Activity Report 2018

Team HYBRID

3D Interaction with Virtual Environments using Body and Mind

Joint team with Inria Rennes – Bretagne Atlantique

D6 – Media and Interactions

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Project-Team HYBRID

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

Keywords:

Computer Science and Digital Science:

A2.5. - Software engineering
A5. - Interaction, multimedia and robotics
A5.1. - Human-Computer Interaction
A5.1.1. - Engineering of interactive systems
A5.1.2. - Evaluation of interactive systems
A5.1.3. - Haptic interfaces
A5.1.4. - Brain-computer interfaces, physiological computing
A5.1.5. - Body-based interfaces
A5.1.6. - Tangible interfaces
A5.1.7. - Multimodal interfaces
A5.1.8. - 3D User Interfaces
A5.1.9. - User and perceptual studies
A5.5.4. - Animation
A5.6. - Virtual reality, augmented reality
A5.6.1. - Virtual reality
A5.6.2. - Augmented reality
A5.6.3. - Avatar simulation and embodiment
A5.6.4. - Multisensory feedback and interfaces
A5.10.5. - Robot interaction (with the environment, humans, other robots)
A6. - Modeling, simulation and control
A6.2. - Scientific computing, Numerical Analysis & Optimization
A6.3. - Computation-data interaction

Other Research Topics and Application Domains:

B1.2. - Neuroscience and cognitive science
B2. - Health
B2.4. - Therapies
B2.5. - Handicap and personal assistances
B2.6. - Biological and medical imaging
B2.7. - Medical devices
B2.7.1. - Surgical devices
B2.8. - Sports, performance, motor skills
B5. - Industry of the future
B5.1. - Factory of the future
B5.2. - Design and manufacturing
B5.6. - Robotic systems
B5.8. - Learning and training
B5.9. - Industrial maintenance

B6.4. - Internet of things
B8.1. - Smart building/home
B8.3. - Urbanism and urban planning
B9.1. - Education
B9.2. - Art
B9.2.2. - Cinema, Television
B9.2.3. - Video games
B9.4. - Sports
B9.6.6. - Archeology, History

1. Team, visitors, external collaborators

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2. Overall Objectives

2.1. Overall Objectives

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 in 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).

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 [51]: 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

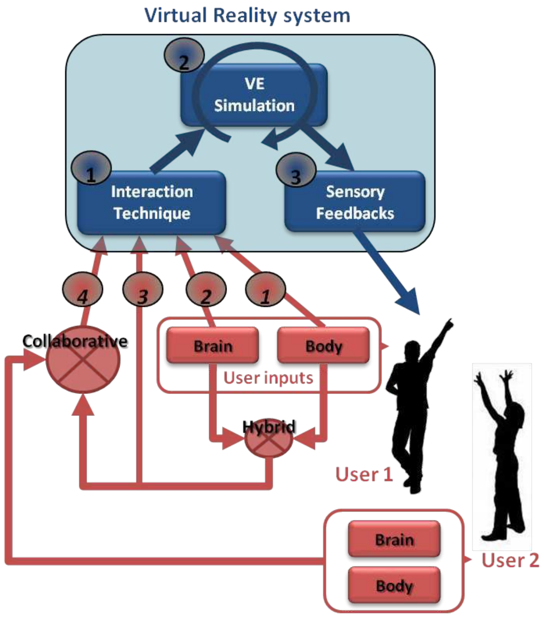

Figure 1. 3D hybrid interaction loop between one or multiple users and a virtual reality system. Top (in blue) three steps of 3D interaction with a virtual environment: (1-blue) interaction technique, (2-blue) simulation of the virtual environment, (3-blue) sensory feedbacks. Bottom (in red) different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

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 [52]. 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

- This year, the Hybrid team has again been strongly involved in the organization of the IEEE Virtual Reality Conference (IEEE VR) in 2018, with M. Marchal: Program Chair, F. Argelaguet: Workshops Chair, A. Lécuyer: Tutorials Chair.
- Hybrid was involved in the publication of a book [49] on Virtual and Augmented Reality, titled "Virtual Reality, Augmented Reality: myths and realities". This book was co-edited by B. Arnaldi and G. Moreau, with contributions [45] [43] [44] from F. Argelaguet, V. Gouranton, A. Lécuyer, M. Marchal, and J.M. Normand.
- Hybrid was involved in the organization of the ACM/Eurographics Symposium on Computer Animation (SCA), in Paris, July 2018, with M. Marchal serving as General Chair.
- Hybrid organized, together with Inria team Visages, a press conference in Paris on the topic of "Neurofeedback" in November 2018, followed by various media coverages.

5.1.1. Awards

- Maud Marchal is junior member of Institut Universitaire de France (IUF) since October 2018.
- Best Paper Award IEEE VR 2018 - Honorable Mention: Paper from Jeunet et al. [18]
- Best Paper Award Euro VR 2018 - Honorable Mention: Paper from Costes et al. [31]
- Best Demo Award IEEE 3DUI Contest 2018 - Runner-Up: Demo from Nouviale et al. [28]

6. New Software and Platforms

6.1. #FIVE

Framework for Interactive Virtual Environments
KEYWORDS: Virtual reality - 3D - 3D interaction - Behavior modeling

SCIENTIFIC DESCRIPTION: #FIVE (Framework for Interactive Virtual Environments) is a framework for the development of interactive and collaborative virtual environments. #FIVE was developed to answer the need for an easier and a faster design and development of virtual reality applications. #FIVE provides a toolkit that simplifies the declaration of possible actions and behaviours of objects in a VE. It also provides a toolkit that facilitates the setting and the management of collaborative interactions in a VE. It is compliant with a distribution of the VE on different setups. It also proposes guidelines to efficiently create a collaborative and interactive VE. The current implementation is in C# and comes with a Unity3D engine integration, compatible with MiddleVR framework.
FUNCTIONAL DESCRIPTION: #FIVE contains software modules that can be interconnected and helps in building interactive and collaborative virtual environments. The user can focus on domain-specific aspects for his/her application (industrial training, medical training, etc) thanks to #FIVE's modules. These modules can be used in a vast range of domains using virtual reality applications and requiring interactive environments and collaboration, such as in training for example.

- Participants: Florian Nouviale, Valérie Gouranton, Bruno Arnaldi, Vincent Goupil, Carl-Johan Jorgensen, Emeric Goga, Adrien Reuzeau and Alexandre Audinot
- Contact: Valérie Gouranton
- Publication: hal-01147734
- URL: https://bil.inria.fr/fr/software/view/2527/tab

6.2. #SEVEN

Sensor Effector Based Scenarios Model for Driving Collaborative Virtual Environments
KEYWORDS: Virtual reality - Interactive Scenarios - 3D interaction
SCIENTIFIC DESCRIPTION: #SEVEN (Sensor Effector Based Scenarios Model for Driving Collaborative Virtual Environments) is a model and an engine based on petri nets extended with sensors and effectors, enabling the description and execution of complex and interactive scenarios
FUNCTIONAL DESCRIPTION: #SEVEN enables the execution of complex scenarios for driving Virtual Reality applications. #SEVEN's scenarios are based on an enhanced Petri net model which is able to describe and solve intricate event sequences. #SEVEN comes with an editor for creating, editing and remotely controlling and running scenarios. #SEVEN is implemented in C# and can be used as a stand-alone application or as a library. An integration to the Unity3D engine, compatible with MiddleVR, also exists.

- Participants: Florian Nouviale, Valérie Gouranton, Bruno Arnaldi, Vincent Goupil, Emeric Goga, Carl-Johan Jorgensen, Adrien Reuzeau and Alexandre Audinot
- Contact: Valérie Gouranton
- Publications: hal-01147733 - hal-01199738 - tel-01419698 - hal-01086237
- URL: https://bil.inria.fr/fr/software/view/2528/tab

6.3. OpenVIBE

KEYWORDS: Neurosciences - Interaction - Virtual reality - Health - Real time - Neurofeedback - Brain-Computer Interface - EEG - 3D interaction

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 60000 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: Cédric Riou, Thierry Gaugry, Anatole Lécuyer, Fabien Lotte, Jussi Tapio Lindgren, Laurent Bougrain, Maureen Clerc and Théodore Papadopoulo
- Partners: INSERM - GIPSA-Lab
- Contact: Anatole Lécuyer
- URL: http://openvibe.inria.fr

6.4. Platforms

6.4.1. Platform: Immerstar

- Participants: Florian Nouviale, Ronan Gaugne
- URL: http://www.irisa.fr/immersia/

With the two virtual reality technological platforms Immersia and Immermove, grouped under the name Immerstar, the team has access to high-level scientific facilities. This equipment benefits the research teams of the center and has allowed them to extend their local, national and international collaborations. The Immerstar platform was granted by an Inria funding for the 2015-2019 period which enables several important evolutions. In particular, in 2018, an haptic system covering the entire volume of the Immersia platform has been installed, allowing various configurations from single haptic device usage to dual haptic devices usage with either one or two users. In addition, a motion platform designed to introduce motion feedback in powered wheelchair simulations has also been incorporated (see Figure 2).

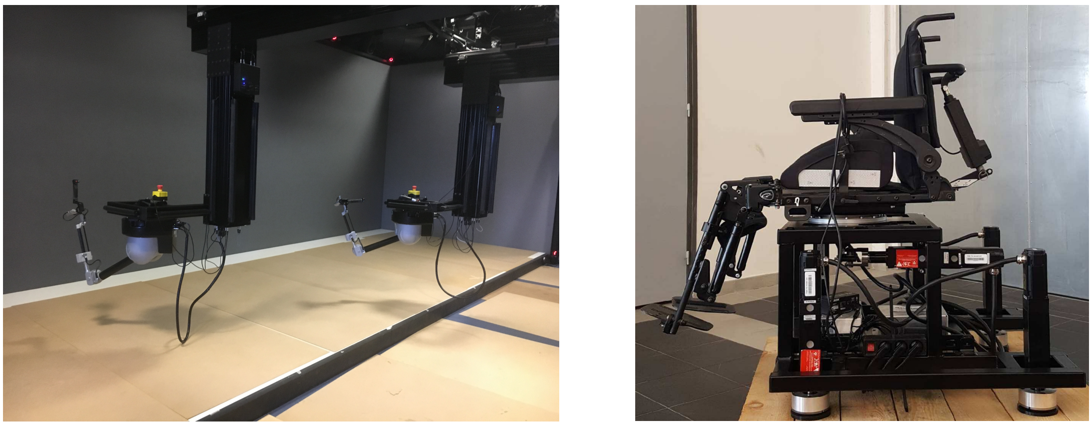

Figure 2. Upgrade of the Immersia platform: two new devices installed. (Left) "Scale-One" Haptic system for one or two users. (Right) Motion platform for powered wheelchair simulation.

7. New Results

7.1. Virtual Reality Tools and Usages

7.1.1. Virtual Embodiment

Studying the Sense of Embodiment in VR Shared Experiences
Participants: Rebecca Fribourg, Ferran Argelaguet, Anatole Lécuyer

In [35], we explored the influence of sharing a virtual environment with another user on the sense of embodiment in virtual reality. For this aim, we conducted an experiment where users were immersed in a virtual environment while being embodied in an anthropomorphic virtual representation of themselves. To evaluate the influence of the presence of another user, two situations were studied: either users were immersed alone, or in the company of another user (see Figure 3). During the experiment, participants performed a virtual version of the well-known whac-a-mole game, therefore interacting with the virtual environment, while sitting at a virtual table. Our results show that users were significantly more "efficient" (i.e., faster reaction times), and accordingly more engaged, in performing the task when sharing the virtual environment, in particular for the more competitive tasks. Also, users experienced comparable levels of embodiment both when immersed alone or with another user. These results are supported by subjective questionnaires but also through behavioural responses, e.g. users reacting to the introduction of a threat towards their virtual body. Taken together, our results show that competition and shared experiences involving an avatar do not influence the sense of embodiment, but can increase user engagement. Such insights can be used by designers of virtual environments and virtual reality applications to develop more engaging applications.

This work was done with collaboration with Mimetic Inria team.

Figure 3. Studying the sense of embodiment in VR shared experiences: Setup of the experiment. Each user was able to interact in the virtual environment with his own avatar, while the physical setup provided both a reference frame and passive haptic feedback. From left to right: experimental conditions Alone, Mirror and Shared; Physical setup of the experiment.

Towards Novel Approaches to Characterise, Manipulate and Measure the Sense of Agency in Virtual Environments
Participants: Camille Jeunet, Ferran Argelaguet, Anatole Lécuyer

While the Sense of Agency (SoA) has so far been predominantly characterised in VR as a component of the Sense of Embodiment, other communities (e.g., in psychology or neurosciences) have investigated the SoA from a different perspective proposing complementary theories. Yet, despite the acknowledged potential benefits of catching up with these theories a gap remains. In [18], we first aimed to contribute to fill this gap by introducing a theory according to which the SoA can be divided into two components, the feeling and the judgment of agency, and relies on three principles, namely the principles of priority, exclusivity and consistency. We argued that this theory could provide insights on the factors influencing the SoA in VR systems. Second, we proposed novel approaches to manipulate the SoA in controlled VR experiments (based on these three principles) as well as to measure the SoA, and more specifically its two components based on neurophysiological markers, using ElectroEncephaloGraphy (EEG). We claim that these approaches would enable us to deepen our understanding of the SoA in VR contexts. Finally, we validated these approaches in an experiment (see Figure 4). Our results (N=24) suggest that our approach was successful in manipulating the SoA as the modulation of each of the three principles induced significant decreases of the SoA (measured using questionnaires). In addition, we recorded participants' EEG signals during the VR experiment, and neurophysiological markers of the SoA, potentially reflecting the feeling and judgment of agency specifically, were revealed. Our results also suggest that users' profile, more precisely their Locus of Control (LoC), influences their level of immersion and SoA.

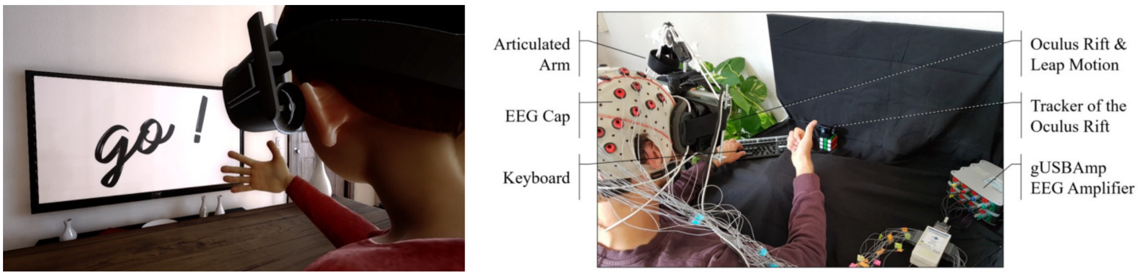

Figure 4. Studying the sense of agency in VR. Left: Third-person perspective: the participant receives a go signal and starts to perform the movement. Right: experimental set-up. The participant is equipped with an EEG cap, plugged to g.USBAmp amplifiers. In addition, he is immersed in the virtual environment using an Oculus Rift attached to his head and supported by an articulated arm (to avoid any pressure on the EEG cap and reduce the risk of muscular fatigue). Finally, his head is tracked by the Oculus tracker and his right hand is tracked by a Leap Motion fixed in front of the Oculus Rift.

Virtual Shadows for Real Humans in a CAVE: Influence on Virtual Embodiment and 3D Interaction
Participants: Guillaume Cortes, Ferran Argelaguet, Anatole Lécuyer

In immersive projection systems (IPS), the presence of the user's real body limits the possibility to elicit a virtual body ownership illusion. But, is it still possible to embody someone else in an IPS even though the users are aware of their real body? In order to study this question, we proposed to consider using a virtual shadow in the IPS, which can be similar or different from the real user's morphology [29]. We conducted an experiment (N=27) to study the users' sense of embodiment whenever a virtual shadow was or was not present (see Figure 5). Participants had to perform a 3D positioning task in which accuracy was the main requirement. The results showed that users widely accepted their virtual shadow (agency and ownership) and felt more comfortable when interacting with it (compare to no virtual shadow). Yet, due to the awareness of their real body, the users have less acceptance of the virtual shadow whenever the shadow gender differs from their own. Furthermore, the results showed that virtual shadows increase the users' spatial perception of the virtual environment by decreasing the inter-penetrations between the user and the virtual objects. Taken together, our results promote the use of dynamic and realistic virtual shadows in IPS and pave the way for further studies on “virtual shadow ownership” illusion.

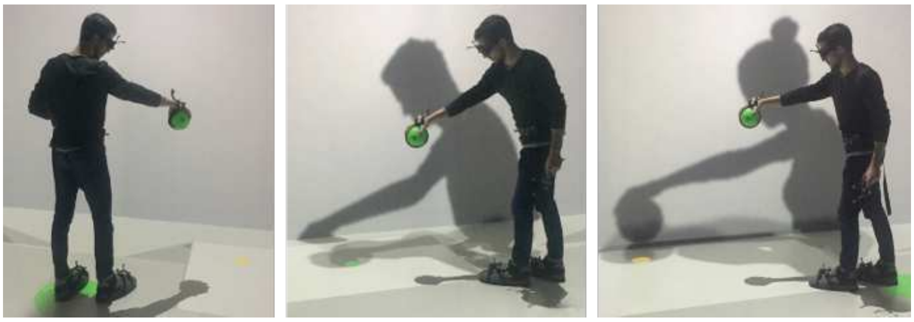

Figure 5. Various virtual shadows conditions. The participants performed a positioning task with 3 different virtual shadow conditions: None (N) (left), Male (M) (middle), Female (F) (right). The real shadow of the user is visible on the floor but does not match the natural behavior of a shadow in the virtual environment and is not taken into consideration.

This work was done with collaboration with Rainbow Inria team.

Influence of Being Embodied in an Obese Virtual Body on Shopping Behavior and Products Perception in VR

Participants: Jean-Marie Normand, Guillaume Moreau

In [26], we studied the changes an obese virtual body has on products perception (e.g., taste, etc.) and purchase behavior (e.g., number purchased) in an immersive virtual retail store. Participants (of a normal BMI on average) were embodied in a normal (N) or an obese (OB) virtual body and were asked to buy and evaluate food products in the immersive virtual store (see Figure 6. Based on stereotypes that are classically associated with obese people, we expected that the group embodied in obese avatars would show a more unhealthy diet, (i.e., buy more food products and also buy more products with high energy intake, or saturated fat) and would rate unhealthy food as being tastier and healthier than participants embodied in “normal weight” avatars. Our participants also rated the perception of their virtual body: the OB group perceived their virtual body as significantly heavier and older. Stereotype activation failed for our participants embodied in obese avatars, who did not exhibit a shopping behavior following the (negative) stereotypes related to obese people. Participants might have rejected their virtual bodies when performing the shopping task, while the embodiment and presence ratings did not show significant differences, and purchased products based on their real (non-obese) bodies. This could mean that stereotype activation is more complex that previously thought.

7.1.2. VR and Building Information Modeling

OpenBIM-based Ontology for Interactive Virtual Environments

Participants: Anne-Solène Dris, François Lehericey, Valérie Gouranton, Bruno Arnaldi

We proposed an ontology improving the use of Building Information Modelling (BIM) models as an Interactive Virtual Environment (IVE) generator [34]. Our results enable to create a bidirectional link between the informed 3D database and the virtual reality application, and to automatically generate object-specific functions and capabilities according to their taxonomy. We presented an illustration of our results based on a Risk-Hunting training application. In such contexts, the notions of objects handling and scheduling of the construction are essential for the immersion of the future trainee as well as for the success of the training.

Risk-Hunting Training in Interactive Virtual Environments

Participants: Anne-Solène Dris, François Lehericey, Valérie Gouranton, Bruno Analdi

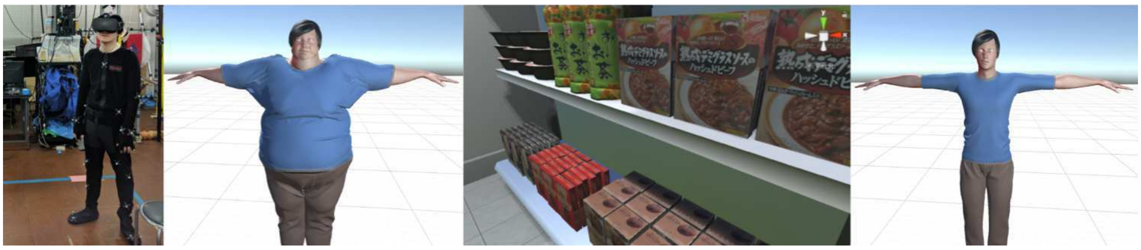

Figure 6. Being embodied in an obese virtual body. From left to right: A participant in a motion capture suit; The obese male avatar; A close-up on some products of our virtual store; The male avatar with a "normal" Body Mass Index.

Safety is an everlasting concern in construction environments. In such applications, when an accident happens it is rarely harmless. To raise awareness and train workers to safety procedures, training centers propose risk-hunting courses in which real-life equipment is set up in an incorrect way. Trainees can safely observe these environments and are supposed to point at risk situations. In [33], we proposed a risk-hunting course in Virtual Reality. With VR, we can put the trainee in a full construction environment with potentially dangerous hazards without engaging his safety. Contrary to others risk-hunting courses, we have designed a virtual environment with interactions to emphasize the importance of learning to correct the errors. First, instead of only having to spot the errors, the trainee had to fix them. Then, a second way to exploit VR interaction capabilities consisted in introducing consequences of not fixing an error. For example, not fixing an error in a scaffolding would make it collapse later. This implies to rely on script-writing the virtual environment to add causality on specific actions. Our goal was here to educate the trainee about the dramatic consequences that could arise when errors are not corrected.

7.1.3. Augmented Reality Methods and Applications

MoSART: Mobile Spatial Augmented Reality for 3D Interaction With Tangible Objects
Participants: Guillaume Cortes, Anatole Lécuyer

In [11] we introduced MoSART: a novel approach for Mobile Spatial Augmented Reality on Tangible objects. MoSART is dedicated to mobile interaction with tangible objects in single or collaborative situations. It is based on a novel "all-in-one" Head-Mounted Display (AMD) including a projector (for the SAR display) and cameras (for the scene registration). Equipped with the HMD the user is able to move freely around tangible objects and manipulate them at will. The system tracks the position and orientation of the tangible 3D objects and projects virtual content over them. The tracking is a feature-based stereo optical tracking providing high accuracy and low latency. A projection mapping technique is used for the projection on the tangible objects which can have a complex 3D geometry. Several interaction tools have also been designed to interact with the tangible and augmented content, such as a control panel and a pointer metaphor, which can benefit as well from the MoSART projection mapping and tracking features. The possibilities offered by our novel approach are illustrated in several use cases, in single or collaborative situations, such as for virtual prototyping, training or medical visualization.

This work was done with collaboration with Rainbow Inria team.
Evaluation of 2D and 3D Ultrasound Tracking Algorithms
Participants: Maud Marchal

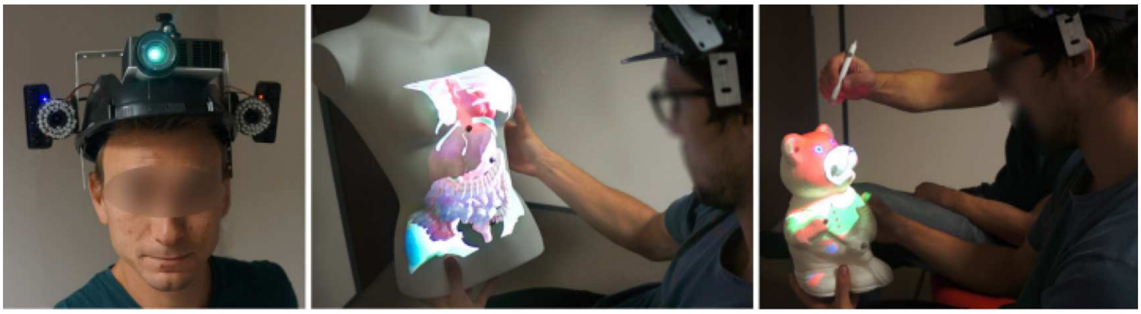

Figure 7. The MoSART headset for wearable augmented reality on tangible objects. Our novel system relies on an "all-in-one" Head-Mounted-Display (Left) which embeds a pico-projector for projection mapping and two cameras for feature-based stereo optical tracking of 3D tangible objects. The user can freely walk around and manipulate tangible objects superimposed with the projected images, such as for medical visualization purposes (Center). Tangible tools can also be used to interact with the virtual content such as for annotating or painting the objects in single or collaborative scenarios (Right).

Compensation for respiratory motion is important during abdominal cancer treatments. In [12], the results of the 2015 MICCAI Challenge on Liver Ultrasound Tracking are reported. These results extend the 2D results to relate them to clinical relevance in form of reducing treatment margins and hence sparing healthy tissues, while maintaining full duty cycle. The different methodologies of the MICCAI challenge are described for estimating and temporally predicting respiratory liver motion from continuous ultrasound imaging, used during ultrasound-guided radiation therapy. Furthermore, the trade-off between tracking accuracy and runtime in combination with temporal prediction strategies and their impact on treatment margins is also investigated. The paper follows the work of the PhD of Lucas Royer defended in 2016 and his methodology that was ranked first in the MICCAI challenge.

Evaluation of AR Inconsistencies on AR Placement Tasks: A VR Simulation Study

Participants: Romain Terrier, Jean-Marie Normand, Ferran Argelaguet

One of the major challenges of Augmented Reality (AR) is the registration of virtual and real contents. When errors occur during the registration process, inconsistencies between real and virtual contents arise and can alter user interaction. In this work, we assessed the impact of registration errors on the user performance and behaviour during an AR pick-and-place task in a Virtual Reality (VR) simulation [41]. The VR simulation ensured the repeatability and control over experimental conditions. The paper describes the VR simulation framework used and three experiments studying how registration errors (e.g., rotational errors, positional errors, shaking) and visualization modalities (e.g., transparency, occlusion) modify the user behaviour while performing a pick-and-place task. Our results show that users kept a constant behavior during the task, i.e., the interaction was driven either by the VR or the AR content, except if the registration errors did not enable to efficiently perform the task. Furthermore, users showed preference towards an half-transparent AR in which correct depth sorting is provided between AR and VR contents. Taken together, our results open perspectives for the design and evaluation of AR applications through VR simulation frameworks.

7.1.4. The 3DUI Contest 2018

Every year, the international IEEE Virtual Reality Conference organizes an annual 3D User Interfaces contest. This year, Hybrid submitted two different proposals.

Toward Intuitive 3D User Interfaces for Climbing, Flying and Stacking

Participants: Antonin Bernardin, Guillaume Cortes, Rebecca Fribourg, Tiffany Luong, Florian Nouviale, Hakim Si-Mohammed

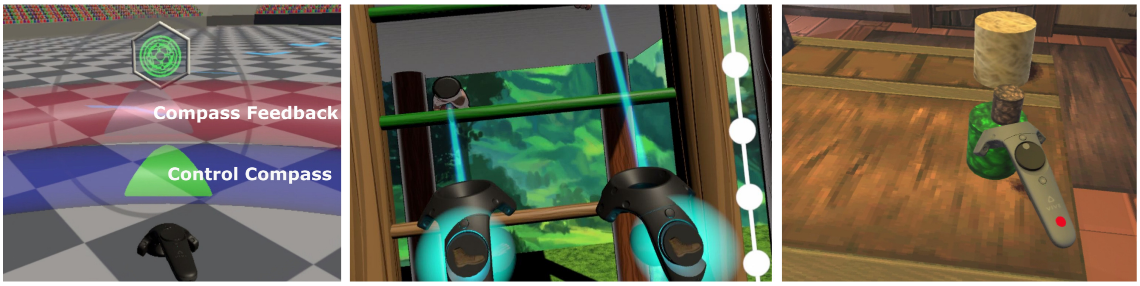

Figure 8. First solution proposed to the 2018 3DUI Contest. First-Person Drone Flying: The 3D User Interface used to control the drone (left). Ladder Climbing: First person point of view of the ladder climbing (center). Object Stacking: Physical object manipulation with frame recording as indicated by the red round on the controller and time control (right).

In this first solution, we proposed 3D user interfaces that are adapted to specific Virtual Reality tasks: climbing a ladder using a puppet metaphor, piloting a drone thanks to a 3D virtual compass and stacking 3D objects with physics-based manipulation and time control [28]. These metaphors have been designed to provide the user with an intuitive, playful and efficient way to perform each task (see Figure 8).

Climb, Fly, Stack: Design of Tangible and Gesture-based Interfaces for Natural and Efficient Interaction

Participants: Alexandre Audinot, Emeric Goga, Vincent Goupil, Carl-Johan Jorgensen, Adrien Reuzeau, Ferran Argelaguet

In this second solution we proposed three different 3D interaction metaphors conceived to fulfill the three tasks proposed in the IEEE VR 3DUI Contest. We proposed the VladdeR, a tangible interface for Virtual laddeR climbing, the FPDrone, a First Person Drone control flying interface, and the Dice Cup, a tangible interface for virtual object stacking [27]. All three metaphors take advantage of body proprioception and previous knowledge of real life interactions without the need of complex interaction mechanics (see Figure 9): climbing a tangible ladder through arm and leg motions, control a drone like a child flies an imaginary plane by extending your arms or stacking objects as you will grab and stack dice with a dice cup.

7.2. Physically-Based Simulation and Haptic Feedback

7.2.1. Haptic Methods and Rendering

KinesTouch: 3D Force-Feedback Rendering for Tactile Surfaces

Participants: Antoine Costes, Ferran Argelaguet, Anatole Lécuyer

Haptic enhancement of touchscreens has been mostly addressed through the use of various types of vibrations, altering the physics of the finger sliding on the screen, in order to provide friction forces and even small relief sensations. However, such approaches do not allow for displaying other haptic properties such as stiffness or large-scale shapes. In [31], we introduced the "KinesTouch", a novel approach for touchscreen enhancement providing four types of haptic feedback with a single force-feedback device: compliance, friction, fine roughness, and shape. Regarding friction in particular, we proposed a novel effect based on large lateral motion that increases or diminishes the sliding velocity between the finger and the screen. Our results show that this effect is able to produce distinct sliding sensations. Our general approach is also illustrated through a set of interactive use cases of 2D/3D content manipulation in various contexts.

This work was done in collaboration with Technicolor.

Haptic Material: a Holistic Approach for Haptic Texture Mapping

Participants: Antoine Costes, Ferran Argelaguet, Anatole Lécuyer

Figure 9. Second solution proposed to the 2018 3DUI Contest. Left, flying interface. Center, climbing interface. Left, stacking interface.

The development of 3D scanning technologies made common the digitizing of objects in realistic virtual copies, but still at the cost of most of their haptic properties. Besides, while haptic devices and setups spread widely, little attention is paid to the reuse and compatibility of haptic data, which are most of the time context- or hardware-specific. In [30], we proposed a new format for haptic texture mapping which is not dependent on the haptic rendering setup hardware. Our "haptic material" format encodes ten elementary haptic features in dedicated maps, similarly to "materials" used in computer graphics. These ten different features enable the expression of compliance, surface geometry and friction attributes through vibratory, cutaneous and kinesthetic cues, as well as thermal rendering. The diversity of haptic data allows various hardware to share this single format, each of them selecting which features to render depending on its capabilities.

This work was done in collaboration with Technicolor.

Combining Tangible Objects and Wearable Haptics

Participants: Xavier de Tinguy, Maud Marchal, Anatole Lécuyer

In [32], we studied the combination of tangible objects and wearable haptics for improving the display of stiffness sensations in virtual environments. Tangible objects enable to feel the general shape of objects, but they are often passive or unable to simulate several varying mechanical properties. Wearable haptic devices are portable and unobtrusive interfaces able to generate varying tactile sensations, but they often fail at providing convincing stiff contacts and distributed shape sensations. We propose to combine these two approaches in virtual and augmented reality (VR/AR), becoming able of arbitrarily augmenting the perceived stiffness of real/tangible objects by providing timely tactile stimuli at the fingers. We developed a proof-of-concept enabling to simulate varying elasticity/stiffness sensations when interacting with tangible objects by using wearable tactile modules at the fingertips. We carried out a user study showing that wearable haptic stimulation can well alter the perceived stiffness of real objects, even when the tactile stimuli is not delivered at the contact point. We illustrated our approach both in VR and AR, within several use cases and different tangible settings, such as when touching surfaces, pressing buttons and pistons, or holding an object (see Figure 12). Taken together, our results pave the way for novel haptic sensations in VR/AR by better exploiting the multiple ways of providing simple, unobtrusive, and low-cost haptic displays.

This work was done in collaboration with Rainbow Inria team.

7.2.2. Haptic Applications

A Survey on the Use of Haptic and Tactile Information in the Car to Improve Driving Safety

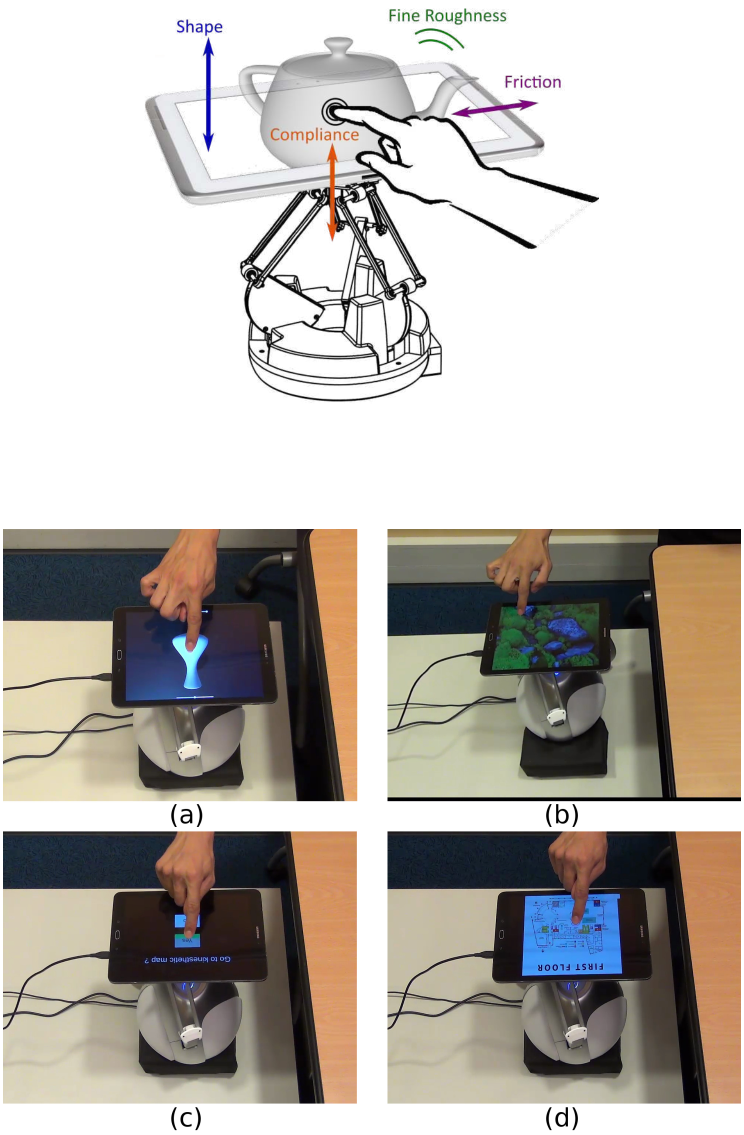

Figure 10. The KinesTouch approach. Top: concept of KinesTouch to provide four different types of haptic feedback to a touchscreen. Bottom: Use cases illustrating our approach: (a) Interaction with a 3D object, (b) Texture of a 2D image, (c) GUI and haptic buttons, (d) Interactive map.

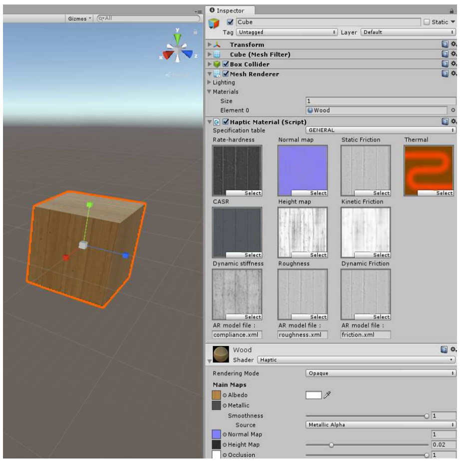

Figure 11. Implementation of our haptic material format in Unity3D.

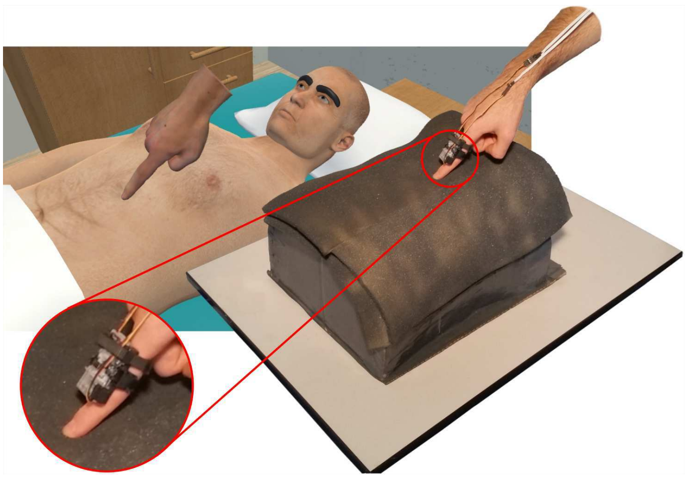

Figure 12. Combining tangible objects and wearable haptics in a VR medical palpation simulator. Passive tangible objects (a tangible chest here) provide haptic information about the global shape/percept of the virtual objects, while wearable haptic devices provide haptic information about dynamically changing mechanical properties (local elasticity here).

Participants: Yoren Gaffary, Anatole Lécuyer

In [15], we presented an overview of haptic technologies deployed in cars and their uses to enhance drivers' safety during manual driving. These technologies enable to deliver haptic (tactile or kinesthetic) feedback at various areas of the car, such as the steering wheel or the pedal. The paper explores two main uses of the haptic modality to fulfill the safety objective: providing driving assistance and warning. Driving assistance concerns the transmission of information usually conveyed with other modalities for controlling the cars' functions, maneuvering support, and guidance. Warning concerns the prevention of accidents using emergency warnings, increasing the awareness of surroundings, and preventing collisions, lane departures, and speeding. This paper discusses how haptic feedback has been introduced so far for these purposes and provides perspectives regarding the present and future of haptic cars meant to increase drivers' safety.

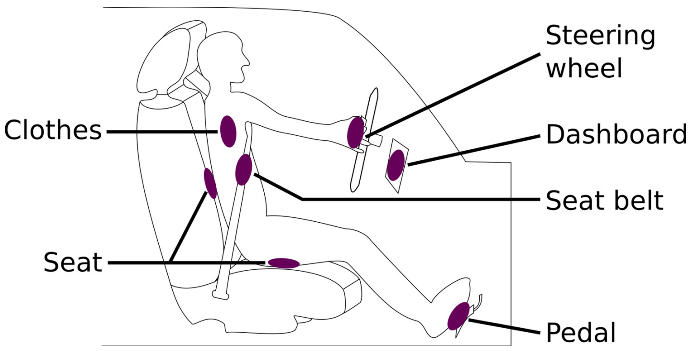

Figure 13. Using haptics in the car to improve driving safety: Different areas covered with haptic stimulations.

Toward Haptic Communication and Tactile Alphabets
Participants: Yoren Gaffary, Maud Marchal, Fernando Argelaguet Sanz, Anatole Lécuyer

In [14], we studied the possibility to convey information using tactile stimulation on fingertips. We designed and evaluated three tactile alphabets which are rendered by stretching the skin of the index's fingertip: (1) a Morse-like alphabet, (2) a symbolic alphabet using two successive dashes, and (3) a display of Roman letters based on the Unistrokes alphabet. All three alphabets (26 letters each) were evaluated through a user study in terms of recognition rate, intuitiveness and learning. Participants were able to perceive and recognize the letters with very good results (80%-97% recognition rates). Tactile alphabets with representations closer to Roman alphabet seem easier to learn. Taken together, our results pave the way to novel kinds of information communication using tactile modality.

This work was done in collaboration with CEA LIST.

7.3. Brain-Computer Interfaces

7.3.1. BCI Methods and Techniques

SimBCI: Novel Software Framework for Studying BCI Methods

Participants: Jussi Lindgren and Anatole Lécuyer

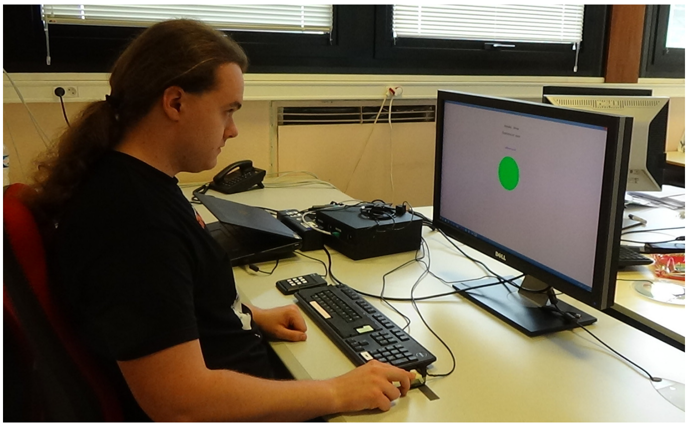

Figure 14. Toward tactile alphabets: A participant perceives a letter haptically stimulated using skin stretching at the level of his index.

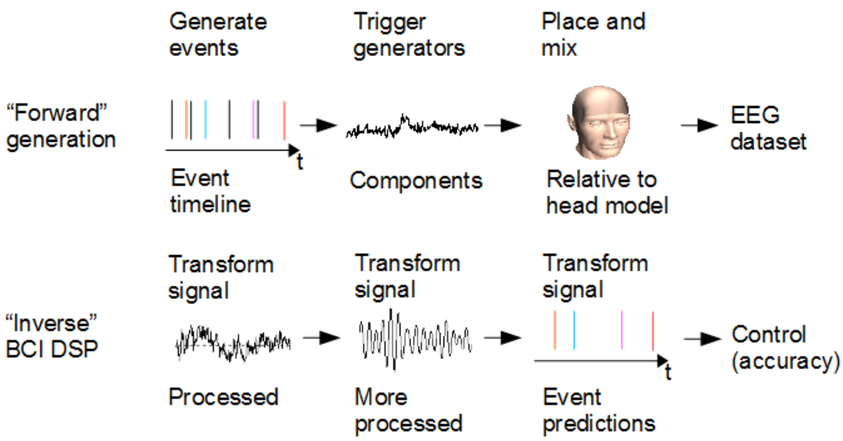

Figure 15. Simulated BCI data generation and testing in simBCI.

How to investigate the applicability of physiology-based source reconstruction for Brain-Computer Interfaces (BCIs)? The classic way is human experiments, but these unfortunately lack ground truth. The electrical activity inside the human brain is not fully described by external EEG measurements. In the CominLabs project SABRE, we have developed a BCI simulator framework called simBCI [22] to help in such studies. The framework allows modifying and changing generative models and their parameters inside a model brain, and studying what effects such changes have on the signal and subsequently the BCI signal processing. The modifiable parameters can include artifact properties, generative source locations, background activity characteristics and so on. We have released the framework as open source to the community (https://gitlab.inria.fr/sb/simbci/).

This work was done in collaboration with IMT Atlantique.

Novel Control Strategy for BCI Exploiting Visual Imagery and Attention

Participants: Jussi Lindgren and Anatole Lécuyer

Current paradigms for Brain-Computer Interfaces (BCIs) leave a lot to be desired in their accuracy and usability. We studied visual imagery as a potential new paradigm. In visual imagery, the user imagines objects or scenes visually, and the BCI is based on trying to classify the imagination type based on the EEG measurements. In [20], we studied to what extent can we distinguish the different mental processes of observing visual stimuli and imagining them based on the EEG. We found in a study of 26 users that we could somewhat differentiate (i) visual imagery vs. visual observation task (71% of classification accuracy), (ii) visual observation task towards different visual stimuli (classifying one observation cue versus another observation cue with an accuracy of 61%) and (iii) resting vs. observation/imagery (77% accuracy between imagery task versus resting state, and the accuracy of 75% between observation task versus resting state). All reported accuracies are averages over the users. Our results suggest that the presence of visual imagery and related alpha power changes may be useful to broaden the range of BCI control strategies.

Figure 16. Imagining or perceiving flowers and hammers. Can we tell from EEG which task the user is performing?

7.3.2. BCI Applications

BCI-based Interfaces for Augmented Reality: Feasibility, Design and Evaluation

Participants: Hakim Si-Mohammed, Camille Jeunet, Ferran Argelaguet and Anatole Lécuyer

In [25], we have studied the combination of BCI and Augmented Reality (AR). We first tested the feasibility of using BCI in AR settings based on Optical See-Through Head-Mounted Displays (OST-HMDs). Experimental results showed that a BCI and an OST-HMD equipment (EEG headset and Hololens in our case) are well compatible and that small movements of the head can be tolerated when using the BCI. Second, we introduced a design space for command display strategies based on BCI in AR, when exploiting a famous brain pattern called Steady-State Visually Evoked Potential (SSVEP). Our design space relies on five dimensions concerning the visual layout of the BCI menu ; namely: orientation, frame-of-reference, anchorage, size and explicitness. We implemented various BCI-based display strategies and tested them within the context of mobile robot control in AR. Our findings were finally integrated within an operational prototype based on a real mobile robot that is controlled in AR using a BCI and a HoloLens headset. Taken together our results (from four user studies) and our methodology could pave the way to future interaction schemes in Augmented Reality exploiting 3D User Interfaces based on brain activity and BCIs.

This work was done in collaboration with Loki Inria team.

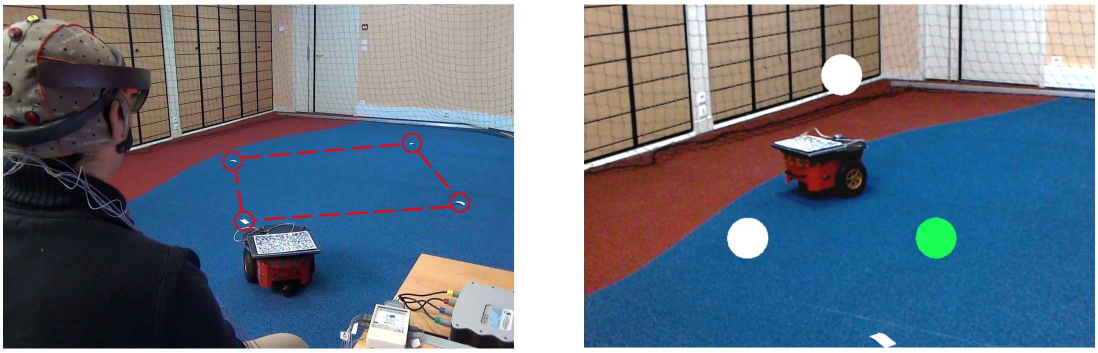

Figure 17. BCI-based interfaces in augmented reality: Illustration of our final prototype in use. (Left) general overview of the setup with the user equipped with EEG, sitting and facing the real mobile robot. (Right) First-person view, as seen from the HoloLens. The dashed line represents the path that the robot moved through during testing sessions.

Neurofeedback for Stroke Rehabilitation: A Case Report

Participants: Giulia Lioi, Mathis Fleury and Anatole Lécuyer

Neurofeedback (NF) consists in training self-regulation of brain activity by providing real-time information about the participant brain function. Few works have shown the potential of NF for stroke rehabilitation however its effectiveness has not been investigated yet. NF approaches are usually based on real-time monitoring of brain activity using a single imaging technique. Recent studies have revealed the potential of combining EEG and fMRI to achieve a more efficient and specific self-regulation. In this case report [50], we tested the feasibility of applying bimodal EEG-MRI NF on two stroke patients affected by left hemiplegia participated. The protocol included a calibration step (motor imagery of hemiplegic hand) and two NF sessions (5 minutes each). The experiment was run using a NF platform performing real-time EEG-fMRI processing and NF presentation. Both patients were found able to self-regulate their brain activity during the NF sessions. The EEG activity was harder to modulate than the BOLD activity. The patients were highly motivated to engage and satisfied with the NF animation, as assessed with a qualitative questionnaire. These results showed the feasibility and the potential of applying EEG-fMRI NF for stroke rehabilitation.

This work was done in collaboration with Visages Inria team.

Using EEG in Sport Performance Analysis

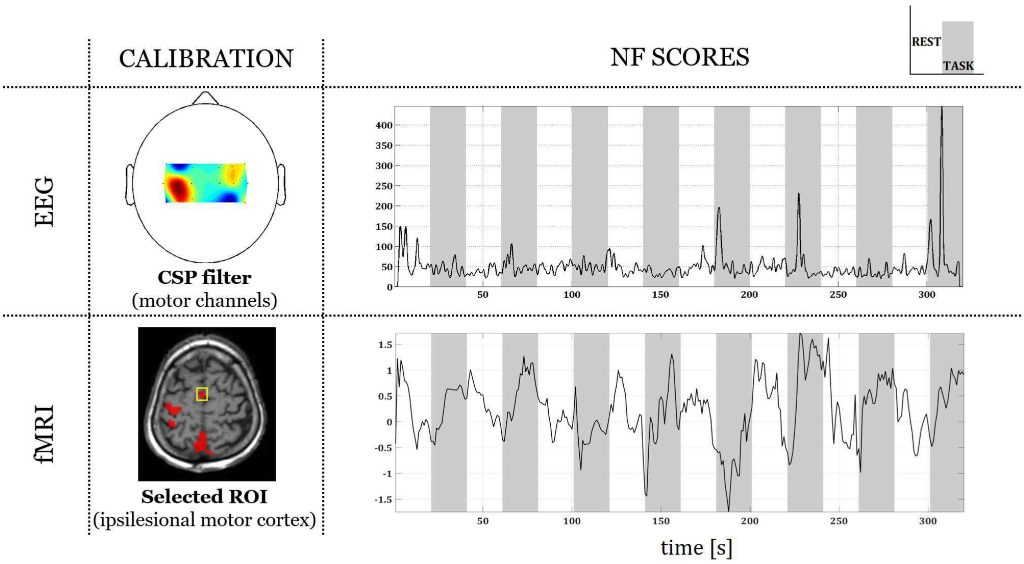

Figure 18. Neurofeedback for stroke patients: Examples of EEG and fMRI neurofeedback (NF) scores for a single session (patient 1). The left column represent the regions of interest selected to compute the NF signal during calibration. Resting blocks (20s) are indicated in white, NF training blocks (20s) in gray.

Participants: Ferran Argelaguet and Anatole Lécuyer

Competition changes the environment for athletes. The difficulty of training for such stressful events can lead to the well-known effect of "choking" under pressure, which prevents athletes from performing at their best level. To study the effect of competition on the human brain we recorded [24] pilot electroencephalography (EEG) data while novice shooters were immersed in a realistic virtual environment representing a shooting range. We found a differential between-subject effect of competition on mu (8–12 Hz) oscillatory activity during aiming; compared to training, the more the subject was able to desynchronize his mu rhythm during competition, the better was his shooting performance. Because this differential effect could not be explained by differences in simple measures of the kinematics and muscular activity, nor by the effect of competition or shooting performance per se, we interpret our results as evidence that mu desynchronization has a positive effect on performance during competition. It remains to show whether this effect can be generalized to expert shooters. Our findings could be relevant in sports training to help athletes avoid choking under pressure during competition. Confirmation through further experimental validation is however needed.

This work was done in collaboration with EPFL.

7.4. Cultural Heritage

Through several collaborations with Cultural Heritage partners such as archaeologists, historians, or curators, the Hybrid team has developed a methodology to propose new practices and tools in this domain. This methodology combines different technologies of digitization, such as CT scan, photogrammetry, or lidar, 3D production, such as 3D modelling or 3D printing, and 3D interactions in VR and AR.

7.4.1. 3D Printing and AR Applications

Lift the Veil of the Block Samples from the Warcq Chariot Burial

Participants: Ronan Gaugne and Valérie Gouranton

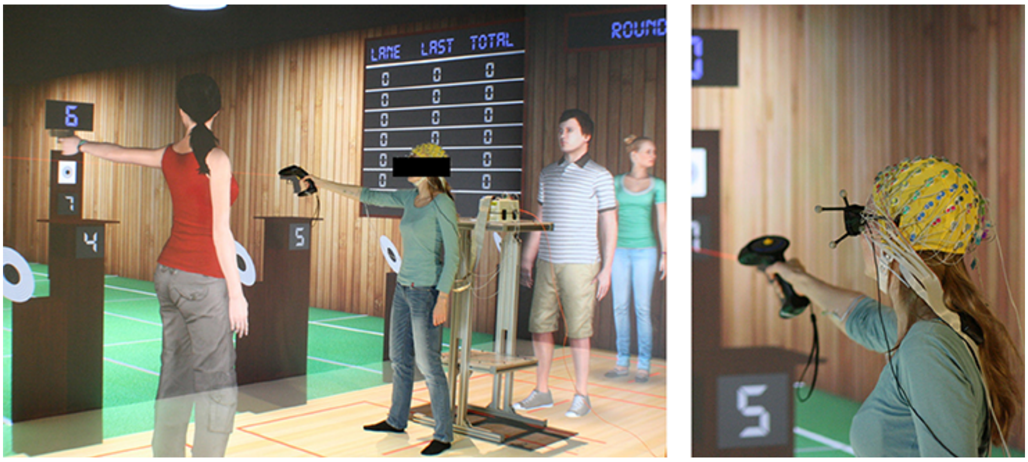

Figure 19. Experimental setup used in our sport performance study. (Left) Subjects were standing in our immersive projection system and were able to interact with the system using an ART Flystick. (Right) Subjects were wearing a high-density 64 channels EEG cap.

Cultural Heritage (CH) professionals such as archaeologists and conservators regularly experience the problem of working on concealed artifacts and face the potential destruction of source material without real understanding of the internal structure or state of decay or modification of the initial context by the micro-excavation process. Medical images-based digitization, such as MRI or CT scan, are increasingly used in CH as they provide information on the internal structure of archaeological material. Likewise, additive technologies are used more and more in the Cultural Heritage process, for example, in order to reproduce, complete, study or exhibit artifacts. 3D copies are based on digitization techniques such as laser scan or photogrammetry. In this case, the 3d copy remains limited to the external surface of objects. Different previous works illustrated the interest of combining 3D printing and Computed Tomography (CT) scans in order to extract concealed artifacts from larger archaeological material. The method was based on 3D segmentation techniques within volume data obtained by CT scans to isolate nested objects. This approach was useful to perform a digital extraction, but in some case it is also interesting to observe the internal spatial organization of an intricate object in order to understand its production process. Then, we proposed a method for the representation of a complex internal structure based on a combination of CT scan and emerging 3D printing techniques mixing colored and transparent parts of an aggregate of objects (see Figure 20), with very small pieces, from an exceptional aristocratic Gallic grave in the context of a preventive archaeological investigation [39].

This project was done in collaboration with UMR Trajectoires, Inrap and Image ET/BCRX.

Digital Introspection of a Mummy Cat

Participants: Ronan Gaugne and Valérie Gouranton

In the last decade, thanks to the dissemination of novel medical imaging technologies, research on the study of animal mummies of Ancient Egypt has became more and more important, leading to a better understanding of the history and culture of this civilization. Modern 3D technologies such as virtual reality, augmented reality and 3D printing enable to enrich the research process and open innovative possibilities for scenography in scientific mediation. In [36] we focused on one particular mummy cat and proposed to combine CT scan, 3D printing and augmented reality in a global process to accompany and support at the same time a scientific study of the object and a preparation of a mediation action in a Museum (see Figure 21 and Figure 22).

Figure 20. Transparent 3D printings from CT scan of archaeological materials.

This project was done in collaboration with Inrap, UMR Trajectoires, HISoMA and Musée des Beaux-Arts, Rennes.

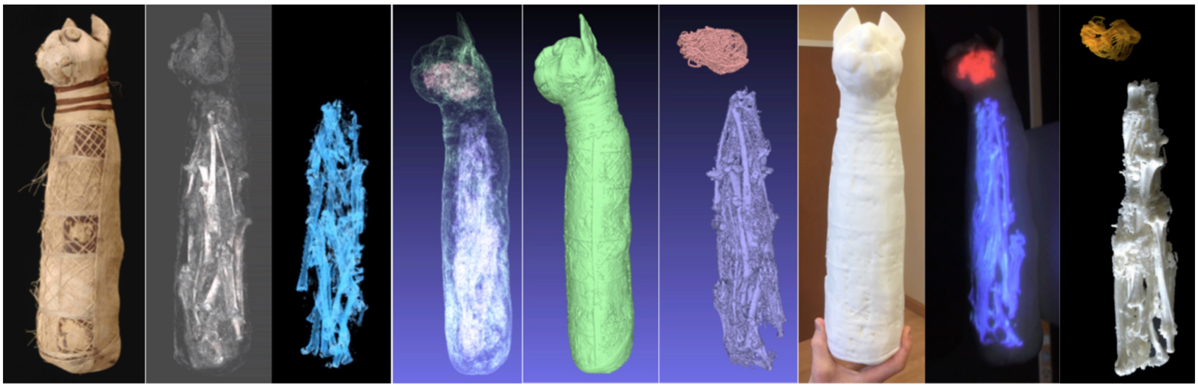

Figure 21. Digital introspection of a mummy cat. From left to right: the original mummy, CT scan of the mummy, volume rendering of the bones, mesh generation from CT scan, mesh of the external shape, meshes of internal parts, 3D printing of the external shape, projective AR of internal parts, 3D printing of internal parts.

7.4.2. VR Applications

EvoluSon: Walking through an Interactive History of Music

Participants: Ronan Gaugne, Florian Nouviale and Valérie Gouranton

The EvoluSon project [16] proposes an immersive experience where the spectator explores an interactive visual and musical representation of the main periods of the history of Western music (see Figure 23). The musical content is constituted of original musical compositions based on the theme of Bach's Art of Fugue to illustrate

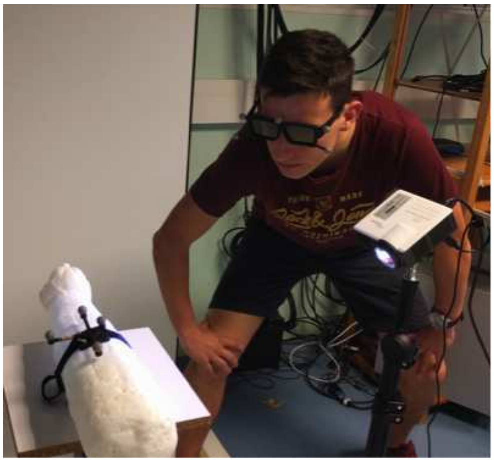

Figure 22. Projective AR system used for the visualization of the internal content of a mummy cat.

the eight main musical eras from Antiquity to the contemporary epoch. The EvoluSon project contributes at the same time to the usage of VR for intangible culture representation and to interactive digital art that puts the user at the centre of the experience. The EvoluSon project focuses on music through a presentation of the history of Western music, and uses virtual reality to valorise the different pieces through the ages. The user is immersed in a coherent visual and sound environment and can interact with both modalities. This project is the result of collaboration between a computer science research laboratory and a research laboratory on art and music. It was first presented to a public event on science and music organised by the computer science research laboratory.

This project was done in collaboration with the Research Laboratory on Art and Music of University Rennes 2.

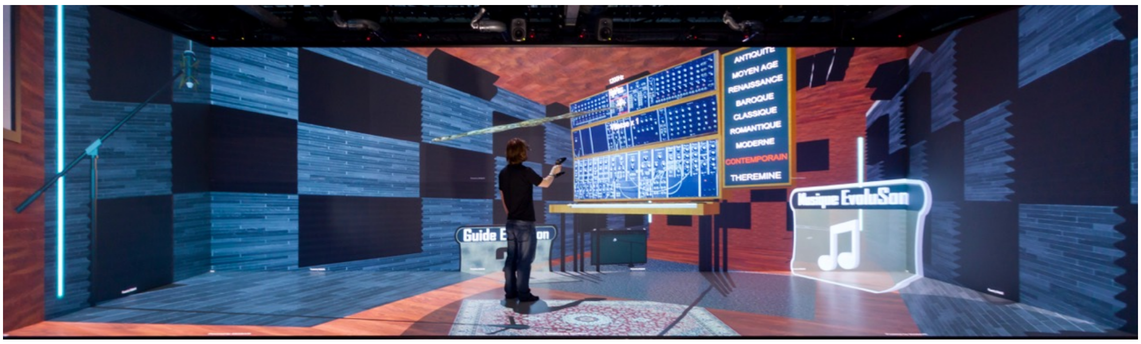

Figure 23. Interacting with the music through the ages inside Evoluson.

INSIDE Interactive and Non-destructive Solution for Introspection in Digital Environments

Participants: Flavien Lécuyer, Valérie Gouranton, Ronan Gaugne and Bruno Arnaldi

The development of scanning technologies allowed to limit the destructiveness induced by the excavation. However, it is not enough, as the rendering is not enough to study a scanned artifact. We proposed to use virtual reality as a legitimate tool for the inspection of artifacts modelled in 3D: INSIDE [38], with tools to lead a complete virtual excavation (see Figure 24). This tool opens a new way of practicing archaeology, more efficient and safer for the content being excavated.

This project was done in collaboration with the Research Laboratory on Archeology and History, UMR CReAAH, UMR Trajectoires, and Inrap.

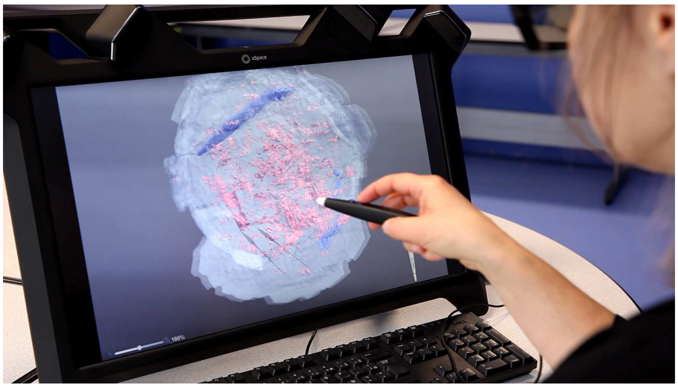

Figure 24. The INSIDE system used by an archaeologist within a workbench system.

VR Interactions with Multiple Interpretations of Archaeological Artefacts

Participants: Ronan Gaugne and Valérie Gouranton

The incorporation of 3D printed artefacts into Virtual Reality and Augmented Reality experiences is gaining strong interest from Cultural Heritage professionals. Indeed, in most cases, virtual environments cannot convey information such as the physical properties of artefacts. In [37], we presented a methodology for the development of VR experiences which incorporate 3D replicas of artefacts as user interfaces. The methodology is applied on the development of an experience to present various interpretations of an urn which was found at the edge of a cliff on the south east coastal area of the United Kingdom in 1910. In order to support the understanding of the multiple interpretations of this artefact, the system deploys a virtual environment and a physical replica to allow users to interact with the artefacts and the environment (see Figure 25). Feedback from heritage users suggests VR technologies along with digitally fabricated replicas can meaningfully engage audiences with multiple interpretations of cultural heritage artefacts.

This project was done in collaboration with University of Brighton (UK), Inrap, CNRS and UMR CReAAH.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Mensia Technologies

Participants: Anatole Lécuyer, Jussi Tapio Lindgren.

Figure 25. Interaction in VR using the physical replica of a funeral urn.

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 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.

The on-going contract between Hybrid and Mensia started in November 2013 and supports the transfer of several softwares designed by Hybrid team (eg, OpenViBE and StateFinder) related to our BCI activity to Mensia Technologies for medical and multimedia applications of Mensia.

8.2. Bilateral Grants with Industry

8.2.1. Technicolor

Participants: Antoine Costes, Anatole Lécuyer, Ferran Argelaguet.

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

8.2.3. VINCI Construction

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

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

8.2.4. Orange Labs

Participants: Guillaume Bataille, Bruno Arnaldi, Valérie Gouranton.

This grant started in October 2017. It supports Guillaume Bataille's PhD program with Orange Labs company on "Natural Interactions with IoT using VR/AR".

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Labex Cominlabs SUNSET

Participants: Bruno Arnaldi, Valérie Gouranton [contact].

SUNSET is a 4-year Labex Cominlabs project (2016-2020). SUNSET partners are MediCIS-LTSI (coordinator), Hybrid, Hycomes (IRISA/Inria), and CHU Rennes. SUNSET aims at developing an innovative training software suite based on immersive and collaborative virtual reality technology for training and evaluating non-technical skills. This approach will be implemented and evaluated in the context of training neurosurgical scrub nurses. We will notably integrate methods and systems developed in the S3PM project (see bellow). By relying on Human Factors approaches, the project also addresses training and evaluation of interpersonal skills. Whereas the developed technologies and approaches will be generic and adaptable to any surgical specialty, the project will evaluate the developed system within training sessions performed with scrub nurses. We ambition to propose novel approaches for surgical non-technical skill learning and assessment, and to install the developed training factory at the University Hospital of Rennes, and evaluate it with real-scale user studies.

9.1.2. Labex Cominlabs HEMISFER

Participants: Mathis Fleury, Anatole Lécuyer [contact], Giulia Lioi.

HEMISFER is a 6-year project (2013-2019) 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 Cominlabs SABRE

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

SABRE was a 4-year project (2014-2018) funded by Labex CominLabs. It involved 1 Inria/IRISA team (Hybrid) and 2 groups from TELECOM BREST engineering school. The goal of SABRE was to improve computational functionnalities and power of current real-time EEG processing pipelines. The project investigated innovative EEG solution methods empowered and speeded-up by ad-hoc, transistor-level, implementations of their key algorithmic operations.

9.1.4. IRT b<>com

Participants: Ferran Argelaguet, Bruno Arnaldi [contact], Valérie Gouranton, Anatole Lécuyer, Maud Marchal, Florian Nouviale.

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 has been regularly involved in collaborations with b<>com within various 3-year projects, such as ImData (on Immersive Interaction) and GestChir (on Augmented Healthcare) which both ended in 2016. Follow-up projects called NeedleWare (on Augmented Healthcare) and VUXIA (on Human Factors) have started respectively in 2016 and 2018.

9.1.5. CNPAO Project

Participants: Valérie Gouranton [contact], Ronan Gaugne.

CNPAO ("Conservatoire Numérique du Patrimoine Archéologique de l'Ouest") is an on-going research project partially funded by the Université Européenne de Bretagne (UEB) and Université de Rennes 1. 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. This project involves a collaboration with Quentin Petit (SED Inria Rennes).

9.1.6. ATT CONSORVIBE

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

CONSORVIBE was a 6-month ATT Inria Project funded by Inria for supporting a prospective effort and the feasibility study of building a consortium of partners dedicated to the sustainability and promotion of the OpenViBE software.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR LOBBY-BOT

Participants: Anatole Lécuyer [contact], Maud Marchal, Victor Mercado.

LOBBY-BOT is a 4-year project (2017-2021) funded by the French National Research Agency (ANR). The objective of LOBBY-BOT is to address the scientific challenges of encountered-type haptic devices (ETHD), which are an alternative category of haptic devices relying on a mobile physical prop, usually actuated by a robot, that constantly follows the user hand, and encounter it only when needed. The project follows two research axes: a first one dealing with robot control, and the second one dealing with interaction techniques adapted to ETHD. The involvement of Hybrid relates to the second research axis of the project. The final project prototype will be used to assess the benefits of ETHD when used in an industrial use-case : the perceived quality in an automotive interior.

9.2.2. Inria projects

9.2.2.1. Ilab CertiViBE

Participants: Anatole Lécuyer [contact], Jussi Tapio Lindgren, Thierry Gaugry, Cédric Riou.

CertiViBE was a 2-year "Inria Innovation Lab" (2015-2018) 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 involved two partners: Hybrid and Mensia Technologies startup company. The project aimed at setting up a quality environment, and developping a novel version of the software compliant with medical certification rules.

9.2.2.2. IPL BCI-LIFT

Participants: Anatole Lécuyer [contact], Jussi Tapio Lindgren, Hakim Si Mohammed.

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 several Inria teams: Hybrid, Potioc, Athena, Neurosys, Loki, 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.

9.2.2.3. IPL AVATAR

Participants: Anatole Lécuyer [contact], Ferran Argelaguet, Diane Dewez, Rebecca Fribourg.

AVATAR is a 4-year "Inria Project Lab" initiative (2018-2022) funded by Inria for supporting a national research effort on Avatars and Virtual Embodiment. This joint lab involves several Inria teams: Hybrid, Potioc, Loki, Mimetic, Graphdeco, Morpheo; as well as external partners: Univ. Bacelona, Faurecia and Technicolor companies. This project aims at improving several aspects of Avatars in immersive applications: reconstruction, animation, rendering, interaction, multi-sensory feedback, etc.

9.2.2.4. IPL NAVISCOPE

Participant: Ferran Argelaguet [contact].

NAVISCOPE is a 4-year "Inria Project Lab" initiative (2018-2022) funded by Inria for supporting a national research effort on image-guided navigation and visualization of large data sets in live cell imaging and microscopy. This joint lab involves several Inria teams: Serpico, Aviz, Beagle, Hybrid, Mosaic, Parietal, Morpheme; as well as external partners: INRA and Institute Curie. This project aims at improving visualization and machine learning methods in order to provide systems capable to assist the scientist to obtain a better understanding of massive amounts of information.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. IMAGINE

Title: IMAGINE - Robots Understanding Their Actions by Imagining Their Effects

Programm: H2020

Duration: January 2017 - December 2020

Coordinator: Univ. Innsbruck (Austria)

Partners:

- Univ. Innsbruck (Austria)
- Univ. Göttingen (Germany)
- Karlsruhe Institute of Technology (Germany)
- INSA Rennes (France)
- Institute of Robotics and Industrial Informatics (Spain)
- Univ. Bogazici (Turkey)
- Electro Cycling (Germany)

Inria contact: Maud Marchal

Abstract: Today's robots are good at executing programmed motions, but they do not understand their actions in the sense that they could automatically generalize them to novel situations or recover from failures. IMAGINE seeks to enable robots to understand the structure of their environment and how it is affected by its actions. "Understanding" here means the ability of the robot (a) to determine the applicability of an action along with parameters to achieve the desired effect, and (b) to discern to what extent an action succeeded, and to infer possible causes of failure and generate recovery actions. The core functional element is a generative model based on an association engine and a physics simulator. "Understanding" is given by the robot's ability to predict the effects of its actions, before and during their execution. This allows the robot to choose actions and parameters based on their simulated performance, and to monitor their progress by comparing observed to simulated behavior. This scientific objective is pursued in the context of recycling of electromechanical appliances. Current recycling practices do not automate disassembly, which exposes humans to hazardous materials, encourages illegal disposal, and creates significant threats to environment and health, often in third countries. IMAGINE will develop a TRL-5 prototype that can autonomously disassemble prototypical classes of devices, generate and execute disassembly actions for unseen instances of similar devices, and recover from certain failures. For robotic disassembly, IMAGINE will develop a multi-functional gripper capable of multiple types of manipulation without tool changes. IMAGINE raises the ability level of robotic systems in core areas of the work programme, including adaptability, manipulation, perception, decisional autonomy, and cognitive ability. Since only one-third of EU e-waste is currently recovered, IMAGINE addresses an area of high economical and ecological impact.

9.3.1.2. H-REALITY

Title: H-REALITY

Programm: H2020 - Fet Open

Duration: 2018 - 2021

Coordinator: Univ. Birmingham (UK)

Partners:

- Univ. Birmingham (UK)
- CNRS (France),
- TU Delft (Netherlands),
- ACTRONIKA (France),
- ULTRAHAPTICS (UK)

Inria contact: Maud Marchal

Abstract: The vision of H-REALITY is to be the first to imbue virtual objects with a physical presence, providing a revolutionary, untethered, virtual-haptic reality: H-Reality. This ambition will be achieved by integrating the commercial pioneers of ultrasonic "non-contact" haptics, state-of-the-art vibrotactile actuators, novel mathematical and tribological modelling of the skin and mechanics of touch, and experts in the psychophysical rendering of sensation. The result will be a sensory experience where digital 3D shapes and textures are made manifest in real space via modulated, focused, ultrasound, ready for the unteathered hand to feel, where next-generation wearable haptic rings provide directional vibrotactile stimulation, informing users of an object's dynamics, and where computational renderings of specific materials can be distinguished via their surface properties. The implications of this technology will transform online interactions; dangerous machinery will be operated virtually from the safety of the home, and surgeons will hone their skills on thin air.

9.3.2. Collaborations in European Programs, Except FP7 & H2020

9.3.2.1. Interreg ADAPT

Program: Interreg VA France (Channel) England

Project acronym: ADAPT

Project title:Assistive Devices for empowering disAbled People through robotic Technologies

Duration: 01/2017 - 06/2021

Coordinator: ESIGELEC/IRSEEM Rouen

Other partners: INSA Rennes - IRISA, LGCGM, IETR (France), Université de Picardie Jules Verne - MIS (France), Pôle Saint Hélier (France), CHU Rouen (France), Réseau Breizh PC (France), Ergovie (France), Pôle TES (France), University College of London - Aspire CREATE (UK), University of Kent (UK), East Kent Hospitals Univ NHS Found. Trust (UK), Health and Europe Centre (UK), Plymouth Hospitals NHS Trust (UK), Canterbury Christ Church University (UK), Kent Surrey Sussex Academic Health Science Network (UK), Cornwall Mobility Center (UK).

Inria contact: Valérie Gouranton

Abstract: This project aims to develop innovative assistive technologies in order to support the autonomy and to enhance the mobility of power wheelchair users with severe physical/cognitive disabilities. In particular, the objective is to design and evaluate a power wheelchair simulator as well as to design a multi-layer driving assistance system.

9.4. International Initiatives

9.4.1. Participation in Other International Programs

9.4.1.1. ANR-FRQSC INTROSPECT

Participants: Valérie Gouranton [contact], Bruno Arnaldi, Ronan Gaugne, Flavien Lécuyer.

INTROSPECT is a 3-year project funded by French ANR and "Fonds de Recherche Société et Culture" (FRQSC) from Quebec region, Canada. This international collaboration involves researchers in computer science and archeology from France and Canada : Hybrid (Inria-IRISA), CReAAH, Inrap, company Image ET, University Laval and INRS-ETE. INTROSPECT aims to develop new uses and tools for archaeologists that facilitate access to knowledge through interactive numerical introspection methods that combine computed tomography with 3D visualization technologies, such as Virtual Reality, tangible interactions and 3D printing. The scientific core of the project is the systematization of the relationship between the artefact, the archaeological context, the digital object and the virtual reconstruction of the archaeological context that represents it and its tangible double resulting from the 3D printing. This axiomatization of its innovative methods makes it possible to enhance our research on our heritage and to make use of accessible digital means of dissemination. This approach changes from traditional methods and applies to specific archaeological problems. Several case studies will be studied in various archaeological contexts on both sides of the Atlantic. Quebec museums are also partners in the project to spread the results among the general public.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Nami Ogawa (University of Tokyo, Japan) visited Hybrid for a 5-month collaboration on "Avatars and Virtual Embodiment" started in January 2018.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Selection

10.1.1.1. Chair of Conference Program Committees

- Anatole Lécuyer was Member of the organization committee of IEEE VR 2018 (Tutorials, Best Paper Award Committee).
- Ferran Argelaguet was Member of the organization committee of IEEE VR 2018 (Workshops).
- Maud Marchal was Program Chair of IEEE Virtual Reality and 3D User Interfaces Conference Papers (IEEE VR 2018).

10.1.1.2. Member of the Conference Program Committees

- Ferran Argelaguet was Member of the conference program committee of IEEE VR 2018, IEEE ISMAR 2018 (International Symposium on Mixed and Augmented Reality) and of EuroVR 2018.
- Maud Marchal was Member of the conference program committee of Eurographics 2018, the best paper committee of "Journées Françaises de l'Informatique Graphique" 2018, and the best Phd award committee of GDR-IGRV/EGFR/AFRV.
- Jean-Marie Normand was Member of the conference program committee of IEEE VR 2018, IEEE AIVR 2018 (International Conference on Artificial Intelligence and Virtual Reality) and of AH 2018 (International Conference on Augmented Human).

10.1.1.3. Reviewer

- Ferran Argelaguet was Reviewer for IEEE VRST 2018, ACM CHI 2018, EuroHaptics 2018.
- Maud Marchal was Reviewer for Eurographics 2018, ACM Siggraph Asia 2018, ACM UIST 2018, Eurohaptics 2018, IEEE Haptic Symposium 2018, IEEE ICRA 2018, IHM 2018.
- Valérie Gouranton was Reviewer for IEEE VR 2018 Conference Track, IEEE VR 2018 Journal Track, CHI 2018.
- Guillaume Moreau was Reviewer for IEEE ISMAR 2018, ACM UIST 2018.

- Jean-Marie Normand was Reviewer for IEEE AIVR 2018, AH 2018, IEEE ISMAR 2018, IEEE VR 2018 Journal Track, IEEE VR 2018 Conference Track.

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

- Anatole Lécuyer is Associate Editor of the IEEE Transactions on Visualization and Computer Graphics, Frontiers in Virtual Environments, and Presence journals. He was also Guest Editor of IEEE Computer Graphics and Applications Special Issue on ”Virtual and Augmented Reality”, and Guest Editor of Frontiers in Virtual Environments Special Topics on ”Brain-Computer Interfaces and VR/AR”.
- Ferran Argelaguet is Review Editor of Frontiers in Virtual Environments.
- Maud Marchal is Review Editor of Frontiers in Virtual Environments.
- Jean-Marie Normand is Review Editor of Frontiers in Virtual Environments.

10.1.2.2. Reviewer - Reviewing Activities

- Ferran Argelaguet was Reviewer for IEEE Transactions on Visualization and Computer Graphics, IEEE Computer Graphics and Applications.
- Guillaume Moreau was reviewer for Computers & Graphics, IEEE Transactions on Visualization and Computer Graphics, Frontiers in Virtual Environments.
- Jean-Marie Normand was Reviewer for Computer Animation and Virtual Worlds.

10.1.3. Invited Talks

- Anatole Lécuyer was invited as Keynote Speaker at the BIOSTEC Conference (Funchal, Portugal, Jan. 2018), and as Invited Speaker at HAPTICS Workshop (IEEE VR 2018, Reutlingen, Germany, Mar. 2018) and at "Journée BioVR" (IRIT, Toulouse, France, Oct. 2018).
- Maud Marchal was invited to give a lecture at the Young Researchers’ day (Journée jeunes chercheurs) of the “Journées de l’Informatique Graphique 2018 (j·FIG 2018)” (Poitiers, France, Nov. 2018).
- Guillaume Moreau was invited to Sino-French Symposium on Virtual Reality (Chengdu, China, Aug. 2018).
- Jean-Marie Normand was invited to give a lecture at the Young Researchers’ day (Journée jeunes chercheurs) of the “Journées de la Réalité Virtuelle 2018 (j·RV 2018)” (Evry, France, Oct. 2018).
- Bruno Arnaldi was invited to give a lecture at the "Journée scientifique - systèmes intelligents : immersion et interaction" at Heudiasic Lab (UMR 7253) at Compiègne in December 2018.

10.1.4. Leadership within the Scientific Community

- Ronan Gaugne is Member of the Selection and Validation Committee for the French cluster "Pôle Images et Réseaux", and of the Consortium 3D of TGIR HumaNum.
- Valérie Gouranton is Member of the Executive Committee of AFRV (French Association for Virtual Reality). She was also Member of the organization of a French Seminar on Archaeology with Inrap, in Rennes, June 2018.
- Maud Marchal is Member of the Executive Committee of Eurographics French Chapter.
- Guillaume Moreau is Member of the Steering Committee of IEEE ISMAR Conference.

10.1.5. Scientific Expertise

- Guillaume Moreau is Member of ANSES (National Health Agency) Working Group on the "sanitary effects of Virtual, Mixed and Augmented Reality". He is also Member of the HCERES (Higher Education and Research Evaluation Council) Committee of the SAMOVAR lab.

10.1.6. Research Administration

- Bruno Arnaldi is Deputy Director of IRISA, and co-Head of the Scientific Council of University of Rennes (ENS Rennes, ENSC Rennes, IEP Rennes, INSA Rennes, University Rennes 1, and University Rennes 2).
- Maud Marchal is Co-Head of the Master of "Research in Computer Science" (SIF) at University Rennes 1.
- Valérie Gouranton is Head of cross-cutting Axis "Art, Heritage & Culture" at IRISA Laboratory.
- Jean-Marie Normand is Head of the Minor "Virtual Reality" at ECN.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Anatole Lécuyer:

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

Master SIBM: "Haptic and Brain-Computer Interfaces", 4.5h, M2, University of Rennes 1, FR

Master CN: "Haptic Interaction and Brain-Computer Interfaces", 9h, M1 and M2, University of Rennes 2, FR

Master SIF: "Pseudo-Haptics and Brain-Computer Interfaces", 6h, M2, University of Rennes 1, FR

Bruno Arnaldi:

Master INSA Rennes: "VRI: Virtual Reality and Multi-Sensory Interaction Course", 4h, M2, INSA Rennes, FR

Master INSA Rennes: "CG: Computer Graphics", 10h, M2, INSA Rennes, FR

Master INSA Rennes: "Virtual Reality", courses 6h, projects 16h, M1 and M2, INSA Rennes, FR

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

Ferran Argelaguet:

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

Master SIF: "Virtual Reality and Multi-Sensory Interaction", 8h, M2, University of Rennes 1, FR

Master SIF: "Data Mining and Visualization", 2h, M2, University of Rennes 1, FR

Maud Marchal:

Master of Research in Computer Science: "Haptic rendering and physically-based simulation", 4h, M2, University of Rennes 1, FR

Master INSA Rennes: "Computer Graphics", 26h, M1 and responsible of this lecture, INSA Rennes, FR

Valérie Gouranton:

Licence: "Introduction to Virtual Reality", 22h, L2 and responsible of this lecture, INSA Rennes, FR

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

Ronan Gaugne:

INSA Rennes: Projects on "Virtual Reality", 41h, L3/M1/M2, Insa Rennes, FR

Master Digital Creation: "Virtual Reality", 9h, M1, University of Rennes 2, FR

Guillaume Moreau:

Dean of studies, Ecole Centrale de Nantes, FR

Virtual Reality Major, "C++ Programming for VR", 30h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Fundamentals of Virtual Reality", 6h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Computer Graphics", 4h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Advanced Software Development", 20h, M1/M2, Ecole Centrale de Nantes, FR

Computer Science Major, "Discrete Mathematics", 10h, M1/M2, Ecole Centrale de Nantes, FR

Jean-Marie Normand:

Virtual Reality Major, "Computer Graphics", 24h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Fundamentals of Virtual Reality", 14h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Computer Vision and Augmented Reality", 24h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Advanced Concepts", 24h, M1/M2, Ecole Centrale de Nantes, FR

Virtual Reality Major, "Projects on Virtual Reality", 20h, M1/M2, Ecole Centrale de Nantes, FR

10.2.2. Supervision

10.2.2.1. PhD (defended)

- Gwendal Le Moulec, "Model-driven Virtual Reality applications synthesis", Defended in September 2018, Supervised by Valérie Gouranton, Bruno Arnaldi and Arnaud Blouin (Diverse, Inria)
- Guillaume Cortes, "Contribution to the study of projection-based systems for industrial applications in mixed reality", Defended in October 2018, Supervised by Anatole Lécuyer and Eric Marchand (Lagadic, Inria)
- Anne-Solène Dris-Kerdreux, "Concept et modèle d'intégration des IFC en tant qu'environnement virtuel interactif", Defended in October 2018, Supervised by Valérie Gouranton and Bruno Arnaldi
- Antoine Costes, "Contribution to the study of the haptic enhancement of images on touchscreens", Defended in November 2018, Supervised by Anatole Lécuyer, Philippe Guillotel (Technicolor), Fabien Danieau (Technicolor) and Ferran Argelaguet

10.2.2.2. PhD (in progress)

- Hakim Si-Mohammed, "BCI and HCI", Started in October 2016, Supervised by Anatole Lécuyer, Géry Casiez (Mjolnir, Inria), Nicolas Roussel (Mjolnir, Inria) and Ferran Argelaguet
- Hadrien Gurnel, "Assistance robotisée d'insertion d'aiguille par comanipulation", Started in October 2016, Supervised by Alexandre Krupa (Rainbow, Inria) and Maud Marchal
- Rebecca Fribourg, "Perception and interaction with and via avatars", Started in September 2017, Supervised by Ferran Argelaguet, Ludovic Hoyet (Mimetic, Inria) and Anatole Lécuyer
- Guillaume Bataille, "Natural interactions with IoT using VR/AR", Started in October 2017, Supervised by Valérie Gouranton, Danielle Pelé (Orange Labs) and Bruno Arnaldi
- Xavier de Tinguy, "Haptic manipulation in virtual environments", Started in September 2017, Supervised by Maud Marchal, Claudio Pacchierotti (Rainbow, Inria) and Anatole Lécuyer
- Flavien Lécuyer, "Interactive digital introspection methods for archeology", Started in September 2017, Supervised by Valérie Gouranton, Grégor Marchand (CNRS) and Bruno Arnaldi
- Etienne Peillard, "Improving Perception and Interaction in Augmented Reality", Started in October 2017, Supervised by Guillaume Moreau, Ferran Argelaguet, Anatole Lécuyer and Jean-Marie Normand

- Antonin Bernardin, "Interactive physically-based simulation of dexterous manipulation for robot understanding", Started in September 2017, Supervised by Maud Marchal and Christian Duriez (Defrost, Inria)
- Romain Lagneau, "Data-driven models for dexterous manipulation of robots", Started in Septembre 2017, Supervised by Maud Marchal and Alexandre Krupa (Rainbow, Inria)
- Romain Terrier, "Presence of self and others in a collaborative virtual environment", Started in October 2017, Supervised by Valérie Gouranton, Thomas Boggini (b<>com) and Bruno Arnaldi
- Mathis Fleury, "Neurofeedback based on fMRI and EEG", Started in November 2017, Supervised by Anatole Lécuyer and Christian Barillot (Visages, Inria)
- Tiffany Luong, “Affective VR: acquisition, modelling, and exploitation of affective states in virtual reality”, Started in February 2018, Supervised by Anatole Lécuyer, Marc Diverrez (b<>com), Ferran Argelaguet
- Hugo Brument, “Towards user-adapted interaction techniques based on human locomotion laws for navigating in virtual environments”, Started in October 2018, Supervised by Ferran Argelaguet, Maud Marchal and Anne-Hélène Olivier (MimeTIC, Inria)
- Diane Dewez, “Avatar-Based Interaction in Virtual Reality”, Started in October 2018, Supervised by Anatole Lécuyer, Ferran Argelaguet and Ludovic Hoyet (MimeTIC)
- Gerard Gallagher, “Mid-air haptics”, Started in October 2018, Supervised by Maud Marchal, Anatole Lécuyer and Claudio Pacchierotti (Rainbow, Inria)
- Victor Rodrigo Mercado Garcia, “Encountered-type haptics”, Started in October 2018, Supervised by Maud Marchal and Anatole Lécuyer
- Guillaume Vaillant, "Outdoor wheelchair assisted navigation: reality versus virtuality", Started in November 2018, Supervised by Valérie Gouranton and Marie Babel (Rainbow, Inria)

10.2.3. Juries

- Anatole Lécuyer was president of the PhD committee for Pierre Bourdin (Univ. Barcelona, Spain). He was also external reviewer for the HDR of Antonio Capobianco (Univ. Strasbourg).
- Maud Marchal was an external reviewer for the PhD defenses of Karolina Golec (Univ. Lyon 1), Farzan Kalantari (Univ. Lille 1), Michael Traoré (Univ. Toulouse), Gaelle Fiard (Univ. Grenoble Alpes). She was a member of the PhD defenses of Alma Cantu (IMT Atlantique), Valentin Rousselet (Univ. Toulouse) and Firas Abi Farraj (Univ. Rennes 1).
- Guillaume Moreau was external reviewer for the PhD defense of Adrien Arnaud (LIMSI), president of the committee for Guillaume Cortes (Hybrid). He was also external reviewer for the HDR of Jean-Yves Didier (IBISC).

10.3. Popularization

As a salient action in 2018, Hybrid could organize a **press conference** on the topic of "Neurofeedback" in Paris (November 14th), which ended up with numerous media coverages (radio, press, etc).

10.3.1. Articles and contents

- "Autour de la question" (07/18) Radio France International: interview of Valérie Gouranton, Ronan Gaugne and Théophane Nicolas on "cultural heritage applications in VR/AR"
- "Sciences Ouest" (11/18) : interview of Anatole Lécuyer about "Neurofeedback"
- "Journal de 7h30" (11/18) France Inter radio : interview of Anatole Lécuyer about "Neurofeedback"
- "Sciences Ouest" (10/18): interview of Maud Marchal for "Epreuve par 7".

10.3.2. Interventions

- Technoférence du Pôle Images et Réseaux (Rennes, 02/18): co-organization by Ronan Gaugne, presentation from Maud Marchal on haptic in VR, demonstrations in Immersia.
- "Journées Science et Musique 2018" (Rennes, 10/18): co-organization of this event, and presentation of several demos of the team.
- Press Conference on "Neurofeedback" (Paris, 11/18): co-organization of this event, and presentation from Anatole Lécuyer, followed by several media coverages.

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] A. EVAIN, F. ARGELAGUET, N. ROUSSEL, G. CASIEZ, A. LÉCUYER. *Can I Think of Something Else when Using a BCI? Cognitive Demand of an SSVEP-based BCI*, in "ACM Conference on Human Factors in Computing Systems", Denver, United States, May 2017, pp. 5120-5125 [*DOI :* 10.1145/3025453.3026037], https://hal.inria.fr/hal-01625088

[3] Y. GAFFARY, B. LE GOUIS, M. MARCHAL, F. ARGELAGUET, A. LÉCUYER, B. ARNALDI. *AR Feels "Softer" than VR: Haptic Perception of Stiffness in Augmented versus Virtual Reality*, in "IEEE Transactions on Visualization and Computer Graphics", November 2017, vol. 23, n^{o} 11, pp. 2372 - 2377 [*DOI :* 10.1109/TVCG.2017.2735078], https://hal.inria.fr/hal-01625290

[4] L. HOYET, F. ARGELAGUET, C. NICOLE, A. LÉCUYER. *"Wow! I Have Six Fingers!": Would You Accept Structural Changes of Your Hand in VR?*, in "Frontiers in Robotics and AI", March 2016, vol. 3, n^{o} 27 [*DOI :* 10.3389/FROBT.2016.00027], https://hal.inria.fr/hal-01334359

[5] T. HÖLLERER, V. INTERRANTE, T. HOLLERER, A. LÉCUYER. *Virtual and Augmented Reality*, in "IEEE Computer Graphics and Applications", March 2018, vol. 38, n^{o} 2, pp. 28-30, https://hal.inria.fr/hal-01848211

[6] C. JEUNET, L. ALBERT, F. ARGELAGUET, A. LÉCUYER. *" Do you feel in control? " : Towards Novel Approaches to Characterise, Manipulate and Measure the Sense of Agency in Virtual Environments*, in "IEEE Transactions on Visualization and Computer Graphics", January 2018, vol. 24, n^{o} 4, pp. 1486-1495 [*DOI :* 10.1109/TVCG.2018.2794598], https://hal.inria.fr/hal-01679143

[7] 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

[8] G. MOREAU, B. ARNALDI, P. GUITTON. *Virtual Reality, Augmented Reality: myths and realities*, Computer engineering series, ISTE, March 2018, 322 p. , https://hal.archives-ouvertes.fr/hal-01812771

[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^{o} 3, https://hal.inria.fr/hal-01218223

[10] H. SI-MOHAMMED, J. PETIT, C. JEUNET, F. ARGELAGUET, F. SPINDLER, A. EVAIN, N. ROUSSEL, G. CASIEZ, A. LÉCUYER. *Towards BCI-based Interfaces for Augmented Reality: Feasibility, Design and Evaluation*, in "IEEE Transactions on Visualization and Computer Graphics", October 2018, pp. 1-12, https://hal.inria.fr/hal-01947344

Publications of the year

Articles in International Peer-Reviewed Journals

[11] G. CORTES, E. MARCHAND, G. BRINCIN, A. LÉCUYER. *MoSART: Mobile Spatial Augmented Reality for 3D Interaction With Tangible Objects*, in "Frontiers in Robotics and AI", August 2018, vol. 5, n^{o} 93, pp. 1-13 [*DOI :* 10.3389/FROBT.2018.00093], https://hal.inria.fr/hal-01858154

[12] V. DE LUCA, J. BANERJEE, A. HALLACK, S. KONDO, M. MAKHINYA, D. NOURI, L. ROYER, A. CIFOR, G. DARDENNE, O. GOKSEL, M. GOODING, C. KLINK, A. KRUPA, A. LE BRAS, M. MARCHAL, A. MOELKER, W. J. NIESSEN, B. PAPIEZ, A. ROTHBERG, J. A. SCHNABEL, T. VAN WALSUM, E. HARRIS, M. LEDIJU BELL, C. TANNER. *Evaluation of 2D and 3D ultrasound tracking algorithms and impact on ultrasound-guided liver radiotherapy margins*, in "Medical Physics", November 2018, vol. 45, n^{o} 11, pp. 4986-5003 [*DOI :* 10.1002/MP.13152], https://hal.archives-ouvertes.fr/hal-01901201

[13] M. FLEURY, C. BARILLOT, E. BANNIER, M. MANO, P. MAUREL. *Automated Electrodes Detection during simultaneous EEG/fMRI*, in "Frontiers in information and communication technologies", 2018, forthcoming, https://hal.inria.fr/hal-01939735

[14] Y. GAFFARY, F. ARGELAGUET, M. MARCHAL, A. GIRARD, F. GOSSELIN, M. EMILY, A. LÉCUYER. *Toward Haptic Communication: Tactile Alphabets Based on Fingertip Skin Stretch*, in "IEEE Transactions on Haptics (ToH)", July 2018, pp. 1 - 10 [*DOI :* 10.1109/TOH.2018.2855175], https://hal.inria.fr/hal-01839061

[15] Y. GAFFARY, A. LÉCUYER. *The Use of Haptic and Tactile Information in the Car to Improve Driving Safety: A Review of Current Technologies*, in "Frontiers in information and communication technologies", March 2018, vol. 5 [*DOI :* 10.3389/FICT.2018.00005], https://hal.archives-ouvertes.fr/hal-01953339

[16] R. GAUGNE, F. NOUVIALE, O. RIOUAL, A. CHIRAT, K. GOHON, V. GOUPIL, M. TOUTIRAIS, B. BOSSIS, V. GOURANTON. *EvoluSon: Walking through an Interactive History of Music*, in "Presence: Teleoperators and Virtual Environments", 2018, vol. 26, n^{o} 3, pp. 281-296 [*DOI :* 10.1162/PRES_A_00298], https://hal.inria.fr/hal-01661727

[17] V. INTERRANTE, A. LÉCUYER, T. HOLLERER. *Virtual and Augmented Reality*, in "IEEE Computer Graphics and Applications", March 2018, vol. 38, n^{o} 2, pp. 28-30, https://hal.inria.fr/hal-01848211

[18] C. JEUNET, L. ALBERT, F. ARGELAGUET, A. LÉCUYER. *" Do you feel in control? " : Towards Novel Approaches to Characterise, Manipulate and Measure the Sense of Agency in Virtual Environments*, in "IEEE Transactions on Visualization and Computer Graphics", January 2018, vol. 24, n^{o} 4, pp. 1486-1495 [*DOI :* 10.1109/TVCG.2018.2794598], https://hal.inria.fr/hal-01679143

[19] C. JEUNET, F. LOTTE, J.-M. BATAIL, P. PHILIP, J.-A. MICOULAUD-FRANCHI. *Using recent BCI literature to deepen our understanding of clinical neurofeedback: A short review*, in "Neuroscience", May 2018, vol. 378, pp. 225-233 [*DOI :* 10.1016/J.NEUROSCIENCE.2018.03.013], https://hal.inria.fr/hal-01728767

[20] N. KOS'MYNA, J. LINDGREN, A. LÉCUYER. *Attending to Visual Stimuli versus Performing Visual Imagery as a Control Strategy for EEG-based Brain-Computer Interfaces*, in "Scientific Reports", December 2018, vol. 8, n° 1 [*DOI :* 10.1038/S41598-018-31472-9], https://hal.inria.fr/hal-01953331

[21] G. LE MOULEC, A. BLOUIN, V. GOURANTON, B. ARNALDI. *Automatic Production of End User Documentation for DSLs*, in "Computer Languages, Systems and Structures", July 2018, vol. 54, pp. 337-357, Accepted for publication in COMLAN. [*DOI :* 10.1016/J.CL.2018.07.006], https://hal.inria.fr/hal-01549042

[22] J. LINDGREN, A. MERLINI, A. LÉCUYER, F. ANDRIULLI. *simBCI—A Framework for Studying BCI Methods by Simulated EEG*, in "IEEE Transactions on Neural Systems and Rehabilitation Engineering", November 2018, vol. 26, n° 11, pp. 2096-2105, https://hal.archives-ouvertes.fr/hal-01953341

[23] F. LOTTE, C. JEUNET. *Defining and Quantifying Users' Mental Imagery-based BCI skills: a first step*, in "Journal of Neural Engineering", June 2018, vol. 15, n° 4, pp. 1-37 [*DOI :* 10.1088/1741-2552/AAC577], https://hal.inria.fr/hal-01846434

[24] M. PEREIRA, F. ARGELAGUET, J. D. R. MILLÁN, A. LÉCUYER. *Novice Shooters With Lower Pre-shooting Alpha Power Have Better Performance During Competition in a Virtual Reality Scenario*, in "Frontiers in Psychology", April 2018, vol. 9, n° 527, pp. 1-5 [*DOI :* 10.3389/FPSYG.2018.00527], https://hal.inria.fr/hal-01834358

[25] H. SI-MOHAMMED, J. PETIT, C. JEUNET, F. ARGELAGUET, F. SPINDLER, A. EVAIN, N. ROUSSEL, G. CASIEZ, A. LÉCUYER. *Towards BCI-based Interfaces for Augmented Reality: Feasibility, Design and Evaluation*, in "IEEE Transactions on Visualization and Computer Graphics", October 2018, pp. 1-12, https://hal.inria.fr/hal-01947344

[26] A. VERHULST, J.-M. NORMAND, C. LOMBART, M. SUGIMOTO, G. MOREAU. *Influence of Being Embodied in an Obese Virtual Body on Shopping Behavior and Products Perception in VR*, in "Frontiers in Robotics and AI", October 2018, vol. 5, pp. 1-20 [*DOI :* 10.3389/FROBT.2018.00113], https://hal.archives-ouvertes.fr/hal-01888990

International Conferences with Proceedings

[27] A. AUDINOT, E. GOGA, V. GOUPIL, C.-J. JORQENSEN, A. REUZEAU, F. ARGELAGUET. *Climb, Fly, Stack: Design of Tangible and Gesture-Based Interfaces for Natural and Efficient Interaction*, in "IEEE Virtual Reality and 3D User Interfaces, 3DUI Contest", Reutlingen, Germany, March 2018, https://hal.inria.fr/hal-01949804

[28] A. BERNARDIN, G. CORTES, R. FRIBOURG, T. LUONG, F. NOUVIALE, H. SI-MOHAMMED. *Toward Intuitive 3D User Interfaces for Climbing, Flying and Stacking*, in "IEEE Virtual Reality and 3D User Interfaces, 3DUI Contest", Reutlingen, Germany, March 2018, https://hal.inria.fr/hal-01949784

[29] G. CORTES, F. ARGELAGUET, E. MARCHAND, A. LÉCUYER. *Virtual Shadows for Real Humans in a CAVE: Influence on Virtual Embodiment and 3D Interaction*, in "SAP '18 - ACM Symposium on Applied Perception", Vancouver, Canada, ACM, August 2018, pp. 1-8 [*DOI :* 10.1145/3225153.3225165], https://hal.inria.fr/hal-01807680

[30] A. COSTES, F. DANIEAU, F. ARGELAGUET, A. LÉCUYER, P. GUILLOTEL. *"Haptic material": A Holistic Approach for Haptic Texture Mapping*, in "EuroHaptics 2018 - Haptics: Science, Technology, and Applica-

tions", Pisa, Italy, LNCS, June 2018, vol. 10894, pp. 37-45 [*DOI :* 10.1007/978-3-319-93399-3_4], https://hal.inria.fr/hal-01841974

[31] A. COSTES, F. DANIEAU, F. ARGELAGUET SANZ, A. LÉCUYER, P. GUILLOTEL. *KinesTouch: 3D Force-Feedback Rendering for Tactile Surfaces*, in "EuroVR 2018: Virtual Reality and Augmented Reality", London, United Kingdom, October 2018, pp. 97-116, https://hal.inria.fr/hal-01947361

[32] X. DE TINGUY, C. PACCHIEROTTI, M. MARCHAL, A. LECUYER. *Enhancing the Stiffness Perception of Tangible Objects in Mixed Reality Using Wearable Haptics*, in "IEEE VR 2018 - 25th IEEE Conference on Virtual Reality and 3D User Interfaces", Reutlingen, Germany, IEEE, March 2018, pp. 81-90 [*DOI :* 10.1109/VR.2018.8446280], https://hal.inria.fr/hal-01701839

[33] A.-S. DRIS, F. LEHERICEY, V. GOURANTON, B. ANALDI. *Risk-Hunting Training in Interactive Virtual Environments*, in "24th CIB W99 Conference", Salvador, Brazil, 2018, pp. pp 1-8, https://hal.archives-ouvertes.fr/hal-01900450

[34] A.-S. DRIS, F. LEHERICEY, V. GOURANTON, B. ARNALDI. *OpenBIM Based IVE Ontology: an ontological approach to improve interoperability for Virtual Reality Applications*, in "35th CIB W78 Conference", Chicago, United States, 2018, pp. 1-10, https://hal.archives-ouvertes.fr/hal-01900424

[35] R. FRIBOURG, F. ARGELAGUET, L. HOYET, A. LÉCUYER. *Studying the Sense of Embodiment in VR Shared Experiences*, in "VR 2018 - 25th IEEE Conference on Virtual Reality and 3D User Interfaces", Reutlingen, Germany, IEEE, March 2018, pp. 273-280 [*DOI :* 10.1109/VR.2018.8448293], https://hal.inria.fr/hal-01804949

[36] R. GAUGNE, S. PORCIER, T. NICOLAS, F. COULON, O. HAYS, V. GOURANTON. *A digital introspection of a mummy cat*, in "Digital Heritage 2018 - 3rd International Congress & Expo, IEEE", San francisco, United States, October 2018, pp. 1-8, https://hal.archives-ouvertes.fr/hal-01875690

[37] R. GAUGNE, M. SAMAROUDI, T. NICOLAS, J.-B. BARREAU, L. GARNIER, K. RODRIGUEZ ECHAVARRIA, V. GOURANTON. *Virtual Reality (VR) interactions with multiple interpretations of archaeological artefacts*, in "EG GCH 2018 - 16th EUROGRAPHICS Workshop on Graphics and Cultural Heritage", Vienna, Austria, November 2018, pp. 1-9, https://hal.archives-ouvertes.fr/hal-01885788

[38] F. LÉCUYER, V. GOURANTON, R. GAUGNE, T. NICOLAS, G. MARCHAND, B. ARNALDI. *INSIDE Interactive and Non-destructive Solution for Introspection in Digital Environments*, in "Digital Heritage 2018 - 3rd International Congress & Expo, IEEE", San Francisco, United States, New Realities: Authenticity & Automation in the Digital Age, October 2018, pp. 1-4, https://hal.archives-ouvertes.fr/hal-01875793

[39] T. NICOLAS, R. GAUGNE, C. TAVERNIER, E. MILLET, R. BERNADET, V. GOURANTON. *Lift the veil of the block samples from the Warcq chariot burial with 3D digital technologies*, in "Digital Heritage 2018 - 3rd International Congress & Expo, IEEE", San Francisco, United States, October 2018, https://hal.archives-ouvertes.fr/hal-01875702

[40] L. PILLETTE, C. JEUNET, R. N 'KAMBOU, B. N'KAOUA, F. LOTTE. *Towards Artificial Learning Companions for Mental Imagery-based Brain-Computer Interfaces*, in "WACAI 2018 - Workshop sur les “Affects, Compagnons Artificiels et Interactions”", Ile de Porquerolles, France, June 2018, pp. 1-8, https://hal.inria.fr/hal-01762612

[41] R. TERRIER, F. ARGELAGUET, J.-M. NORMAND, M. MARCHAL. *Evaluation of AR Inconsistencies on AR Placement Tasks: A VR Simulation Study*, in "EuroVR 2018 - 15th EuroVR International Conference", London, United Kingdom, October 2018, pp. 190-210, https://hal.inria.fr/hal-01946959

[42] R. TERRIER, F. ARGELAGUET, J.-M. NORMAND, M. MARCHAL. *Evaluation of AR Inconsistencies on AR Placement Tasks: A VR Simulation Study*, in "EuroVR 2018: Virtual Reality and Augmented Reality", London, United Kingdom, October 2018, pp. 190-210, https://hal.inria.fr/hal-01947356

Scientific Books (or Scientific Book chapters)

[43] F. ARGELAGUET SANZ, B. ARNALDI, J.-M. BURKHARDT, G. CASIEZ, S. DONIKIAN, F. GOSSELIN, X. GRANIER, P. LE CALLET, V. LEPETIT, M. MARCHAL, G. MOREAU, J. PERRET, T. VIGIER. *Complexity and Scientific Challenges*, in "Virtual Reality and Augmented Reality - Myths and Realities", B. ARNALDI, P. GUITTON, G. MOREAU (editors), ISTE - Wiley, March 2018, vol. chapitre 3, pp. 123-216 [*DOI :* 10.1002/9781119341031.CH3], https://hal.archives-ouvertes.fr/hal-01944915

[44] B. ARNALDI, S. COTIN, N. COUTURE, J.-L. DAUTIN, V. GOURANTON, F. GRUSON, D. LOURDEAUX. *New applications*, in "Virtual Reality and Augmented Reality - Myths and Realities", B. ARNALDI, P. GUITTON, G. MOREAU (editors), John Wiley & Sons, Inc., March 2018, vol. chapter 1, pp. 1-71 [*DOI :* 10.1002/9781119341031.CH1], https://hal.inria.fr/hal-01955969

[45] C. BAILLARD, P. GUILLOTEL, A. LÉCUYER, F. LOTTE, N. MOLLET, J.-M. NORMAND, G. SEYDOUX. *Scientific and Technical Prospects*, in "Virtual Reality and Augmented Reality: Myths and Realities", John Wiley & Sons, Inc., March 2018, pp. 247-288, https://hal.inria.fr/hal-01946504

[46] G. CASIEZ, X. GRANIER, M. HACHET, V. LEPETIT, G. MOREAU, O. NANNIPIERI. *Towards VE that are More Closely Related to the Real World*, in "Virtual Reality and Augmented Reality - Myths and Realities", B. ARNALDI, P. GUITTON, G. MOREAU (editors), ISTE - Wiley, March 2018, vol. chapitre 4 [*DOI :* 10.1002/9781119341031.CH4], https://hal.inria.fr/hal-01735022

[47] C. JEUNET, S. DEBENER, F. LOTTE, J. MATTOUT, R. SCHERER, C. ZICH. *Mind the Traps! Design Guidelines for Rigorous BCI Experiments*, in "Brain–Computer Interfaces Handbook: Technological and Theoretical Advances", C. S. NAM, A. NIJHOLT, F. LOTTE (editors), CRC Press , 2018, pp. 1-33, https://hal.inria.fr/hal-01620186

[48] F. LOTTE, C. JEUNET, J. MLADENOVIC, B. N 'KAOUA, L. PILLETTE. *A BCI challenge for the signal processing community: considering the user in the loop*, in "Signal Processing and Machine Learning for Brain-Machine Interfaces", IET, 2018, pp. 1-33, Chapter 8, https://hal.inria.fr/hal-01762573

Books or Proceedings Editing

[49] G. MOREAU, B. ARNALDI, P. GUITTON (editors). *Virtual Reality, Augmented Reality: myths and realities*, Computer engineering series, ISTE, March 2018, 322 p. , https://hal.archives-ouvertes.fr/hal-01812771

Other Publications

[50] G. LIOI, M. FLEURY, S. BUTET, A. LÉCUYER, C. BARILLOT, I. BONAN. *Bimodal EEG-fMRI Neurofeedback for Stroke Rehabilitation BACKGROUND METHODS*, July 2018, 1 p. , ISPRM 2018 - 12th World Congress of the International Society of Physical and Rehabilitation Medicine., Poster, https://www.hal.inserm.fr/inserm-01932954

References in notes

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

[52] 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