the virtual fingers can be controlled for each finger individually or for several fingers in parallel through sliding motions on the surface of the tablet. We designed two variants of THING: **(1)** *MobileTHING*, which maps the spatial location and orientation of the tablet to that of the virtual hand, and **(2)** *DesktopTHING*, which combines multi-touch controls of fingers with traditional mouse controls for the global position and orientation of the hand model. We compared the usability of THING against mouse-only controls and a data glove in two controlled experiments. Results show that DesktopTHING was significantly preferred by users while providing performance similar to data gloves. Together, these results could pave the way to the introduction of novel hybrid user interfaces based on tablets and computer mice in future animation pipelines. This work was done in collaboration with Géry Casiez (Inria team MJOLNIR).

Figure 2. THING enables the control of 3D hand models (in blue) by sliding fingers along sliders arranged in a morphologically-consistent pattern on the tablet's screen. This creates a strong correspondence between user's input and pose of the controlled hand. Here, the user closes the virtual hand and then points the index finger.

Plasticity for 3D User Interfaces: New Models for Devices and Interaction Techniques Jérémy Lachoche and Bruno Arnaldi

We have introduced new models for device and interaction techniques to overcome plasticity limitations in Virtual Reality (VR) and Augmented Reality (AR) [26]. We aimed to provide developers with solutions to use and create interaction techniques that fit to the 3D application tasks and to the input and output devices available. The device model describes input and output devices and includes capabilities, limitations and representations in the real world. We also propose a new way to develop interaction techniques with an approach based on PAC and ARCH models [43]. These techniques are implemented independently from the specific devices used thanks to the proposed device model. Moreover, our approach aims to facilitate the portability of interaction techniques over different target OS and 3D frameworks. This work was done in collaboration with Thierry Duval (Lab-STICC), Éric Maisel (ENIB) and Jérome Royan (IRT B-Com).

Dealing with Frame Cancellation for Stereoscopic Displays in 3D User Interfaces Jérémy Lacoche, Morgan Le Chénéchal, Valérie Gouranton and Bruno Arnaldi

We explored new methods to reduce ocular discomfort when interacting with stereoscopic content, focusing on frame cancellation [27]. Frame cancellation appears when a virtual object in negative parallax (front of the screen) is clipped by the screen edges; stereopsis cue lets observers perceive the object popping-out from the screen while occlusion cue provides observers with an opposite signal. Such a situation is not possible in the real world. This explains some visual discomfort for observers and leads to a poor depth perception of the virtual scene. This issue is directly linked to the physical limitations of the display size that may not cover the entire field of view of the observer. To deal with these physical constraints we introduce two new methods in the context of interactive applications. The first method consists in two new rendering effects based on progressive transparency that aim to preserve the popping-out effect of the stereo. The second method focuses on adapting the interaction of the user, not allowing him to place virtual objects in an area subject to frame cancellation. This work was done in collaboration with Sébastien Chalmé (IRT B-Com), Thierry Duval (Lab-STICC) and Éric Maisel (ENIB).

7.1.2. Understanding Human Perception in VR

Distance Estimation in Large Immersive Projection Systems, Revisited Ferran Argelaguet and Anatole Lécuyer

When walking within an immersive projection environment, accommodation distance, parallax and angular resolution vary according to the distance between the user and the projection walls which can influence spatial perception. As CAVE-like virtual environments get bigger, accurate spatial perception within the projection setup becomes increasingly important for application domains that require the user to be able to naturally explore a virtual environment by moving through the physical interaction space. In this work we performed two experiments which analyze how distance estimation is biased when accommodation distance, parallax and angular resolution vary [23]. The experiments were conducted in a large immersive projection setup with up to ten meter interaction range. The results showed that both accommodation distance and parallax have a strong asymmetric effect on distance judgments. We found an increased distance underestimation for positive parallax conditions as the accommodation-convergence difference increased. In contrast, we found less distance overestimation for negative and zero parallax conditions. Our findings also showed that angular resolution has a negligible effect on distance estimation. This work was done in collaboration with Anne-Hélène Olivier (MIMETIC) and Gerd Bruder (University of Hamburg).

Virtual Proxemics: Locomotion in the Presence of Obstacles in Large Immersive Projection Environments Ferran Argelaguet, Anatole Lécuyer

In the real world we navigate with ease by walking in the presence of obstacles, we develop avoidance strategies and behaviors which govern the way we locomote in the proximity of physical objects and other persons during everyday tasks. With the advances of virtual reality technology, it becomes important to gain an understanding of how these behaviors are affected in a virtual reality application. In this work, we analyzed the walking and collision avoidance behavior when avoiding real and virtual static obstacles [19]. In order to generalize our study, we considered both anthropomorphic and inanimate objects, each having his virtual and real counterpart. The results showed that users exhibit different locomotion behaviors in the presence of real and virtual obstacles, and in the presence of anthropomorphic and inanimate objects. Precisely, the results showed a decrease of walking speed as well as an increase of the clearance distance (i. e., the minimal distance between the walker and the obstacle) when facing virtual obstacles compared to real ones. Moreover, our results suggest that users act differently due to their perception of the obstacle: users keep more distance when the obstacle is anthropomorphic compared to an inanimate object and when the orientation of anthropomorphic obstacle is from the profile compared to a front position. We discussed implications on future large shared immersive projection spaces. This work was done in collaboration with Anne-Hélène Olivier (MIMETIC), Julien Pettré (MIMETIC) and Gerd Bruder (University of Hamburg).

7.1.3. Sports and Virtual Reality

A Methodology for Introducing Competitive Anxiety and Pressure in VR Sports Training Ferran Argelaguet and Anatole Lécuyer

Athletes' performance is influenced by internal and external factors, including their psychological state and environmental factors, especially during competition. As a consequence, current training programs include stress management. In this work, we explored whether highly immersive systems can be used for such training programs [11]. First, we proposed methodological guidelines to design sport training scenarios both on considering the elements that a training routine must have, and how external factors might influence the participant. The proposed guidelines are based on flow and social-evaluative threat theories. Second, to illustrate and validate our methodology, we designed an experiment reproducing a 10m Olympic pistol shooting competition 3. We analyzed whether changes in the environment are able to induce changes in user performance, physiological responses and the subjective perception of the task. The simulation included stressors in order to raise a social-evaluative threat, such as aggressive public behavior or unforced errors, increasing the pressure while performing the task. The results showed significant differences in the user behavior and in their subjective impressions, trends in the physiological data were also observed. Taken together our results suggest that highly immersive systems could be further used for training systems in sports. This work was done in collaboration with Frank Multon (MIMETIC).

Figure 3. The proposed methodology was illustrated and evaluated in a virtual Olympic shooting experiment. The experiment was conducted in a wide immersive projection system being able to enclose a ten meter wide shooting range with six virtual opponents and one participant.

7.1.4. Experiencing the Past in Virtual Reality

An Immersive Virtual Sailing on the 18 th -Century Ship Le Boullongne Jean-Baptiste Barreau, Florian Nouviale and Valérie Gouranton

This work is the result of the collaboration between historians and computer scientists whose goal was the digital reconstitution of "Le Boullongne", an 18th-century merchant ship of "La Compagnie des Indes orientale" [12]. This ship has now disappeared and its reconstitution aims at understanding on-board living conditions. Three distinct research laboratories have participated in this project so far. The first, a department of naval history, worked on historical documents, especially the logbooks describing all traveling events of the ship. The second, a research laboratory in archeology, archaeoscience and history, proposed a 3D model of the ship based on the original naval architectural plans. The third, a computer science research laboratory, implemented a simulation of the ship sailing in virtual reality. This work focuses on the reconstitution of the ship in virtual reality, aiming at restoring a realistic interactive naval simulation: the 3D model of the ship has been integrated in an ocean simulation, with a physical rendering of the buoyancy. The simulation allows a user to walk around on the ship, at a scale of 1:1, and even steer it through a natural interaction. Several characteristics of the simulation reinforce the sensation of being on-board: (1) A sonic environment mixing spatialized sounds (gulls flying, a whale swimming, wood cracking, cannons firing) and global soundscape (ocean and wind). (2) The meteorology of the simulation is dynamically modifiable; the user can increase the swell height and speed. The global illumination and wind sound vary in accordance with these parameters. The buoyancy simulation entails realistic movements of the ship. (3) Several interactions are proposed allowing the user to steer the ship with his/her hand, walk around on the ship, fire the cannons, and modify the weather. (4) Three animated sailors accompany the user in his/her sailing experience. They are wearing realistic period costumes. The immersive simulation has allowed historians to embark on "Le Boullongne" and to better understand how life was organized on-board. It has also been presented at several public exhibitions, in CAVE-like structures and HMD. This work was done in collaboration with Ronan Gaugne (Univ. Rennes 1), Yann Bernard (CReAAH) and Sylviane Llinares (CERHIO, UBS Lorient).

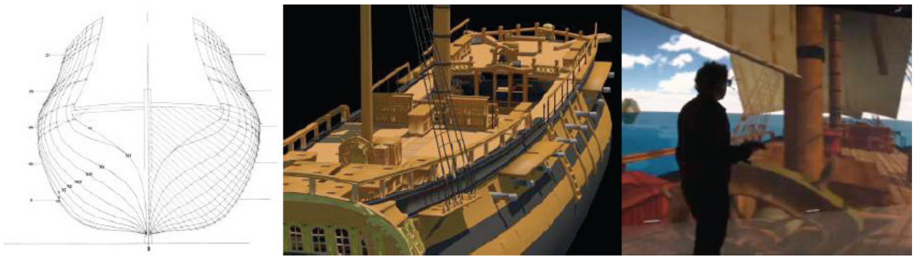

Figure 4. Digital reconstitution of "Le Boullongne". From architectural plans to virtual reality implementation.

Touching and interacting with inaccessible cultural heritage Valérie Gouranton and Bruno Arnaldi

Sense of touch provides a particular access to our environment, enabling a tangible relation with it. In the particular use case of cultural heritage, touching the past, apart from being a universal dream, can provide essential information to analyze, understand, or restore artifacts. However, archaeological objects cannot always offer a tangible access, either because they have been destroyed or too damaged, or because they are part of a larger assembly. In other cases, it is the context of use that has become inaccessible, as it is related to an extinct activity. In [15] we proposed a workflow based on a combination of computed tomography, 3D images, and 3D printing to provide concrete access to cultural heritage, and we illustrate this workflow in different contexts of inaccessibility. These technologies are already used in cultural heritage, but seldom combined, and mostly for exceptional artifacts. We proposed to combine these technologies in case studies corresponding to relevant archaeological situations.

This work was done in collaboration with Théophane Nicolas (INRAP), Ronan Gaugne (Univ. Rennes 1), Cédric Tavernier (Image ET) and Quentin Petit (CNRS).

3D reconstruction of the loyola sugar plantation and virtual reality applications Jean-Baptiste Barreau, Valérie Gouranton

Discovered in 1988, the Loyola sugar plantation, owned by the Jesuits in French Guiana, is a major plantation of colonial history and slavery. Ongoing archaeological excavations have uncovered the Jesuit's house and the outbuildings usually associated with a plantation such as a chapel and its cemetery, a blacksmith shop, a pottery, the remains of the entire sugar production (a windmill, a boiler and a dryer), coffee and indigo warehouses etc. Based on our findings and our network with 3D graphic designers and researchers in virtual reality, a 3D restitution integrated within a virtual reality platform was initiated to develop a better understanding of the plantation and its surrounding landscape. A specific work on the interactive changes of sunlight and animal sounds aimed to reconstruct a coherent evolution during one day of the site's environment [21].

This work was done in collaboration with Quentin Petit (CNRS),Yann Bernard (CReAAH), Reginald Auger (Laval University, Canada), Yannick Le Roux (Laval University, French Guiana) Ronan Gaugne (IMMERSIA), and Cédric Tavernier (Image ET).

7.2. Physically-Based Simulation and Multisensory Feedback

7.2.1. Interactive Physically-Based Simulation

Aggregate constraints for virtual manipulation with soft fingers, Maud Marchal, Anthony Talvas

Figure 5. Interaction with deformable fingers generates many interconnected contact points which are expensive to solve with friction. Our approach aggregates contact constraints per phalanx with torsional friction. The subsequent increase in performance allows real time dexterous manipulation of virtual objects using soft fingers.

Interactive dexterous manipulation of virtual objects remains a complex challenge that requires both appropriate hand models and accurate physically-based simulation of interactions. In [16], we proposed an approach based on novel aggregate constraints for simulating dexterous grasping using soft fingers. Our approach aims at improving the computation of contact mechanics when many contact points are involved, by aggregating the multiple contact constraints into a minimal set of constraints. We also introduced a method for non-uniform pressure distribution over the contact surface, to adapt the response when touching sharp edges. We used the Coulomb-Contensou friction model to efficiently simulate tangential and torsional friction. We showed through different use cases that our aggregate constraint formulation is well-suited for simulating interactively dexterous manipulation of virtual objects through soft fingers, and efficiently reduces the computation time of constraint solving. This work was done in collaboration with Christian Duriez (Inria team DEFROST) and Miguel Otaduy (Univ. Rey Juan Carlos, Madrid, Spain).

7.2.2. Multimodal Feedback

Elastic-Arm: Human-scale passive feedback for augmenting interaction and perception in virtual environments Merwan Achibet, Adrien Girard, Maud Marchal, Anatole Lécuyer

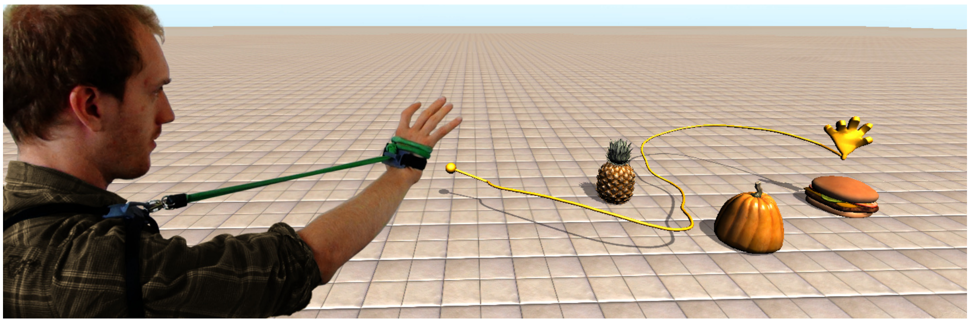

Figure 6. The Elastic-Arm is a body-mounted armature that provides egocentric passive haptic feedback. It presents an alternative to more complex active haptic devices that are generally less adapted to large immersive environments. In this example, a user performs a selection task by stretching his virtual arm using a combination of the Bubble and Go-Go techniques reimplemented with our system.

Haptic feedback is known to improve 3D interaction in virtual environments but current haptic interfaces remain complex and tailored to desktop interaction. In [18], we introduced the *ElasticArm*, a novel approach for incorporating haptic feedback in immersive virtual environments in a simple and cost-effective way. The Elastic-Arm is based on a body-mounted elastic armature that links the user's hand to her shoulder. As a result, a progressive resistance force is perceived when extending the arm. This haptic feedback can be incorporated with various 3D interaction techniques and we illustrate the possibilities offered by our system through several use cases based on well-known examples such as the *Bubble* technique, *Redirected Touching*, and pseudo-haptics. These illustrative use cases provide users with haptic feedback during selection and navigation tasks but they also enhance their perception of the virtual environment. Taken together, these examples suggest that the Elastic-Arm can be transposed in numerous applications and with various 3D interaction metaphors in which a mobile haptic feedback can be beneficial. It could also pave the way for the design of new interaction techniques based on human-scale egocentric haptic feedback.

Visual vibrations to simulate taps on different materials Maud Marchal, Anatole Lécuyer

In [40], we presented a haptic visualization technique for conveying material type through visual feedback, expressed as visible decaying sinusoidal vibration resulting from tapping an object. The technique employs cartoon-inspired visual effects and modulates the scale of the vibration to comply with visual perception. The results of a user study showed that participants could successfully perceive three types of material (rubber, wood, and aluminum) using our novel visual effect. This work was done in collaboration with Taku Hachisu and Hiroyuki Kajimoto (Univ. of Electro Communication, Tokyo, Japan).

7.2.3. GPU-based Collision Detection in Virtual Environments

GPU Ray-Traced Collision Detection: Fine Pipeline Reorganization François Lehericey, Valérie Gouranton, Bruno Arnaldi

Ray-tracing algorithms can be used to render a virtual scene and to detect collisions between objects. Numerous ray-tracing algorithms have been proposed which use data structures optimized for specific cases (rigid objects, deformable objects, etc.). Some solutions try to optimize performance by combining several algorithms to use the most efficient algorithm for each ray. In [31], we presented a ray-traced collision detection pipeline that improves the performance on a graphic processing unit (GPU) when several ray-tracing algorithms are used.

When combining several ray-tracing algorithms on a GPU, a well-known drawback is thread divergence among work-groups that can cause loss of performance by causing idle threads. We avoid branch divergence by dividing the ray tracing into three steps with appended buffers in between. We also show that prediction can be used to avoid unnecessary synchronizations between the CPU and GPU. Applied to a narrow-phase collision detection algorithm, results show an improvement of performance up to 2.7 times.

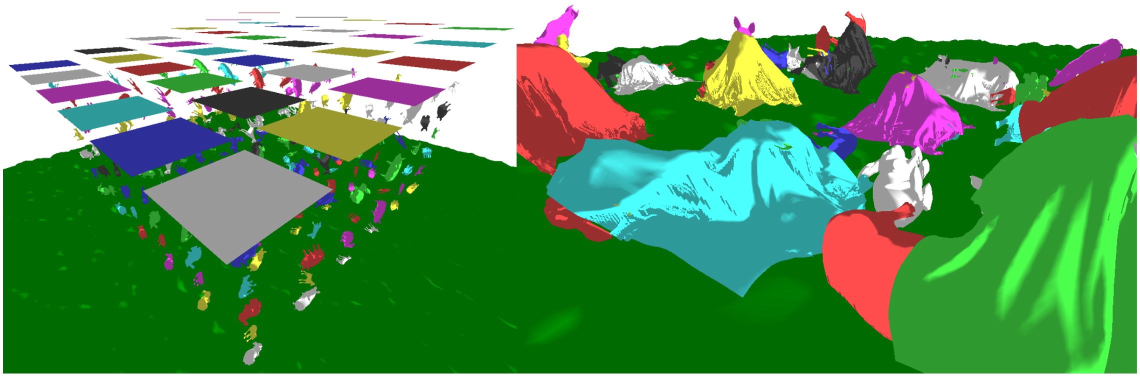

Figure 7. 216 concave objects fall on an irregular ground and 36 deformable sheets fall over them [31].

GPU Ray-Traced Collision Detection for Cloth Simulation François Lehericey, Valérie Gouranton, Bruno Arnaldi

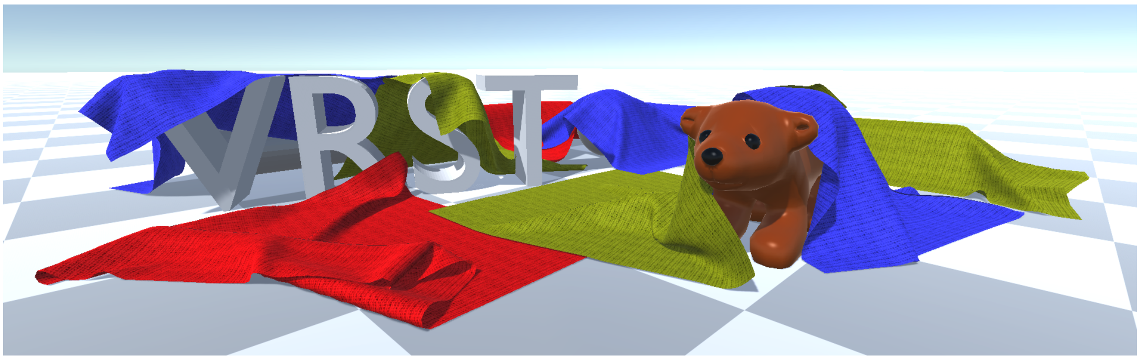

Figure 8. Our method can perform collision detection between clothes and handle self collision detection [30].

In [30], we proposed a method to perform collision detection with cloths with ray-tracing at an interactive frame-rate. Our method is able to perform collision detection between cloths and volumetric objects (rigid or deformable) as well as collision detection between cloths (including auto-collision). Our method casts rays between objects to perform collision detection, and an inversion-handling algorithm is introduced to correct errors introduced by discrete simulations. GPU computing is used to improve the performances by parallelizing the ray-tracing. Our implementation handles scenes containing deformable objects at an interactive frame-rate, with collision detection lasting a few milliseconds.

7.2.4. Medical Applications

Real-time tracking of deformable targets in 3D ultrasound images Maud Marchal

In [35], [36], we presented a novel approach for tracking a deformable anatomical target within 3D ultrasound volumes. Our method is able to estimate deformations caused by the physiological motions of the patient. The displacements of moving structures are estimated from an intensity-based approach combined with a physically-based model and has therefore the advantage to be less sensitive to the image noise. Furthermore, our method does not use any fiducial marker and has real-time capabilities. The accuracy of our method is evaluated on real data acquired from an organic phantom. The validation is performed on different types of motions comprising rigid and non-rigid motions. Thus, our approach opens novel possibilities for computer-assisted interventions where deformable organs are involved.

Our approach was also evaluated on the MICCAI CLUST'15 challenge 3D database. We achieved a mean tracking error of 1.78 mm with an average computation time of 350 ms per frame, ranking our method first during the on-site challenge [34]. This work was done in collaboration with Lucas Royer, Anthony Le Bras and Guillaume Dardenne (IRT bcom), and Alexandre Krupa (Inria team LAGADIC).

Statistical study of parameters for deep brain stimulation automatic pre-operative planning of electrodes trajectories Maud Marchal

Automatic methods for pre-operative trajectory planning of electrodes in Deep Brain Stimulation are usually based on the search for a path that resolves a set of surgical constraints to propose an optimal trajectory. In [13], we studied the use of parameters based on real trajectories of surgeons. For that purpose we firstly retrieve the actual weighting factors used by neurosurgeons thanks to a retrospective study, secondly we compare the results from two different hospitals to evaluate their similarity, and thirdly we compare these trends to the weighting factors usually empirically set in most current approaches. We proposed two approaches, one based on a stochastic sampling and the other on an exhaustive search. In each case, we get a sample of combinations of weighting factors along with a measure of their quality, i.e. the similarity between the optimal trajectory they lead to and the trajectory manually planned by the surgeon as a reference. Then visual and statistical analysis are performed on the number of occurrences and on the rank means. We performed our study on 56 retrospective cases from two different hospitals.We could observe a trend of the occurrence of each weight on the number of occurrences. We also proved that each weight had a significant influence on the ranking. Additionally, we observed no influence of the medical center parameters, suggesting that the trends were comparable in both hospitals. Finally, the obtained trends were confronted to the usual weights chosen by the community, showing some common points but also some discrepancies. These results tend to show a predominance of the choice of a trajectory close to a standard direction. Secondly, the avoidance of the vessels or sulci seems to be sought in the surroundings of the standard position. The avoidance of the ventricles seem to be less predominant, but this could be due to the already reasonable distance between the standard direction and the ventricles. The similarity of results between two medical centers tend to show that it is not an exceptional practice. This work was done in collaboration with Caroline Essert and Antonio Capobianco (Univ. Strasbourg), Claire Haegelen and Pierre Jannin (LTSI, Rennes), Sara Fernandez-Vidal, Carine Karachi and Eric Bardinet (Institut du Cerveau et de la Moëlle Epinière, Paris).

7.3. Collaborative Virtual Environments

Asymetric Remote Collaboration in Mixed Reality: Awareness and Navigation Morgan Le Chénéchal, Valérie Gouranton and Bruno Arnaldi

We first focused on the lack of mutual awareness that may appear in many situations and we evaluated different ways to present the distant user and his actions in the Virtual Environment (VE) in order to understand his perception and cognitive process. We focused on a common case consisting in estimating accurately the time at which a distant user analyzed the meaning of a remotely pointed object. Amongst others, our experimental results presented at CTS [28], show that expertise of the users influences on how they estimate the distant activity and the type of applied strategies.

Then, in a similar asymmetric setup, we proposed a demo at IEEE VR to deal with real estate business. In this context, it is quite difficult for estate agents to make customers understand the potential and the volumes of free spaces. The demo aimed to solve these issues based on a laying out scenario in which a seller and a customer collaborate. As the roles of both users are different, we proposed an asymmetric collaboration where the two users do not use the same interaction setup and do not benefit from the same interaction capabilities.

Last, we focused on a remote collaborative maintenance scenario in which a remote expert helps an operator in performing a physical task 9. Our system is based on a VR setup for the remote expert in order to virtually co-locates him in the real workspace, and an AR interface for the display of the helping gestures to the agent. In a preliminary user study, we evaluated the performance of our system in a navigation task, and we presented results at ICAT-EGVE [29].

This work was done in collaboration with Thierry Duval (Lab-STICC) and Jérome Royan (IRT B-Com).

Figure 9. Remote collaborative maintenance using mixed reality.

High-Level Components for Developing Collaborative and Interactive Virtual Environments Rozenn Bouville, Valérie Gouranton, Thomas Boggini, Florian Nouviale and Bruno Arnaldi

We proposed a framework called #FIVE (Framework for Interactive Virtual Environments) for the development of interactive and collaborative virtual environments [22]. It has been developed for an easier and a faster design and development of virtual reality applications. It was designed with a constant focus on re-usability with as few hypotheses as possible on the final application in which it could be used. Whatever the chosen implementation for the Virtual Environment (VE), #FIVE : (1) provides a toolkit that eases the declaration of possible actions and behaviours of objects in the VE, (2) provides a toolkit that facilitates the setting and the management of collaborative interactions in a VE, (3) is compliant with distribution of the VE on different setups and (4) proposes guidelines to efficiently create a collabo-rative and interactive VE. It is composed of several modules, among them, two core modules : the relation engine and the collaborative interaction engine. On the one hand, the relation engine manages the relations between the objects of the environment. On the other hand, the collaborative interaction engine manages how users can collaboratively control objects. The modules that compose the #FIVE framework can be used either independently or simultaneously , depending on the requirements of the application. They can also communicate and work with other modules thanks to an API. For instance, a scenario engine can be plugged to any or both of the #FIVE modules if the application is scenario-based. #FIVE has already been used in VR applications by several members of our team (see section 6.5). The feedbacks are rather positive and we intend to further develop #FIVE with additional functionalities, notably by extending it to the control of avatars whether they are controlled by a user or by the system.

High-Level Components for Developing Collaborative Scenarios Guillaume Claude, Valérie Gouranton and Bruno Arnaldi

We were interested in the description of activities of actors in Collaborative Virtual Environments for Training to team working on procedures. We have proposed #SEVEN, a model for the description of procedures as

Collaborative Virtuel Environments Scenarios (see also section 6.6). In [25] we have demonstrated the abilities of this model to be adapted to a wide range of use cases. We showed that it can adapt its abstraction level to the required guidance level and describe more or less complex unfolding of events. In [24] we have provided a novel approach to the distribution of the actions between the actors of the simulation by using an action filtering model in conjunction with a reactive team model. The action filtering model uses data about the actors such as their abilities or their rights. Our reactive team model can be used to define relationships between the team members and the effects of inner rules of the team upon the involvement of the actors in the procedure. To our knowledge, our solution is the closest to the existing models proposed by the social science domain known as role theory. Our work has been applied to several domains, including the training of scrub nurses to neurosurgery procedures 10.

Figure 10. The #FIVE and #SEVEN models used in the S3PM project to provide an interactive environment and define collaborative scenarios and handle dynamic team structures in a surgical context.

7.4. Brain-Computer Interfaces

7.4.1. Novel Usages of BCI

Mind-Window: Real-Time Brain Activity Visualization Using Tablet-Based Augmented Reality and EEG for Single or Multiple Users, Anatole Lécuyer, Jonathan Mercier, Maud Marchal

Figure 11. Our novel "Mind-Window" approach enables one or multiple users to visualize the brain activity of a person in real-time by using tablets and augmented reality. It proposes to see through the tablet a virtual brain model "as if the skull is transparent". The display of the virtual brain is updated in real-time according to the real brain activity of the person which is measured thanks to an EEG headset.

We introduced a novel approach, called the “Mind-Window”, for real-time visualization of brain activity [33]. The Mind-Window enables one or multiple users to visualize the brain activity of another person as if his/her skull was transparent. Our approach relies on the use of multiple tablet PCs that the observers can move around the head of the observed person wearing an electroencephalography cap (EEG). A 3D virtual brain model is superimposed to the head of the observed person using augmented reality by tracking a 3D marker placed on top the head. The EEG cap records the electrical fields emitted by the brain, and they are processed in real-time to update the display of the virtual brain model. Several visualization techniques are proposed such as an interactive cutting plane which can be manipulated with touch-based inputs on the tablet. The Mind-Window approach could be used for medical applications, e.g. by providing a simple way for physicians to diagnose and observe brain activity of patients. Teachers could also use our system to teach brain anatomy/activity and EEG features, e.g., electrodes localization, electrical patterns, etc. Finally, video conferences or video games could be “brain-augmented”, making use of the Mind-Window for entertainment purposes.

B-C-Invisibility Power: Optical Camouflage Based on Mental Activity in Augmented Reality, Anatole Lécuyer, Jonathan Mercier, Maud Marchal

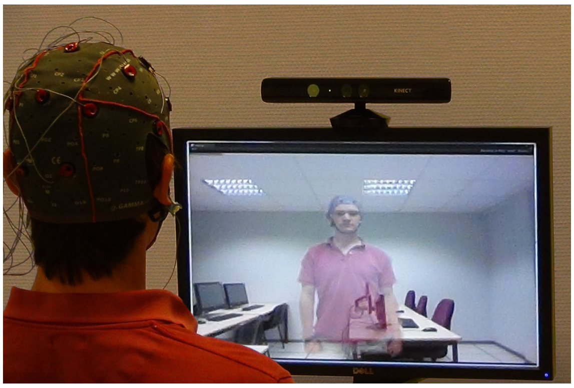

Figure 12. The "B-C-Invisibility power” enables users to become virtually invisible by performing mental tasks. Brain signals are extracted using EEG electrodes and analyzed within the BCI.

In the context of the ANR project HOMO-TEXTILUS which focuses on the design of novel "smart clothes", we introduced a kind of "invisibility cloak": an interactive approach for using Brain-Computer Interfaces for controlling optical camouflage called "B-C-Invisibility power”. We proposed to combine augmented reality and BCI technologies to design a system which somehow provides the "power of becoming invisible” [32]. Our optical camouflage is obtained on a PC monitor combined with an optical tracking system. A cut out image of the user is computed from a live video stream and superimposed to the prerecorded background image using a transparency effect. The transparency level is controlled by the output of a BCI, making the user able to control her invisibility directly with mental activity. The mental task required to increase/decrease the invisibility is related to a concentration/relaxation state. Results from a preliminary study based on a simple video-game inspired by the Harry Potter universe could notably show that, compared to a standard control made with a keyboard, controlling the optical camouflage directly with the BCI could enhance the user experience and the feeling of “having a super-power”.

7.4.2. BCI Methodology and Techniques

A methodological framework for applications combining BCI and videogames, Anatole Lécuyer

We have proposed a user-centered methodological framework [41] to guide design and evaluation of applications based on Brain-Computer Interface (BCI). Our framework is based on the contributions of ergonomics to ensure that these applications are well suited for end-users. It provides methods, criteria and metrics to perform the phases of the human-centered design process aiming to understand the context of use, specify the user needs and evaluate the solutions in order to define design choices. Several ergonomic methods (e.g., interviews, longitudinal studies, user based testing), objective metrics (e.g., task success, number of errors) and subjective metrics (e.g., mark assigned to an item) are suggested to define and measure the usefulness, usability, acceptability, hedonic qualities, appealingness, emotions related to user experience, immersion and presence to be respected. The benefits and contributions of our user centred framework for the ergonomic design of videogames based on BCI were also discussed.

This work was done in collaboration with Fabien Lotte (Inria team POTIOC).

Feasibility and specificity of simultaneous EEG and fMRI, Marsel Mano, Lorraine Perronnet, Jussi Lindgren, Anatole Lécuyer

In the field of fMRI, Arterial Spin Labeling (ASL) imaging relies on control and label radio-frequency pulses. This generates alternate gradient patterns as well as higher specific absorption rate (SAR). To date, only a few studies have addressed the issue of connecting EEG signal to ASL perfusion. Furthermore, previous studies have shown reduced blood-oxygen-level dependent (BOLD) signal-to-noise ratio (SNR) in the presence of EEG. ASL being a low SNR technique, the aim of this study was to assess ASL-EEG at 3T in terms of safety as well as EEG and magnetic resonance signal quality. Our experimental results show that ASL-EEG can be safely performed [20] [38]. Standard ASL acquisitions generated more than 2.5-fold SAR increase compared to a standard BOLD echo planar imaging sequence. This corresponded to up to 4°C temperature increase on the bundle, yet not exceeding 36°C. Gradient artifact correction of the EEG signal by average artifact subtraction was generally good for BOLD-EEG and ASL-EEG. However, residual gradient artifacts affecting 1% of the pulsed ASL-EEG data have to be considered. Further research is needed to understand the artifact variability and to develop an appropriate correction strategy. No residual artifacts were observed for alternating control and label pulses ASL-EEG. Neither a change of the number of reference volumes for artifact subtraction nor an independent component analysis could help tackle this gradient artifact correction issue. Regarding magnetic resonance imaging, a 20% loss in SNR was observed when compared to acquisitions performed without EEG. Taken together our results suggest that EEG and ASL MRI can be simultanously combined for the purpose of real-time experiments which could for instance be envisionned in our HEMISFER project.

This work was done in collaboration with VISAGES team.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Mensia Technologies

Participants: Anatole Lécuyer, Jussi Lindgren.

Mensia Technologies is an Inria start-up company created in November 2012 as a spin-off of Hybrid team. Mensia is focused on wellness and healthcare applications emerging from the BCI and Neurofeedback technologies. The Mensia startup should benefit from the team's expertise and of valuable and proprietary BCI research results. Mensia is based in Rennes and Paris. Anatole Lécuyer and Yann Renard (former Inria expert engineer who designed the OpenViBE software architecture and was involved in team projects for 5 years) are co-founders of Mensia Technologies together with CEO Jean-Yves Quentel.

The on-going contract between Hybrid and Mensia started in November 2013 and supported the transfer of several softwares designed by Hybrid team ("OpenViBE", "StateFinder") related to our BCI activity and our OpenViBE software (section 6.1) to Mensia Technologies for 5 years, for future multimedia or medical applications of Mensia.

8.1.2. MBA Multimedia

Participants: Ferran Argelaguet Sanz, Maud Marchal, Anatole Lécuyer.

This on-going contract started in June 2013 and supported the transfer of several softwares designed by Hybrid team (e.g., "Elastic Images") in the frame of the W3D project to MBA Multimédia company for future applications in the field of multimedia and web design based mainly on HTML5 and Word Press software.

8.1.3. Polymorph Studio

Participants: Ferran Argelaguet Sanz, Maud Marchal, Anatole Lécuyer.

This on-going contract started in June 2013 and supported the transfer of several softwares designed by Hybrid team (e.g., "Pseudo-haptik", "Elastic Images") in the frame of the W3D project to Polymorph Studio company for future applications in the field of multimedia and web design based mainly on Unity3D software.

8.2. Bilateral Grants with Industry

8.2.1. Technicolor

Participants: Antoine Costes, Anatole Lécuyer, Ferran Argelaguet.

This grant started in December 2015. It supports Antoine Costes's CIFRE PhD program with Technicolor company on "Haptic Texturing".

8.2.2. Realyz

Participants: Guillaume Cortes, Anatole Lécuyer.

This grant started in December 2015. It supports Guillaume Cortes's CIFRE PhD program with Realyz company on "Improving tracking in VR".

8.2.3. VINCI

Participants: Anne-Solène Dris-Kerdreux, Bruno Arnaldi, Valérie Gouranton.

This grant started in November 2015. It supports Anne-Solene Dris-Kerdreux's CIFRE PhD program with Vinci company on "Training in VR for construction applications".

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Labex Cominlabs S3PM

Participants: Bruno Arnaldi, Guillaume Claude, Valérie Gouranton [contact].

S3PM ("Synthesis and Simulation of Surgical Process Models") is a 4-year Labex Cominlabs project (2013-2017). S3PM partners are MediCIS - LTSI (coordinator), Hybrid - IRISA/Inria, Hycomes - IRISA/Inria. The objective of S3PM is to propose a solution for the computation of surgical procedural knowledge models from recordings of individual procedures, and their execution. The goal of the Hybrid team is to propose and use new models for collaborative and interactive virtual environments for procedural training. The Hybrid team also works on the creation of a surgical training application in virtual reality, exposing the different contributions.

9.1.2. Labex HEMISFER

Participants: Anatole Lécuyer [contact], Marsel Mano, Lorraine Perronnet.

HEMISFER is a 3-year project (2013-2016) funded by Labex CominLabs. It involves 4 Inria/IRISA teams (Hybrid, Visages (lead), Panama, Athena) and 2 medical centers: the Rennes Psychiatric Hospital (CHGR) and the Reeducation Department of Rennes Hospital (CHU Pontchaillou). The goal of HEMISFER is to make full use of neurofeedback paradigm in the context of rehabilitation and psychiatric disorders. The major breakthrough will come from the use of a coupling model associating functional and metabolic information from Magnetic Resonance Imaging (fMRI) to Electro-encephalography (EEG) to “enhance” the neurofeedback protocol. Clinical applications concern motor, neurological and psychiatric disorders (stroke, attention-deficit disorder, treatment-resistant mood disorders, etc).

9.1.3. Labex SABRE

Participants: Anatole Lécuyer [contact], Jussi Lindgren, Nataliya Kosmina.

SABRE is a 3-year project (2014-2017) funded by Labex CominLabs. It involves 1 Inria/IRISA team (Hybrid) and 2 groups from TELECOM BREST engineering school. The goal of SABRE is to improve computational functionnalities and power of current real-time EEG processing pipelines. The project will investigate innovative EEG solution methods empowered and speeded-up by ad-hoc, transistor-level, implementations of their key algorithmic operations. A completely new family of fully-hardware-integrated, new computational EEG imaging methods will be developed that are expected to speed up the imaging process of an EEG device of several orders of magnitude in real case scenarios.

9.1.4. IRT b<>com

Participants: Bruno Arnaldi [contact], Valérie Gouranton, Maud Marchal.

b<>com is a French Institute of Research and Technology (IRT). The main goal of this IRT is to fasten the development and marketing of tools, products and services in the field of digital technologies. Our team collaborate with b<>com within two 3-year projects: ImData (on "Immersive Interaction") and GestChir (on "Augmented Healthcare").

9.1.5. CNPAO Project

Participants: Valérie Gouranton [contact], Jean-Baptiste Barreau, Quentin Petit.

CNPAO ("Conservatoire Numérique du Patrimoine Archéologique de l'Ouest") is an on-going research project partially funded by the Université Européenne de Bretagne (UEB). It involves IRISA/Hybrid and CReAAH. The main objectives are: (i) a sustainable and centralized archiving of 2D/3D data produced by the archaeological community, (ii) a free access to metadata, (iii) a secure access to data for the different actors involved in scientific projects, and (iv) the support and advice for these actors in the 3D data production and exploration through the latest digital technologies, modeling tools and virtual reality systems.

9.1.6. Imag'In CNRS IRMA

Participants: Bruno Arnaldi, Jean-Baptiste Barreau, Valérie Gouranton [contact].

The IRMA project is an Imag'In project directly funded by CNRS which aims at developping innovative methodologies for research in the field of cultural heritage based on a combination of medical imaging technologies and methods of interactive 3D modalities (virtual reality, augmented reality, haptic, additive manufacturing). These tools are based on recent research results from a close collaboration between Hybrid team with the National Institute of Preventive Archaeological Research (Inrap), the Research Center Archaeology, and History Archéosciences (CReAAH UMR 6566) and the company Image ET, and are intended for cultural heritage professionals such as museums, curators, restorers, and archaeologists. The innovative methodologies proposed in the project gave rise to a real interest in the archaeological community. We worked on a large number of archeological artefacts (15), of different nature, composition and/or fabrication on various time period (Paleolithic, Mesolithic, and Iron Age Medieval) from all over France. We mention in particular: the oldest human bones found in Brittany (clavicle Beg Er Vil), a bone-made flute outcome of an archeo-musicology study conducted at the University of Burgundy, a cremation of the late First Iron Age Guipry (35), metal and organic furniture from the chariot burial of Warcq (08) (horses harnessed skull, char tiller, buckets), a Bronze Cauldron from a burial of the Merovingian necropolis Crassés Saint-Dizier (51). This work involves a strong collaboration with Ronan Gaugne (IMMERSIA), Théophane Nicolas (INRAP), and Grégor Marchand (CReAAH).

9.2. National Initiatives

9.2.1. ANR MANDARIN

Participants: Merwan Achibet, Adrien Girard, Anatole Lécuyer, Maud Marchal [contact].

MANDARIN ("MANipulation Dextre hAptique pour opéRations INdustrielles en RV") is a 4-year ANR project (2012-2015). MANDARIN partners are CEA-List (coordinator), Inria/Hybrid, UTC, Haption and Renault. It aims at designing new hardware and software solutions to achieve natural and intuitive mono and bi-manual dextrous interactions, suitable for virtual environments. The objective of Hybrid in MANDARIN is to design novel multimodal 3D interaction techniques and metaphors allowing to deal with haptic gloves limitations (portability, under-actuation) and to assist the user in virtual reality applications requiring dexterous manipulation. The results will be evaluated with a representative industrial application which is not feasible with currently existing technologies: the bi-manual manipulation of complex rigid objects and cables bundles.

9.2.2. ANR HOMO-TEXTILUS

Participants: Anatole Lécuyer [contact], Maud Marchal, Jonathan Mercier-Ganady.

HOMO-TEXTILUS is a 4-year ANR project (2012-2015). Partners of the project are : Inria/Hybrid, CHART, LIP6, TOMORROW LAND, RCP and potential end-user is Hussein Chalayan fashion designer. The objective of HOMO TEXTILUS is to study what could be the next generation of smart and augmented clothes, and their influence and potential impact on behavior and habits of their users. The project is strongly oriented towards human science, with both user studies and sociological studies. The involvement of Hybrid team in the project consists in studying the design of next-gen prototypes of clothes embedding novel kinds of sensors and actuators. Envisionned sensors relate to physiological measurements such as with EEG (electroencephalograpohy and Brain-Computer Interfaces), EMG (muscular activity), GSR (galvanic skin response) or Heart Rate (HR). Envisionned actuators relate to new sensory stimulations such as vibrotactile displays or novel visual (eg LED) displays. These prototypes will thus be used in the various experiments planned in the project.

9.2.3. FUI Previz

Participants: Bruno Arnaldi [contact], Valérie Gouranton [contact], Emmanuel Badier, Thomas Boggini, Rozenn Bouville Berthelot, Cédric Le Cam.

Previz is a 3-year project (2013-2016) funded by the competitive cluster "Images et Réseaux". Previz involves 4 Academic partners (Hybrid/INSA Rennes, ENS Louis-Lumière, LIRIS, Gipsa-Lab) and 9 Industrial partners (Technicolor, Ubisoft, SolidAnim, loumasystem, Polymorph). Previz aims at proposing new previsualization tools for movie directors. The goal of Hybrid in Previz is to introduce new interactions between real and virtual actors so that the actor's actions, no matter his/her real or virtual nature, impact both the real and the virtual environment. The project will end up with a new production pipeline in order to automatically adapt and synchronize the visual effects (VFX), in space and time, to the real performance of an actor.

9.2.4. ADT MAN-IP

Participant: Valérie Gouranton [contact].

The ADT MAN-IP is a 2-year project (2013-2015) funded by Inria for software support and development. MAN-IP involves two Inria teams: Hybrid and MimeTIC. MAN-IP aims at proposing a common software pipeline for both teams to facilitate the production of populated virtual environments. The resulting software should include functionalities for motion capture, automatic aquisition and modification, and high-level authoring tools.

9.2.5. ADT OpenViBE-NT

Participants: Anatole Lécuyer [contact], Jussi Lindgren [contact].

The ADT OpenViBE-NT is a 3-year project (2012-2015) funded by Inria for support and development of the OpenViBE software (section 6.1). OpenViBE-NT involves four Inria teams: Hybrid, Potioc, Athena, Neurosys - all being extensive users of OpenViBE. OpenViBE-NT aims at improving the current functionalities of OpenViBE platform, and helping in supporting its active and ever growing community of users.

9.2.6. Ilab CertiViBE

Participants: Anatole Lécuyer [contact], Jussi Lindgren, Charles Garraud, Jérôme Chabrol.

CertiViBE is a 1-year "Inria Innovation Lab" (2015-2016) funded by Inria for supporting the development of OpenViBE software, and notably its evolution in order to enable and fasten the medical transfer and the medical certification of products based on OpenViBE. This joint lab involves two partners: Hybrid and Mensia Technologies startup company. The project aims at setting up a quality environment, and developping a novel version of the software wich should comply with medical certification rules.

9.2.7. IPL BCI-LIFT

Participants: Anatole Lécuyer [contact], Jussi Lindgren [contact], Andéol Evain, Lorraine Perronnet, Nataliya Kosmina.

BCI-LIFT is a 4-year "Inria Project Lab" initiative (2015-2019) funded by Inria for supporting a national research effort on Brain-Computer Interfaces. This joint lab involves sevearl Inria teams: Hybrid, Potioc, Athena, Neurosys, Mjolnir, Demar; as well as external partners: INSERM-Lyon, and INSA Rouen. This project aims at improving several aspects of Brain-Computer Interfaces : learning and adaptation of BCI systems, user interfaces and feedback, training protocols, etc.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. HAPPINESS

Title: HAptic Printed Patterned INtErfaces for Sensitive Surface

Programm: H2020

Duration: January 2015 - January 2018

Coordinator: CEA

Partners:

- Arkema France (France)
- Robert Bosch (Germany)
- Commissariat A L'Energie Atomique et Aux Energies Alternatives (France)
- Fundacion Gaiker (Spain)
- Integrated Systems Development S.A. (Greece)
- University of Glasgow (United Kingdom)
- Walter Pak Sl (Spain)

Inria contacts: Nicolas Roussel, Anatole Lécuyer

The Automotive HMI (Human Machine Interface) will soon undergo dramatic changes, with large plastic dashboards moving from the 'push-buttons' era to the 'tactile' era. User demand for aesthetically pleasing and seamless interfaces is ever increasing, with touch sensitive interfaces now commonplace. However, these touch interfaces come at the cost of haptic feedback, which raises concerns regarding the safety of eyeless interaction during driving. The HAPPINESS project intends to address these concerns through technological solutions, introducing new capabilities for haptic feedback on these interfaces. The main goal of the HAPPINESS project is to develop a smart conformable surface able to offer different tactile sensations via the development of a Haptic Thin and Organic Large Area Electronic technology (TOLAE), integrating sensing and feedback capabilities, focusing on user requirements and ergonomic designs. To this aim, by gathering all the value chain actors (materials, technology manufacturing, OEM integrator) for application within the automotive market, the HAPPINESS project will offer a new haptic Human-Machine Interface technology, integrating touch sensing and disruptive feedback capabilities directly into an automotive dashboard. Based on the consortium skills, the HAPPINESS project will demonstrate the integration of Electro-Active Polymers (EAP) in a matrix of mechanical actuators on plastic foils. The objectives are to fabricate these actuators with large area and cost effective printing technologies and to integrate them through plastic molding injection into a small-scale dashboard prototype. We will design, implement and evaluate new approaches to Human-Computer Interaction on a fully functional prototype that combines in packaging both sensors and actuator foils, driven by custom electronics, and accessible to end-users via software libraries, allowing for the reproduction of common and accepted sensations such as Roughness, Vibration and Relief.

9.4. International Research Visitors

9.4.1. Visits of Scientists

We have welcomed Dr. Antonio Capobianco from team IGG (Université de Strasbourg) between November 3rd and December 4th, 2015.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- Bruno Arnaldi was Chair of "Journées de l'AFRV" 2015, Bordeaux, France.

10.1.1.2. Member of the organizing committees

- Bruno Arnaldi was Supporters Chair of IEEE Virtual Reality 2015.
- Ferran Arguelaguet was Research Demos Chair of IEEE Virtual Reality 2015.
- Florian Nouviale was Exhibit Chair of IEEE Virtual Reality 2015.
- Maud Marchal was Research Demos Chair of IEEE Virtual Reality 2015.

10.1.2. Scientific events selection

10.1.2.1. Chair of the conference program committees

- Anatole Lécuyer was Program Chair of IEEE Virtual Reality 2015.

10.1.2.2. Member of the conference program committees

- Bruno Arnaldi was Member of the conference program committee of IEEE Virtual Reality 2015 and Motion in Game 2015.
- Ferran Arguelaguet was Member of the conference program committee of IEEE Virtual Reality 2015, IEEE Symposium on 3D User Interfaces 2015, ACM Virtual Reality Software and Technology 2015, and ACM Symposium on Spatial User Interfaces 2015.
- Maud Marchal was Member of the conference program committee of IEEE Symposium on 3D User Interfaces 2015, ACM Symposium on Virtual Reality Software and Technology 2015.
- Valérie Gouranton was Member of the program committee of 3DCVE Workshop 2015.

10.1.2.3. Reviewer

- Bruno Arnaldi was Reviewer for Motion in Game 2015.
- Ferran Arguelaguet was Reviewer for ACM CHI 2015.
- Maud Marchal was Reviewer for IEEE Virtual Reality 2015, IEEE Symposium on 3D User Interfaces 2015, Worldhaptics 2015, ACM VRST 2015, ACM CHI 2015, ACM MIG 2015, IHM 2015.
- Valérie Gouranton was Reviewer for IEEE Virtual Reality 2015.

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- Anatole Lécuyer is Associate Editor of Frontiers in Virtual Environments, and Presence:Teleoperators and Virtual Environments.
- Ferran Arguelaguet is Review Editor of Frontiers in Virtual Environments.
- Maud Marchal is Associate Editor of Computer Graphics Forum, Review Editor of Frontiers in Virtual Environments, and Member of the Editorial Board of Revue Francophone d'Informatique Graphique.

10.1.3.2. Reviewer - Reviewing activities

- Ferran Arguelaguet was Reviewer for IEEE Transactions on Visualization and Computer Graphics.
- Maud Marchal was Reviewer for IEEE Transactions on Visualization and Computer Graphics, IEEE Transactions on Haptics, IEEE Transactions on Automation Science and Engineering, SMC Magazine, Presence, Medical Image Analysis.
- Valérie Gouranton was Reviewer for Revue d'Intelligence Artificielle.

10.1.4. Invited talks

- Maud Marchal was invited at Journées Jeunes Chercheurs de l'Association Française en Informatique Graphique 2015.

10.1.5. Leadership within the scientific community

- Bruno Arnaldi is Vice-President of AFRV (French Association for Virtual Reality).
- Valérie Gouranton is Member of Executive Committee of AFRV.

10.1.6. Scientific expertise

- Valérie Gouranton was Expert for French ANR (Agence Nationale de la Recherche).

10.1.7. Research administration

- Bruno Arnaldi is Deputy Director of IRISA and Vice-President of Scientific Committee of INSA de Rennes
- Maud Marchal is Co-Head of MRI Master Research in Computer Science since August 2015.
- Valérie Gouranton was Co-Head of MRI Master Research in Computer Science until August 2015.

10.2. Teaching - Supervision - Juries

Anatole Lécuyer:

Master MNRV: "Haptic Interaction", 9h, M2, ENSAM, Laval, FR

Ecole Centrale de Nantes : “Haptic Interaction and Brain-Computer Interfaces”, 4,5h, M1-M2, Ecole Centrale de Nantes, FR

Master SIBM: "Haptic and Brain-Computer Interfaces", 4,5h, M2, University of Rennes 1, FR

Bruno Arnaldi:

Master INSA Rennes: "VAR: Virtual and Augmented Reality", 12h, M2, INSA Rennes, FR

Master INSA Rennes: "Virtual Reality", 6h, M2, INSA Rennes, FR

Master INSA Rennes: Projects on "Virtual Reality", 20h, M1, INSA Rennes, FR

Ferran Argelaguet:

Master STS Informatique MITIC: "Techniques d'Interaction Avancées", 26h, M2, ISTIC, University of Rennes 1, FR

Maud Marchal:

Master INSA Rennes: "Modeling and Engineering for Biology and Health Applications", 48h, M2 and responsible of this lecture, INSA Rennes, FR

Master SIBM: "Biomedical simulation", 3h, M2, University of Rennes 1, FR

Valérie Gouranton:

Licence: "Introduction to Virtual Reality", 12h, L2 and responsible of this lecture, INSA Rennes, FR

Licence: Project on "Virtual Reality", 16h, L3 and responsible of this lecture, INSA Rennes, FR

Master INSA Rennes: "Virtual Reality", 16h, M2, INSA Rennes, FR

Master INSA Rennes: Projects on "Virtual Reality", 30h, M1, INSA Rennes, FR

10.2.1. Supervision

PhD : Merwan Achibet, "Contributions to the Design of Novel Hand-Based Interaction Techniques for Virtual Environments", INSA Rennes, December 14th, Supervised by M. Marchal and A. Lécuyer

PhD : Jonathan Mercier, "Contribution to the Study of the Use of Brain-Computer Interfaces in Virtual and Augmented Reality", INSA Rennes, October 12th 2015, Supervised by M. Marchal and A. Lécuyer

PhD in progress: Jean-Baptiste Barreau, "Virtual Reality and Archaelogy", Started in February 2014, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: Benoit Le Gouis, "Multi-scale physical simulation", Started in October 2014, Supervised by B. Arnaldi, M. Marchal and A. Lécuyer

PhD in progress: Lorraine Perronet, "Neurofeedback applications based on EEG, fMRI and VR", Started in January 2014, Supervised by C. Barillot and A. Lécuyer

PhD in progress: Jérémy Lacoche, "Plasticity for user interfaces in mixed reality", Started in September 2013 at b<>com Research Institute, Supervised by T. Duval, B. Arnaldi, É. Maisel and J. Royan

PhD in progress: Morgan Le Chénéchal, "Activity and perception for distant collaboration in virtual environments", Started in September 2013 at b<>com Research Institute, Supervised by B. Arnaldi, T. Duval, V. Gouranton and J. Royan

PhD in progress: Lucas Royer, "Visualization tools for needle insertion in interventional radiology", Started in September 2013 at b<>com Research Institute, Supervised by A. Krupa, M. Marchal and G. Dardenne

PhD in progress: Andéol Evain, "BCI-based Interaction", Started in September 2013, Supervised by N. Roussel, G. Casiez, F. Argelaguet and A. Lécuyer

PhD in progress: Guillaume Claude, "Synthesis and Simulation of Process Models ", Started in September 2013, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: François Lehericey, "Collision Detection HPC", Started in October 2013, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: Gwendal Le Moulec, "Automatic generation of VR applications", Started in October 2015, Supervised by V. Gouranton, B. Arnaldi and A. Blouin (Team Diverse)

PhD in progress: Anne-Solène Dris-Kerdreux, "Training in virtual reality for construction applications", Started in November 2015, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: Antoine Costes, "Haptic texturing", Started in November 2015, Supervised by A. Lécuyer and F. Argelaguet

PhD in progress: Guillaume Cortes, "Improving tracking in VR", Started in November 2015, Supervised by A. Lécuyer

10.2.2. Juries

10.2.2.1. Selection committees

- Bruno Arnaldi was President of Selection committee of Full-time Professor Position at University of Rennes 1 (ISTIC) and Member of Selection committee of Full-time Professor Position at University of Rennes 1 (ENSSAT) and and Member of Selection committee of Full-time Professor Position at Ecole Normale Supérieure de Rennes.
- Maud Marchal was Member of Selection committee of Research Scientist (CR2 and CR1) Inria Nancy.

10.2.2.2. PhD and HDR juries

- Anatole Lécuyer was Member of PhD juries of Merwan Achibet (INSA de Rennes), Jonathan Mercier (INSA de Rennes), Lucile Dupin (Univ. Paris 5), Jérémy Frey (Univ. Bordeaux), Toinon Vigier (Ecole Centrale de Nantes), and Member of HDR committee of Reinhold Scherer (TU Graz, Austria).
- Bruno Arnaldi was President of PhD juries of Merwan Achibet (INSA de Rennes), Jonathan Mercier (INSA de Rennes), Kevin Jordao (INSA de Rennes), Karl Jorgensen (University of Rennes 1), Steve Tonneau (INSA de Rennes) and Member of PhD jury of Mukesh Barange (ENIB Brest), Siju WU (Evry University)
- Maud Marchal was Member of PhD juries of Merwan Achibet (INSA de Rennes), Julien Bosman (Univ. Lille 1), Jonathan Mercier (INSA de Rennes), Alvaro Perez (Univ. Rey Juan Carlos, Madrid, Spain).

10.3. Popularization

The team has participated to numerous events in 2015 :

- "Futur en Seine 2015" (Paris, 05/15) : booth and demo of the PREVIZ project results.
- "Festival de la Science 2015" (Rennes, 10/15) : booth and demos of the team.
- "Journées Science et Musique 2015" (Rennes, 11/15) : co-organization of this event, and presentation of several demos.
- Technoférence du Pôle Images et Réseaux (Rennes, 02/15) : presentation from Anatole Lécuyer on VR.

The results of the team were also disseminated in several TV appearances and media coverages :

- « Télématin », France2 channel (02/15) : presentation of the Mind-Mirror system.
- « On est pas que des cobayes », France 3 channel (04/15) : presentation and testings of the FlyVIZ system.
- « E=M6 », M6 channel (05/15) : presentation and testing of the Mind-Mirror system.
- « Thalassa », France3 channel (05/15) : presentation of several cultural heritage applications of Hybrid.
- « Future Mag », Arte channel (12/15) : presentation of several cultural heritage applications of Hybrid.

11. Bibliography

Major publications by the team in recent years

[1] M. Achibet, G. Casiez, A. Lécuyer, M. Marchal. *THING: Introducing a Tablet-based Interaction Technique for Controlling 3D Hand Models*, in "In Proceedings of CHI'15, the 33th Conference on Human Factors in Computing Systems", Seoul, South Korea, A. Press (editor), April 2015, pp. 317-326 [*DOI :* 10.1145/2702123.2702158], https://hal.inria.fr/hal-01252496

[2] G. CIRIO, M. MARCHAL, S. HILLAIRE, A. LÉCUYER. *Six Degrees-of-Freedom Haptic Interaction with Fluids*, in "IEEE Transactions on Visualization and Computer Graphics", 2011, vol. 17, n° 11, pp. 1714-1727, http://hal.archives-ouvertes.fr/hal-00642814

[3] F. DANIEAU, J. FLEUREAU, P. GUILLOTEL, N. MOLLET, M. CHRISTIE, A. LÉCUYER. *Toward Haptic Cinematography: Enhancing Movie Experience with Haptic Effects based on Cinematographic Camera Motions*, in "IEEE MultiMedia", January 2014, https://hal.inria.fr/hal-00918074

[4] L. GLONDU, M. MARCHAL, G. DUMONT. *Real-Time Simulation of Brittle Fracture using Modal Analysis*, in "IEEE Transactions on Visualization and Computer Graphics", 2012, vol. 19, n° 2, pp. 201-209, http://hal.inria.fr/hal-00752372

[5] T. LOPEZ, R. BOUVILLE BERTHELOT, E. LOUP-ESCANDE, F. NOUVIALE, V. GOURANTON, B. ARNALDI. *Exchange of avatars : Toward a better perception and understanding*, in "IEEE Transactions on Visualization and Computer Graphics", March 2014, pp. 1-10, https://hal.archives-ouvertes.fr/hal-01003200

[6] T. LOPEZ, P. CHEVAILLIER, V. GOURANTON, P. EVRARD, F. NOUVIALE, M. BARANGE, R. BOUVILLE BERTHELOT, B. ARNALDI. *Collaborative Virtual Training with Physical and Communicative Autonomous Agents*, in "Computer Animation and Virtual Worlds", May 2014, pp. 1-9, https://hal.archives-ouvertes.fr/hal-01003212

[7] A. LÉCUYER. *Simulating Haptic Feedback Using Vision: A Survey of Research and Applications of Pseudo-haptic Feedback*, in "Presence: Teleoper. Virtual Environ.", 2009, vol. 18, n° 1, pp. 39–53, http://dx.doi.org/10.1162/pres.18.1.39

[8] A. LÉCUYER, L. GEORGE, M. MARCHAL. *Toward Adaptive VR Simulators Combining Visual, Haptic, and Brain-Computer Interfaces*, in "IEEE Computer Graphics and Applications", September 2013, vol. 33, n° 5, pp. 18-23 [*DOI :* 10.1109/MCG.2013.80], http://hal.inria.fr/hal-00934846

[9] T. NICOLAS, R. GAUGNE, C. TAVERNIER, Q. PETIT, V. GOURANTON, B. ARNALDI. *Touching and interacting with inaccessible cultural heritage*, in "Presence: Teleoperators and Virtual Environments", 2015, vol. 24, n° 3, https://hal.inria.fr/hal-01218223

[10] Y. RENARD, F. LOTTE, G. GIBERT, M. CONGEDO, E. MABY, V. DELANNOY, O. BERTRAND, A. LÉCUYER. *OpenViBE: An Open-Source Software Platform to Design, Test and Use Brain-Computer Interfaces in Real and Virtual Environments*, in "Presence: Teleoperators and Virtual Environments", 2010, vol. 19, n° 1, pp. 35-53, http://hal.archives-ouvertes.fr/hal-00477153

Publications of the year

Articles in International Peer-Reviewed Journals

[11] F. ARGELAGUET SANZ, F. MULTON, A. LÉCUYER. *A methodology for introducing competitive anxiety and pressure in VR sports training*, in "Frontiers in Robotics and AI", April 2015, vol. 2, n° 10, 11 p. [*DOI :* 10.3389/FROBT.2015.00010], https://hal.inria.fr/hal-01140454

[12] J.-B. BARREAU, F. NOUVIALE, R. GAUGNE, Y. BERNARD, S. LLINARES, V. GOURANTON. *An Immersive Virtual Sailing on the 18 th -Century Ship Le Boullongne*, in "Presence: Teleoperators and Virtual Environments", 2015, vol. 24, n° 3, https://hal.inria.fr/hal-01218209

[13] C. ESSERT, S. FERNANDEZ-VIDAL, A. CAPOBIANCO, C. HAEGELEN, C. KARACHI, E. BARDINET, M. MARCHAL, P. JANNIN. *Statistical study of parameters for deep brain stimulation automatic preoperative planning of electrodes trajectories*, in "International Journal of Computer Assisted Radiology and Surgery", July 2015 [*DOI :* 10.1007/S11548-015-1263-5], https://hal-univ-rennes1.archives-ouvertes.fr/hal-01207334

[14] L. LAPORTE, C. BIZIEN-JAGLIN, J. WATTEZ, J.-N. GUYODO, J.-B. BARREAU, Y. BERNARD, D. AOUSTIN, V. GUITTON, G. HAMON, L. JALLOT, A. LUCQUIN, R. MARCH, N. MARCOUX, E. MENS, L. SOLER, E. WERTHE. *Another brick in the wall: fifth millennium BC earthen-walled architecture on the Channel shores*, in "Antiquity", 2015, vol. 89, n^o 346, pp. 800–817 [*DOI :* 10.15184/AQY.2015.55], https://hal-univ-rennes1.archives-ouvertes.fr/hal-01245165

[15] T. NICOLAS, R. GAUGNE, C. TAVERNIER, Q. PETIT, V. GOURANTON, B. ARNALDI. *Touching and interacting with inaccessible cultural heritage*, in "Presence: Teleoperators and Virtual Environments", 2015, vol. 24, n^o 3, https://hal.inria.fr/hal-01218223

[16] A. TALVAS, M. MARCHAL, C. DURIEZ, M. A. OTADUY. *Aggregate Constraints for Virtual Manipulation with Soft Fingers*, in "IEEE Transactions on Visualization and Computer Graphics", January 2015, vol. 21, n^o 4, 9 p. [*DOI :* 10.1109/TVCG.2015.2391863], https://hal.inria.fr/hal-01246562

International Conferences with Proceedings

[17] M. ACHIBET, G. CASIEZ, A. LÉCUYER, M. MARCHAL. *THING: Introducing a Tablet-based Interaction Technique for Controlling 3D Hand Models*, in "In Proceedings of CHI'15, the 33th Conference on Human Factors in Computing Systems", Seoul, South Korea, A. PRESS (editor), April 2015, pp. 317-326 [*DOI :* 10.1145/2702123.2702158], https://hal.inria.fr/hal-01252496

[18] M. ACHIBET, A. GIRARD, A. TALVAS, M. MARCHAL, A. LÉCUYER. *Elastic-Arm: Human-scale passive haptic feedback for augmenting interaction and perception in virtual environments*, in "Proceedings of IEEE Virtual Reality Conference", Arles, France, March 2015, pp. 63-68 [*DOI :* 10.1109/VR.2015.7223325], https://hal.inria.fr/hal-01252555

[19] F. ARGELAGUET SANZ, A.-H. OLIVIER, G. BRUDER, J. PETTRÉ, A. LÉCUYER. *Virtual Proxemics: Locomotion in the Presence of Obstacles in Large Immersive Projection Environments*, in "Proceedings of IEEE Virtual Reality Conference", Arles, France, March 2015, pp. 75 - 80, https://hal.inria.fr/hal-01149962

[20] E. BANNIER, M. MANO, S. ROBERT, I. COROUGE, L. PERRONNET, J. LINDGREN, A. LÉCUYER, C. BARILLOT. *On the feasibility and specificity of simultaneous EEG and ASL MRI at 3T*, in "Proceedings of ISMRM", Toronto, Canada, May 2015, http://www.hal.inserm.fr/inserm-01113276

[21] J.-B. BARREAU, Q. PETIT, Y. BERNARD, R. AUGER, Y. LE ROUX, R. GAUGNE, V. GOURANTON. *3D reconstitution of the loyola sugar plantation and virtual reality applications*, in "Proceedings of Computer Applications & Quantitative Methods in Archaeology, CAA", Sienna, Italy, 2015, https://hal.inria.fr/hal-01244849

[22] R. BOUVILLE, V. GOURANTON, T. BOGGINI, F. NOUVIALE, B. ARNALDI. *#FIVE : High-Level Components for Developing Collaborative and Interactive Virtual Environments*, in "Proceedings of Eighth Workshop on Software Engineering and Architectures for Realtime Interactive Systems (SEARIS 2015), conjunction with IEEE Virtual Reality (VR)", Arles, France, March 2015, https://hal-univ-rennes1.archives-ouvertes.fr/hal-01147734

[23] G. BRUDER, F. ARGELAGUET SANZ, A.-H. OLIVIER, A. LÉCUYER. *Distance Estimation in Large Immersive Projection Systems, Revisited*, in "Proceedings of IEEE Virtual Reality Conference", Arles, France, March 2015, https://hal.inria.fr/hal-01149964

[24] G. CLAUDE, V. GOURANTON, B. ARNALDI. *Roles in Collaborative Virtual Environments for Training*, in "Proceedings of International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments", Kyoto, Japan, M. IMURA, P. FIGUEROA, B. MOHLER (editors), 2015, pp. 1-8, https://hal.archives-ouvertes.fr/hal-01199738

[25] G. CLAUDE, V. GOURANTON, B. ARNALDI. *Versatile Scenario Guidance for Collaborative Virtual Environments*, in "Proceedings of 10th International Conference on Computer Graphics Theory and Applications (GRAPP'15)", berlin, Germany, March 2015, https://hal-univ-rennes1.archives-ouvertes.fr/hal-01147733

[26] J. LACOCHE, T. DUVAL, B. ARNALDI, É. MAISEL, J. ROYAN. *Plasticity for 3D User Interfaces: new Models for Devices and Interaction Techniques*, in "Proceedings of EICS 2015 : 7th ACM SIGCHI Symposium on Engineering Interactive Computing Systems", Duisburg, Germany, June 2015, pp. 28 - 33 [*DOI :* 10.1145/2774225.2775073], https://hal.archives-ouvertes.fr/hal-01175000

[27] J. LACOCHE, M. LE CHÉNÉCHAL, S. CHALMÉ, J. ROYAN, T. DUVAL, V. GOURANTON, É. MAISEL, B. ARNALDI. *Dealing with Frame Cancellation for Stereoscopic Displays in 3D User Interfaces*, in "Proceedings of 10th IEEE Symposium on 3D User Interfaces", Arles, France, March 2015, pp. 73 - 80, https://hal.archives-ouvertes.fr/hal-01157886

[28] M. LE CHÉNÉCHAL, S. CHALMÉ, T. DUVAL, J. ROYAN, V. GOURANTON, B. ARNALDI. *Toward an Enhanced Mutual Awareness in Asymmetric CVE*, in "Proceedings of International Conference on Collaboration Technologies and Systems (CTS 2015)", Atlanta, United States, 2015, https://hal-univ-rennes1.archives-ouvertes.fr/hal-01147753

[29] M. LE CHÉNÉCHAL, T. DUVAL, V. GOURANTON, J. ROYAN, B. ARNALDI. *The Stretchable Arms for Collaborative Remote Guiding*, in "Proceedings of International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments", Kyoto, Japan, 2015, https://hal.inria.fr/hal-01218184

[30] F. LEHERICEY, V. GOURANTON, B. ARNALDI. *GPU Ray-Traced Collision Detection for Cloth Simulation*, in "Proceedings of ACM Symposium on Virtual Reality Software and Technology", Pékin, China, 2015, https://hal.inria.fr/hal-01218186

[31] F. LEHERICEY, V. GOURANTON, B. ARNALDI. *GPU Ray-Traced Collision Detection: Fine Pipeline Reorganization*, in "Proceedings of 10th International Conference on Computer Graphics Theory and Applications (GRAPP'15)", Berlin, Germany, March 2015, https://hal-univ-rennes1.archives-ouvertes.fr/hal-01147732

[32] J. MERCIER-GANADY, M. MARCHAL, A. LÉCUYER. *B-C-invisibility power: introducing optical camouflage based on mental activity in augmented reality*, in "Proceedings of the 6th ACM Augmented Human International Conference", Singapour, Singapore, March 2015, pp. 97-100 [*DOI :* 10.1145/2735711.2735835], https://hal.inria.fr/hal-01252562

[33] J. MERCIER-GANADY, M. MARCHAL, A. LÉCUYER. *The mind-window: brain activity visualization using tablet-based AR and EEG for multiple users*, in "Proceedings of the 6th ACM Augmented Human International Conference", Singapour, Singapore, March 2015 [*DOI :* 10.1145/2735711.2735809], https://hal.inria.fr/hal-01252572

[34] L. ROYER, G. DARDENNE, A. LE BRAS, M. MARCHAL, A. KRUPA. *Tracking of Non-rigid Targets in 3D US Images: Results on CLUST 2015*, in "Proceedings of MICCAI 2015 Challenge on Liver Ultrasound Tracking", Munich, Germany, October 2015, https://hal.inria.fr/hal-01242227

[35] L. ROYER, M. MARCHAL, A. LE BRAS, G. DARDENNE, A. KRUPA. *Real-time Tracking of Deformable Target in 3D Ultrasound Images*, in "Proceedings of IEEE International Conference on Robotics and Automation (ICRA'15)", Seattle, United States, May 2015, https://hal.inria.fr/hal-01122026

[36] L. ROYER, M. MARCHAL, A. LE BRAS, G. DARDENNE, A. KRUPA. *Tracking of Deformable Target in 2D Ultrasound Images*, in "Proceedings of SPIE Medical Imaging Conference", Orlando, United States, February 2015, https://hal.archives-ouvertes.fr/hal-01080672

National Conferences with Proceedings

[37] M. ACHIBET, A. GIRARD, M. MARCHAL, A. LÉCUYER. *Elastic-Arm: A Novel Human-Scale Passive Haptic Approach for Augmenting Interaction and Perception in Virtual Environments*, in "Proceedings of Journées de l'Association Française de la Réalité Virtuelle", Bordeaux, France, October 2015, https://hal.inria.fr/hal-01255936

[38] E. BANNIER, M. MANO, S. ROBERT, I. COROUGE, L. PERRONNET, J. LINDGREN, A. LÉCUYER, C. BARILLOT. *Faisabilité et spécificités de l'ASL-EEG simultané à 3T*, in "SFRMBM", Grenoble, France, March 2015, http://www.hal.inserm.fr/inserm-01113279

[39] F. LEHERICEY, V. GOURANTON, B. ARNALDI. *Extended version: GPU Ray-Traced Collision Detection for Cloth Simulation*, in "Proceedings of Journées de l'Association Française de la Réalité Virtuelle", Bordeaux, France, 2015, https://hal.inria.fr/hal-01223152

Scientific Books (or Scientific Book chapters)

[40] T. HACHISU, G. CIRIO, M. MARCHAL, A. LÉCUYER, H. KAJIMOTO. *Visual Vibrations to Simulate Taps on Different Materials*, in "Haptic Interaction - Perception, Devices and Applications", Lecture Notes in Electrical Engineering, Springer, June 2015, vol. 277, pp. 297-303 [*DOI :* 10.1007/978-4-431-55690-9_54], https://hal.inria.fr/hal-01252665

[41] E. LOUP-ESCANDE, F. LOTTE, G. LOUP, A. LÉCUYER. *User-Centred BCI Videogame Design*, in "Handbook of Digital Games and Entertainment Technologies", R. NAKATSU, M. RAUTERBERG, P. CIANCARINI (editors), Springer, 2015 [*DOI :* 10.1007/978-981-4560-52-8_3-1], https://hal.inria.fr/hal-01230571

References in notes

[42] D. A. BOWMAN, E. KRUIJFF, J. J. LAVIOLA, I. POUPYREV. *3D User Interfaces: Theory and Practice*, Addison Wesley, 2004

[43] T. DUVAL, C. FLEURY. *PAC-C3D: A New Software Architectural Model for Designing 3D Collaborative Virtual Environments*, in "ICAT 2011", Osaka, Japan, VRSJ, November 2011, pp. 53-60, https://hal.inria.fr/inria-00636143

[44] A. LÉCUYER. *Simulating Haptic Feedback Using Vision: A Survey of Research and Applications of Pseudo-Haptic Feedback*, in "Presence: Teleoperators and Virtual Environments", January 2009, vol. 18, n^{o} 1, pp. 39–53, http://www.mitpressjournals.org/doi/abs/10.1162/pres.18.1.39