IRISA

Activity Report 2017

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
A5.1.2. - 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
A5.5.4. - Animation
A5.6. - Virtual reality, augmented reality
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
B5.8. - Learning and training
B5.9. - Industrial maintenance
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
B9.3. - Sports
B9.5.6. - Archeology, History

1. Personnel

Research Scientists
- Anatole Lécuyer [Team leader, Inria, Senior Researcher, HDR]
- Ferran Argelaguet Sanz [Inria, Researcher]

Faculty Members
- Bruno Arnaldi [INSA Rennes, Professor, HDR]
- Valérie Gouranton [INSA Rennes, Associate Professor]
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- Benoit Le Gouis [Univ. Rennes I, ATER, from Sep 2017]

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- Giulia Lioi [Inria, from Nov 2017]
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- Guillaume Bataille [Orange Labs, from Oct 2017]
- Antonin Bernardin [INSA Rennes, from Sep 2017]
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- Mathis Fleury [Inria, from Nov 2017]
- Guillaume Cortes [Realyz]
- Antoine Costes [Technicolor]
- Xavier de Tinguy de La Girouliere [ENS Paris-Saclay, from Sep 2017]
- Anne-Solène Dris-Kerdreux [VINCI Construction]
- Rebecca Fribourg [Inria, from Sep 2017]
- Romain Lagneau [INSA Rennes, from Sep 2017]
- Gwendal Le Moulec [INSA Rennes]
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Technical staff
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- Ronan Gaugne [Univ. Rennes 1, SED Research Engineer, 15%]
- Kevin-Yoren Gaffary [INSA Rennes, from Oct 2017]
- Alexandre Audinot [INSA Rennes, from Apr 2017]
- Guillaume Claude [INSA Rennes, until Apr 2017]
- Thierry Gaugry [Inria]
- Emeric Goga [SATT Ouest Valorisation, from Sep 2017]
- Vincent Goupil [SATT Ouest Valorisation, from Sep 2017]
- Carl-Johan Jorgensen [SATT Ouest Valorisation, from Sep 2017]
- Jussi Tapio Lindgren [Inria]
- Marsel Mano [Inria, until Sep 2017]
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- Nathalie Denis [Inria]

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Théophane Nicolas [CNRS, until Jun 2017]

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Francois Lehericey [VINCI Construction]
Guillaume Moreau [Ecole Centrale de Nantes, from Mar 2017]
Jean-Marie Normand [Ecole Centrale de Nantes, from Mar 2017]

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.

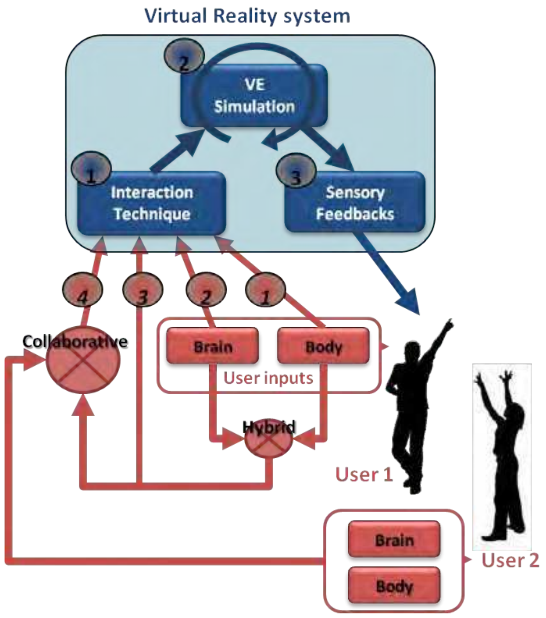

Figure 1. 3D hybrid interaction loop between one or multiple users and a virtual reality system. Top (in blue) three steps of 3D interaction with a virtual environment: (1-blue) interaction technique, (2-blue) simulation of the virtual environment, (3-blue) sensory feedbacks. Bottom (in red) different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

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 [34]: navigating the virtual world, selecting a virtual object, manipulating it, or controlling the application (entering text, activating options, etc). The addition of a third dimension, the use of stereoscopic rendering and the use of advanced VR interfaces make however inappropriate many techniques that proved efficient in 2D, and make it necessary to design specific interaction techniques and adapted tools. This challenge is here renewed by the various kinds of 3D interaction which are targeted. In our case, we consider various cases, with motor and/or cerebral inputs, and potentially multiple users.
- **Modeling and simulation of complex 3D scenarios:** This second step corresponds to the update of the state of the virtual environment, in real-time, in response to all the potential commands or actions sent by the user. The complexity of the data and phenomena involved in 3D scenarios is constantly increasing. It corresponds for instance to the multiple states of the entities present in the simulation (rigid, articulated, deformable, fluids, which can constitute both the user’s virtual body and the different manipulated objects), and the multiple physical phenomena implied by natural human interactions (squeezing, breaking, melting, etc). The challenge consists here in modeling and simulating these complex 3D scenarios and meeting, at the same time, two strong constraints of virtual reality systems: performance (real-time and interactivity) and genericity (e.g., multi-resolution, multi-modal, multi-platform, etc).
- **Immersive sensory feedbacks:** This third step corresponds to the display of the multiple sensory feedbacks (output) coming from the various VR interfaces. These feedbacks enable the user to perceive the changes occurring in the virtual environment. They are closing the 3D interaction loop, making the user immersed, and potentially generating a subsequent feeling of presence. Among the various VR interfaces which have been developed so far we can stress two kinds of sensory feedback: visual feedback (3D stereoscopic images using projection-based systems such as CAVE systems or Head Mounted Displays); and haptic feedback (related to the sense of touch and to tactile or force-feedback devices). The Hybrid team has a strong expertize in haptic feedback, and in the design of haptic and “pseudo-haptic” rendering [35]. 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

- The Hybrid team has considerably grown this year, reaching a total of nearly 40 team members at the end of 2017. In particular, 10 new PhD Students have been recruited in 2017, and 2 new Associate Members have joined Hybrid this year: Guillaume Moreau (Professor, Ecole Centrale de Nantes), and Jean-Marie Normand (Associate Professor, Ecole Centrale de Nantes).
- The Hybrid team was strongly involved in conference organization this year, in particular with: IEEE ISMAR 2017 and IGRV 2017. The IEEE Symposium on Mixed and Augmented Reality 2017 (IEEE ISMAR 2017) notably took place for the first time in France with around 350 attendees, in Nantes, October 9-13, with G. Moreau and A. Lécuyer: General Chairs, J.-M. Normand: Deputy General Chair, F. Argelaguet: Posters Chair, F. Nouviale: Demos Chair, V. Gouranton and R. Gaugne: VR Tour Chairs.

- The team has also organized a 1-week "hackathon" on Virtual Reality, at Inria Rennes in June 2017, with more than 20 participants and 4 teams. It was a very successful event which ended up with 4 live demos presented at Inria/IRISA Rennes and assessed by a Jury of experts.
- We have officially started to work on the topic of "Augmented Reality" this year, with a first paper published in IEEE ISMAR 2017, and several PhD students recruited on this hot topic (Etienne Peillard, Hakim Si-Mohammed, Guillaume Bataille).

5.1.1. Awards

- IEEE VGTC Virtual Reality Best Dissertation Award 2017 - Honorable Mention : for former PhD student Merwan Achibet for his work "Contributions to the Design of Novel Hand-based Interaction Techniques for Virtual Environments".
- GdR IG-RV Best PhD Thesis Award 2017 - Honorable Mention : for former PhD student Merwan Achibet for his work "Contributions to the Design of Novel Hand-based Interaction Techniques for Virtual Environments".
- b<>com Award for Best Publication of the year 2017 : for former PhD student Lucas Royer for his paper "Real-time Target Tracking of Soft Tissues in 3D Ultrasound Images Based on Robust Visual Information and Mechanical Simulation" published in Medical Image Analysis journal [9].

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, Thomas Boggini, Guillaume Claude, Thomas Lopez and Quentin Petit
- Contact: Valérie Gouranton
- Publication: #FIVE : High-Level Components for Developing Collaborative and Interactive Virtual Environments
- 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, Guillaume Claude, Thomas Boggini and Rozenn Bouville Berthelot
- Contact: Valérie Gouranton
- Publications: Actions sequencing incollaborative virtual environment - Short Paper: #SEVEN, a Sensor Effector Based Scenarios Model for Driving Collaborative Virtual Environment
- 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 40000 times, and it is used by numerous laboratories, projects, or individuals worldwide. More information, downloads, tutorials, videos, documentations are available on the OpenViBE website.

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

6.4. Platforms

6.4.1. Immerstar

- Participants : Florian Nouviale, Ronan Gaugne

With the two platforms of virtual reality, 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 is granted by a Inria CPER funding for 20152019 that enables important evolutions of the equipment. In 2017, WQXGA laser projectors were installed in Immersia as well as a new tracking system and a new cluster of computers, improving the quality, homogeneity and latency of the platform

7. New Results

7.1. Virtual Reality Tools and Usages

7.1.1. Gesture recognition for VR

Spatial and Rotation Invariant 3D Gesture Recognition Based on Sparse Representation

Participants: Ferran Argelaguet and Anatole Lécuyer

Advances in motion tracking technology, especially for commodity hardware, still require robust 3D gesture recognition in order to fully exploit the benefits of natural user interfaces. In this work [11], we introduced a novel 3D gesture recognition algorithm based on the sparse representation of 3D human motion. The sparse representation of human motion provides a set of features that can be used to efficiently classify gestures in real-time. Compared to existing gesture recognition systems, the proposed approach enables full spatial and rotation invariance and provides high tolerance to noise. Moreover, the proposed classification scheme takes into account the inter-user variability which increases gesture classification accuracy in user-independent scenarios. We validated our approach with existing motion databases for gestural interaction and performed a user evaluation with naive subjects to show its robustness to arbitrarily defined gestures. The results showed that our classification scheme has high classification accuracy for user-independent scenarios even with users who have different handedness. We believe that sparse representation of human motion will pave the way for a new generation of 3D gesture recognition systems in order to fully open the potential of natural user interfaces.

Figure 2. A participant interacting with the proposed gesture recognition system.

This work was done in collaboration with PANAMA team.

7.1.2. Automatic tools for the evaluation of VR systems

AGENT: Automatic Generation of Experimental Protocol Runtime

Participants: Gwendal Le Moulec, Ferran Argelaguet, Valérie Gouranton and Bruno Arnaldi

Due to the nature of Virtual Reality (VR) research, conducting experiments in order to validate the researchers' hypotheses is a must. However, the development of such experiments is a tedious and time-consuming task. We proposed in [19] to make this task easier, more intuitive and faster with a method able to describe and generate the most tedious components of VR experiments. The main objective is to let experiment designers focus on their core tasks: designing, conducting, and reporting experiments. To that end, we propose the use of Domain-Specific Languages (DSLs) to ease the description and generation of VR experiments. An analysis of published VR experiments is used to identify the main properties that characterize VR experiments. This allowed us to design AGENT (Automatic Generation of ExperimeNtal proTocols), a DSL for specifying and generating experimental protocol runtimes. AGENT allows experiment designers to design an Experimental Conditions Model (see Figure 3-left) and a Protocol Model (see Figure 3-right) in the AGENT editor. The models are then automatically compiled into code that can be integrated into VR development tools, e.g. Unity. We demonstrated the feasibility of our approach by using AGENT within two experiments.

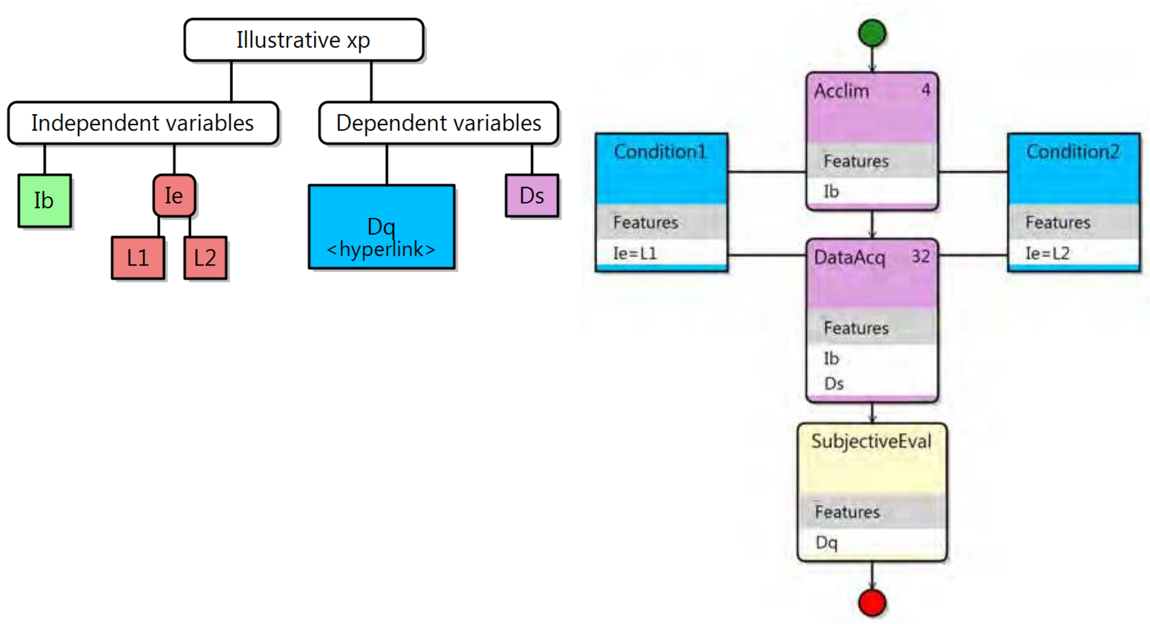

Figure 3. Examples of "Experimental Conditions" Model (left) and "Protocol" Model (right) which are both editable with the AGENT editor.

This work was done in collaboration with DIVERSE team.

7.1.3. Customer behavior and analyses in VR

The use of immersive Virtual Reality to investigate consumer perceptions and purchase behavior toward non-standard fruits and vegetables

Participants: Jean-Marie Normand and Guillaume Moreau

With the growth of organic Fruits and Vegetables (FaVs) markets, there is now a trend in marketing research toward studies of non-standardized fruits and vegetables in stores. Yet, because of the decaying nature of FaVs, it is difficult to conduct such studies. A solution is to conduct them within a Virtual Environment (VE) (with virtual FaVs). Therefore, it is of interest to develop an approach to generate a large variety and variability of FaVs, so one can later use them in a VE. First, we introduced a pipeline to generate a large variability of FaVs, focusing both on their shape and on their external appearance [30]. Regarding the shape, we use a semi-automated approach. A parametric Skeletal Structure and Generalized Cylinders (GCs) generates their overall shape and metaball-based techniques give them an organic aspect. Regarding their external appearance, we use a particle system approach to simulate their modifications over time. This particle system-based approach decomposes FaVs appearance changes into distinct visual characteristics producing different texture maps that can be combined.

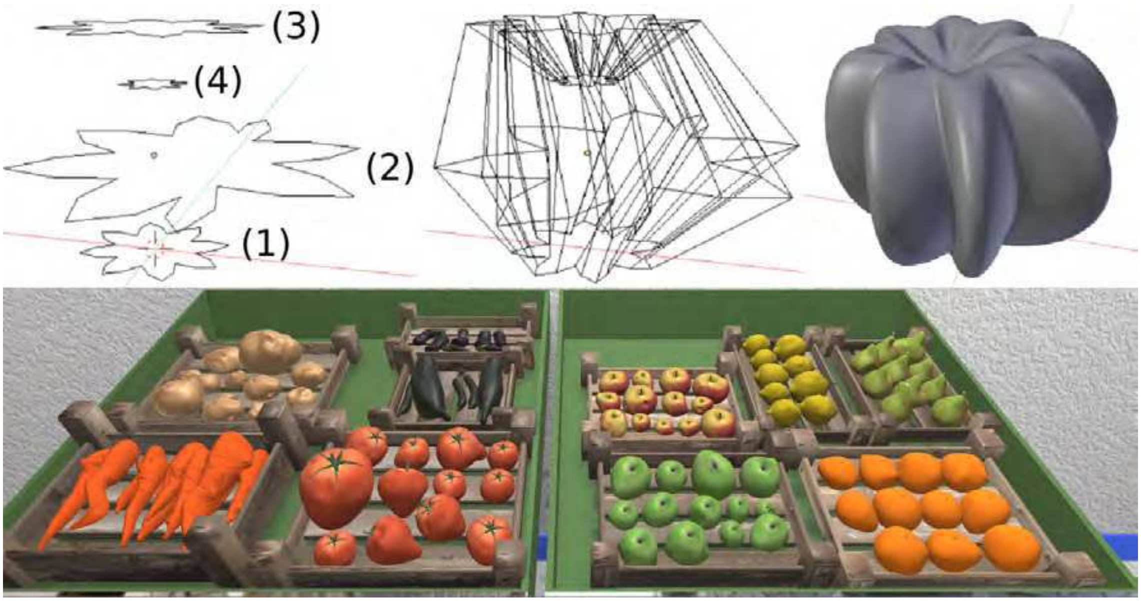

Figure 4. Our semi-automated process using a skeletal structure and cross-sections to generate different Fruits and Vegetables (Top). An example of semi-automatically generated FaVs with different levels of deformity (Bottom).

Second, we conducted an immersive virtual reality user study aimed at investigating how customers perceive and if they would purchase non standard (i.e. misshaped) fruits and vegetables (FaVs) in supermarkets and hypermarkets [24]. Indeed, food waste is a major issue for the retail sector and a recent trend is to reduce it by selling non-standard goods. An important question for retailers relates to the FaVs' " level of abnormality " that consumers would agree to buy. However, this question cannot be tackled using " classical " marketing techniques that perform user studies within real shops since fresh produce such as FaVs tend to rot rapidly preventing studies to be repeatable or to be run for a long time. In order to overcome those limitations, we created a virtual grocery store with a fresh FaVs section where 142 participants were immersed using an Oculus Rift DK2 HMD. Participants were presented either "normal", "slightly misshaped", "misshaped" or "severely misshaped" FaVs. Results show that participants tend to purchase a similar number of FaVs whatever their deformity. Nevertheless participants' perceptions of the quality of the FaV depend on the level of abnormality.

This work was done in collaboration with Audencia Business School, Nantes, France.

7.2. Physically-Based Simulation and Haptic Feedback

7.2.1. Physically-based simulation

Figure 5. Our virtual supermarket, a participant and a close-up view of the participant on the Fruits and Vegetables booth.

Elasticity-based Clustering for Haptic Interaction with Multi-Resolution Heterogeneous Deformable Objects

Participants: Benoît Le Gouis, Maud Marchal, Bruno Arnaldi and Anatole Lécuyer

Physically-based simulation of heterogeneous objects remains a strong computational challenge for many VR applications, especially when involving haptic interaction. In [18], we introduced a novel physically-based multi-resolution approach for haptic interaction with heterogeneous deformable objects. Our method called "Elasticity-based Clustering" is based on the clustering and aggregation of elasticity inside an object, so to create large homogeneous volumes preserving important features of the initial repartition. Such a creation of large and homogeneous volumes simplifies the attribution of elasticity to the elements of the coarser geometry. We could successfully implement and test our approach within a complete and real-time haptic interaction pipeline compatible with consumer-grade haptic devices. We evaluated the performance of our approach on a large set of elasticity configurations using a perception-based quality criterion. Our results show that for 90% of studied cases our method can achieve a 6 times speedup in the simulation time with no theoretical perceptual difference.

Real-time Target Tracking of Soft Tissues in 3D Ultrasound Images Based on Robust Visual Information and Mechanical Simulation

Participants: Maud Marchal

In [9], we presented a real-time approach that allows tracking deformable structures in 3D ultrasound sequences. Our method consists in obtaining the target displacements by combining robust dense motion estimation and mechanical model simulation. We performed evaluation of our method through simulated data, phantom data, and real-data. Results demonstrated that this novel approach has the advantage of providing correct motion estimation regarding different ultrasound shortcomings including speckle noise, large shadows and ultrasound gain variation. Furthermore, we could show the good performance of our method with respect to state-of-the-art techniques by testing on the 3D databases provided by MICCAI CLUST'14 and CLUST'15 challenges.

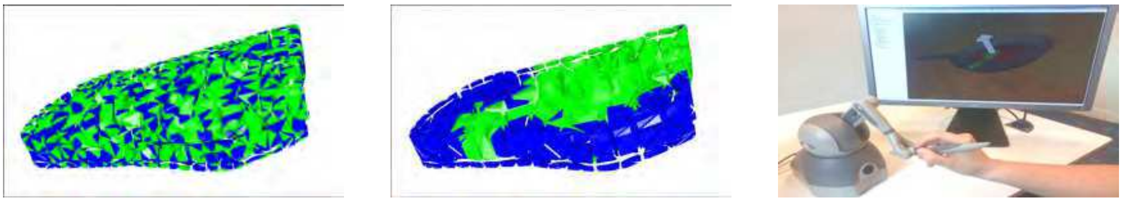

Figure 6. Overview of our elasticity-based clustering approach: (left) Based on an heterogeneous object composed of elements with different elasticity values, (center) we propose to build elasticity clusters to improve the computation time performances, (right) thus allowing haptic interaction while keeping similar perceptual sensations.

This work was done in collaboration with Lagadic team and IRT B-Com.

7.2.2. *Haptic feedback*

Haptic Rendering of FEM-based Tearing Simulation using Clusterized Collision Detection

Participants: Benoît Le Gouis, François Lehericey, Maud Marchal, Valérie Gouranton, Bruno Arnaldi and Anatole Lécuyer

Haptic rendering of deformable phenomena remains computationally-demanding, especially when topology modifications are simulated. Within this context, the haptic rendering of tearing phenomena is under-explored as of today. In [17] we proposed a fully-functional interaction pipeline for physically-based simulation of deformable surface tearing allowing to reach haptic interactive rates. It relies on a high efficiency collision detection algorithm for deformable surface meshes, combined with an efficient FEM-based simulation of deformable surfaces enabling tearing process. We especially introduced a novel formulation based on clusters for the collision detection to improve computation time performances. Our approach was illustrated through interactive use-cases of tearing phenomena with haptic feedback, showing its ability to handle realistic rendering of deformable surface tearing on consumer-grade haptic devices.

FlexiFingers: Multi-Finger Interaction in VR Combining Passive Haptics and Pseudo-Haptics

Participants: Maud Marchal, Benoît Le Gouis, Ferran Argelaguet and Anatole Lécuyer

3D interaction in virtual reality often requires to manipulate and feel virtual objects with our fingers. Although existing haptic interfaces can be used for this purpose (e.g. force-feedback exoskeleton gloves), they are still bulky and expensive. We introduced a novel multi-finger device called "FlexiFingers" that constrains each digit individually and produces elastic forcefeedback [10]. FlexiFingers leverages passive haptics in order to offer a lightweight, modular, and affordable alternative to active devices. Moreover, we combined Flexifingers with a pseudo-haptic approach that simulates different levels of stiffness when interacting with virtual objects. We illustrated how this combination of passive haptics and pseudo-haptics could benefit multi-finger interaction through several use cases related to music learning and medical training. These examples suggest that our approach could find applications in various domains that require an accessible and portable way of providing haptic feedback to the fingers.

7.3. Augmented Reality

7.3.1. *Perception in augmented reality*

AR Feels "Softer" than VR: Haptic Perception of Stiffness in Augmented versus Virtual Reality

Participants: Yoren Gaffary, Benoît Le Gouis, Maud Marchal, Ferran Argelaguet, Anatole Lécuyer and Bruno Arnaldi

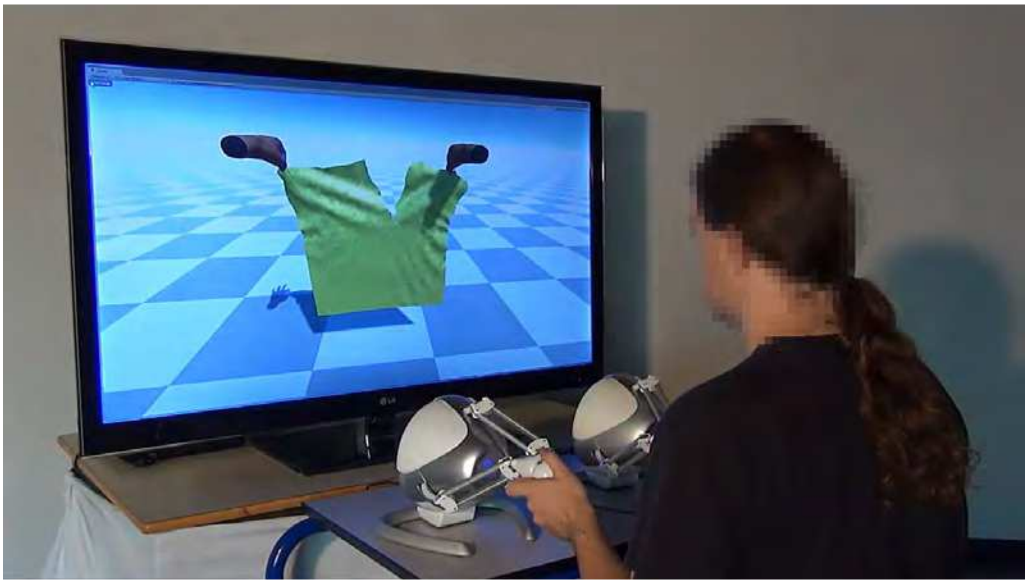

Figure 7. Our FEM-based method allows for the bimanual haptic tearing of deformable surfaces.

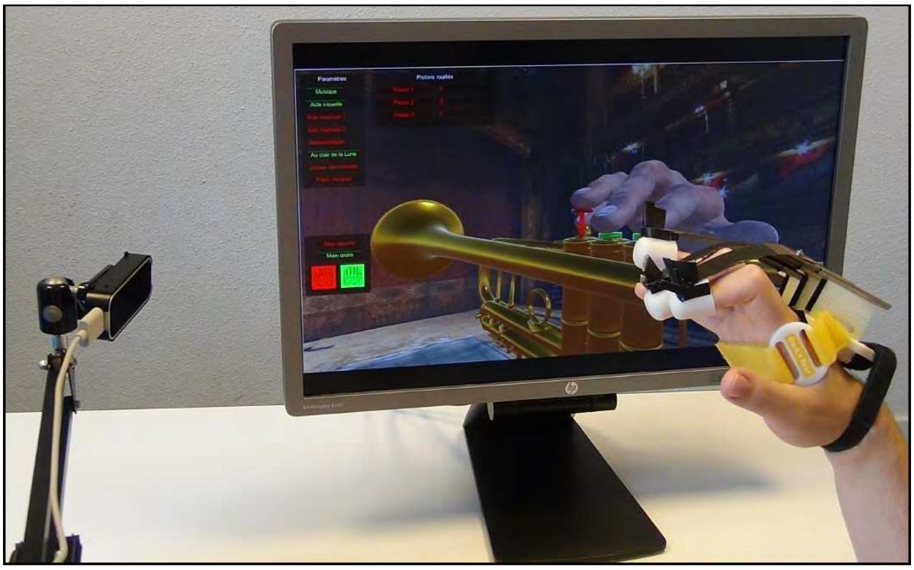

Figure 8. The FlexiFingers is a multi-finger device, combined with a pseudo-haptic approach, that can be used in music learning applications for instance.

Does it feel the same when you touch an object in Augmented Reality (AR) or in Virtual Reality (VR)? In [3] we studied and compared the haptic perception of stiffness of a virtual object in two situations: (1) a purely virtual environment versus (2) a real and augmented environment. We have designed an experimental setup based on a Microsoft HoloLens and a haptic force-feedback device, enabling to press a virtual piston, and compare its stiffness successively in either Augmented Reality (the virtual piston is surrounded by several real objects all located inside a cardboard box) or in Virtual Reality (the same virtual piston is displayed in a fully virtual scene composed of the same other objects). We have conducted a psychophysical experiment with 12 participants. Our results show a surprising bias in perception between the two conditions. The virtual piston is on average perceived stiffer in the VR condition compared to the AR condition. For instance, when the piston had the same stiffness in AR and VR, participants would select the VR piston as the stiffer one in 60% of cases. This suggests a psychological effect as if objects in AR would feel ”softer” than in pure VR. Taken together, our results open new perspectives on perception in AR versus VR, and pave the way to future studies aiming at characterizing potential perceptual biases.

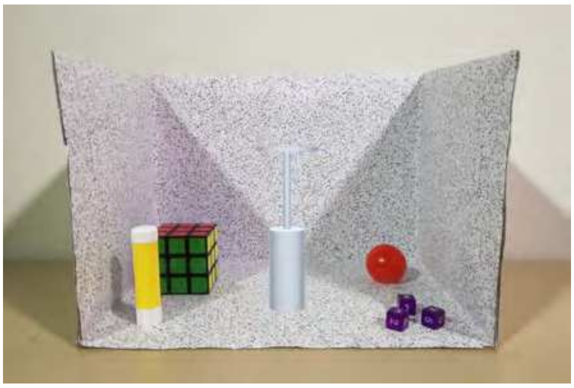

Figure 9. In our experiment, participants could interact with a virtual piston superimposed inside a real cardboard box in AR (left), and with the same piston inside a virtual replica of the box in VR (right).

7.3.2. *Interaction in augmented reality*

Evaluation of Facial Expressions as an Interaction Mechanism and their Impact on Affect, Workload and Usability in an AR game

Participants: Jean-Marie Normand and Guillaume Moreau

With the recent development of Head Mounted Display (HMD) for Virtual Reality (VR) allowing to track and recognize user’s Facial Expression (FE)s in real-time, we investigated the impact that the use of FEs as an action-trigger input mechanism (e.g. a FE mapped to a single action) has on our emotional state; as well as their workload and usability compared to the use of a controller button. In [23] we developed an Augmented Reality (AR)-based memory card where the users select virtual cards using a wand and flip them using either a FE (smiling; frowning) or a Xbox controller button. The users were separated into three groups: (1) flipping the card with a smile (n = 10); (2) flipping the card with a frown (n = 8) and (3) flipping the cards with the Xbox controller button (n = 11). We did not see any significant differences between our groups in: (i) the positive and negative affect of the participants and (ii) the reported workload and usability, thus highlighting that the FEs could be used inside a HMD in the same way as a controller button.

This work was done in collaboration with the Interactive Media Lab of Keio University (Japan).

A Sate-of-the-Art on the Combination of Brain-Computer Interfaces and Augmented Reality

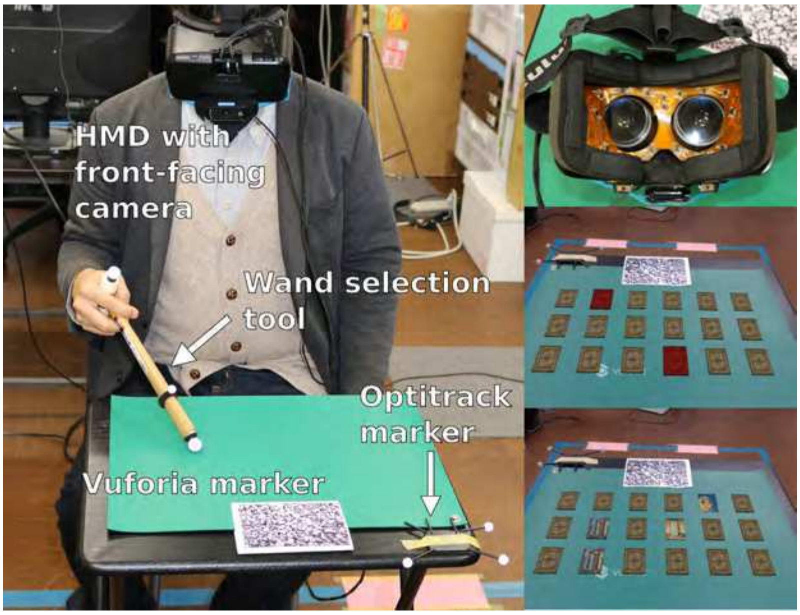

Figure 10. A participant wearing the Expression-Wear and playing our AR memory card game. Top right: The ExpressionWear embedded in the Oculus Rift. Middle and Bottom right: two states of our AR memory card game.

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

We have reviewed the state-of-the art of using Brain-Computer Interfaces in combination with Augmented Reality (AR) [22]. In this work, first we introduced the field of AR and its main concepts. Second, we described the various systems designed so far combining AR and BCI categorized by their application field: medicine, robotics, home automation and brain activity visualization. Finally, we summarized and discussed the results of our survey, showing that most of the previous works made use of P300 or SSVEP paradigms with EEG in Video See-Through systems, and that robotics is a main field of application with the highest number of existing systems.

This work was done in collaboration with MJOLNIR team.

7.3.3. Tracking

Increasing Optical Tracking Workspace of VR Applications using Controlled Cameras

Participants: Guillaume Cortes, Anatole Lécuyer

We have proposed an approach to greatly increase the tracking workspace of VR applications without adding new sensors [15]. Our approach relies on controlled cameras able to follow the tracked markers all around the VR workspace providing 6DoF tracking data. We designed the proof-of-concept of such approach based on two consumer-grade cameras and a pan-tilt head. The resulting tracking workspace could be greatly increased depending on the actuators' range of motion. The accuracy error and jitter were found to be rather limited during camera motion (resp. 0.3cm and 0.02cm). Therefore, whenever the final VR application does not require a perfect tracking accuracy over the entire workspace, we recommend using our approach in order to enlarge the tracking workspace.

This work was done in collaboration with LAGADIC team.

An Optical Tracking System based on Hybrid Stereo/Single-View Registration and Controlled Cameras

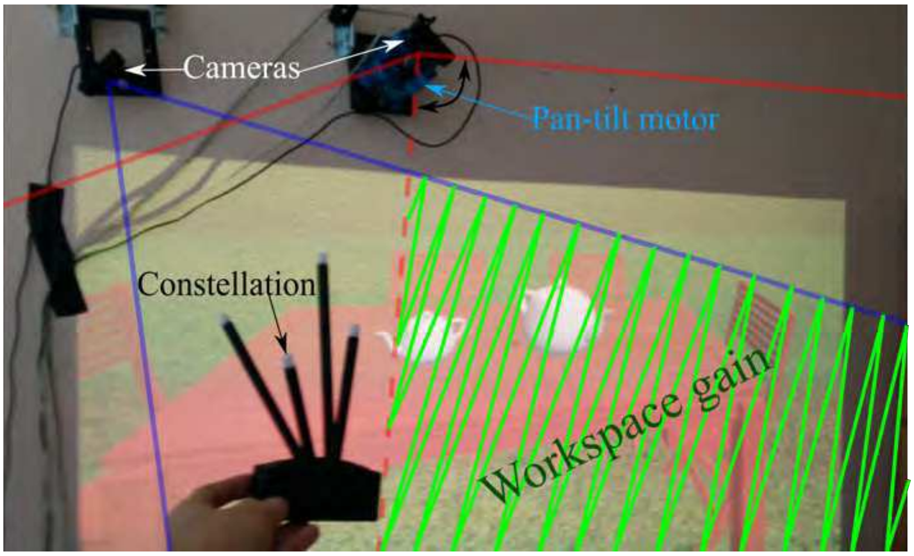

Figure 11. Our optical tracking prototype based on controlled cameras illustrated on a wall-sized VR application.

Participants: Guillaume Cortes, Anatole Lécuyer

Optical tracking is also widely used in robotics applications such as unmanned aerial vehicle (UAV) localization. Unfortunately, such systems require many cameras and are, consequently, expensive. We proposed an approach to increase again the optical tracking volume without adding cameras [14]. First, when the target becomes no longer visible by at least two cameras we propose a single-view tracking mode which requires only one camera. Furthermore, we propose to rely again on controlled cameras able to track the UAV all around the volume to provide 6DoF tracking data through multi-view registration. This is achieved by using a visual servoing scheme. The two methods can be combined in order to maximize the tracking volume. We propose a proof-of-concept of such an optical tracking system based on two consumer-grade cameras and a pan-tilt actuator and we used this approach on UAV localization.

This work was done in collaboration with LAGADIC team.

7.4. Brain-Computer Interfaces

7.4.1. BCI methods and techniques

Designing Guiding Systems for BCI

Participants: Nataliya Kosmyna and Anatole Lécuyer

The Brain–Computer Interface (BCI) community has focused the majority of its research efforts on signal processing and machine learning, mostly neglecting the human in the loop. Guiding users on how to use a BCI is crucial in order to teach them to produce stable brain patterns. In [5] we explored the instructions and feedback for BCIs in order to provide a systematic taxonomy to describe the BCI guiding systems. The purpose of our work was to give necessary clues to the researchers and designers in Human–Computer Interaction (HCI) in making the fusion between BCIs and HCI more fruitful but also to better understand the possibilities BCIs can provide to them.

Towards Understanding Inverse Models in BCI

Participants: Jussi Lindgren

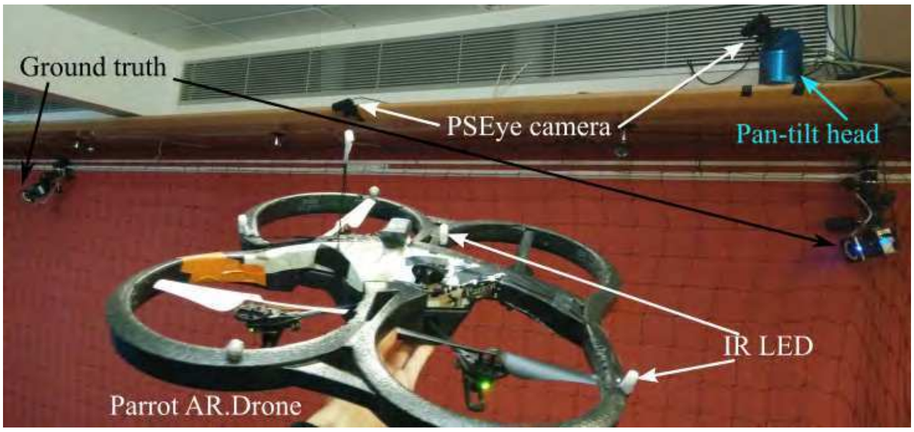

Figure 12. Our optical tracking prototype based on controlled cameras and hybrid stereo/single-view registration. The tracking is used for UAV indoor localization purposes.

In the scope of the LABEX CominLabs project "SABRE", we have investigated the applicability of physiology-based source reconstruction for Brain-Computer Interfaces. The BCI interfaces leave a lot to be desired in terms of their accuracy and speed. Can source reconstruction help? We explained how the source reconstruction techniques relate to the currently mainstream machine learning methods that may recover the sources implicitly [6]. We explained the different approaches in a common linear dictionary framework and review the different ways to obtain the dictionary parameters. Our analysis suggests physiological source reconstruction may improve BCI accuracy if machine learning is not used or where it produces less optimal parameters. We considered the effect of source reconstruction on some major difficulties in BCI classification, namely information loss, feature selection and nonstationarity of the EEG. The provided analysis and discussion should help in understanding, applying, comparing and improving such techniques in the future.

Cognitive Demand of BCI

Participants: Andeol Evain, Ferran Argelaguet and Anatole Lécuyer

BCIs are presumably supposed to require the full attention of their users and to lose accuracy if they pay attention to another task. This assertion has been verified with several BCI paradigms (e.g. P300). But the cognitive demand of the promising SSVEP paradigm had never been specifically assessed yet. In [16] we measured the accuracy of an SSVEP-based BCI used by 26 participants in various conditions of mental workload. Our analysis revealed that surprisingly, for this type of BCI, little attention is actually needed from participants to reach optimal accuracy: participants were able to successfully perform a complex secondary task (N-back) without degrading the BCI accuracy. The same observation was made whether visual or auditive attention was solicited. These results indicate that SSVEP is a low-demanding paradigm in terms of cognitive resources, and are encouraging for its use in complex interaction settings.

This work was done in collaboration with MJOLNIR team.

7.4.2. Neurofeedback

How to Build a Hybrid Neurofeedback Platform Combining EEG and fMRI

Participants: Marsel Mano, Lorraine Perronnet and Anatole Lécuyer

Multimodal neurofeedback estimates brain activity using information acquired with more than one neurosignal measurement technology. We have studied and described how to set up and use a hybrid platform based on simultaneous electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), then we

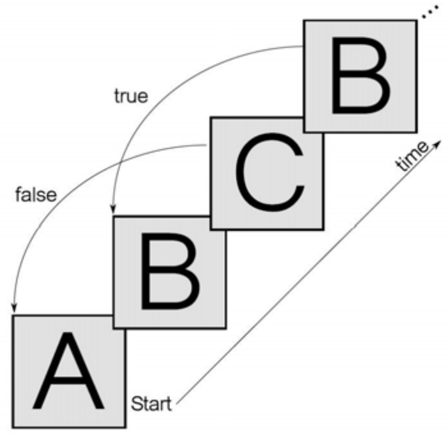

Figure 13. N-back task used in our study to control the level of difficuly and cognitive workload.

illustrated how to use it for conducting bimodal neurofeedback experiments in [21]. This work is intended for those willing to build a multimodal neurofeedback system, to guide them through the different steps of the design, setup, and experimental applications, and help them choose a suitable hardware and software configuration. Furthermore, we reported practical information from bimodal neurofeedback experiments conducted in our lab (see Figure 14). The platform that we presented has a modular parallel processing architecture that promotes real-time signal processing performance and simple future addition and/or replacement of processing modules. Various unimodal and bimodal neurofeedback experiments conducted in our lab showed high performance and accuracy. Currently, the platform is able to provide neurofeedback based on electroencephalography and functional magnetic resonance imaging, but the architecture and the working principles described here are valid for any other combination of two or more real-time brain activity measurement technologies.

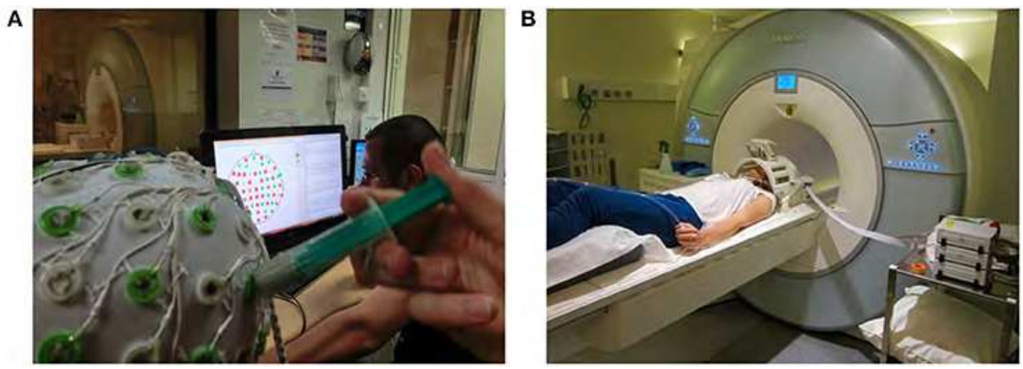

Figure 14. Experimental platform: (A) EEG subsystem installation outside the MR room, (B) installation of the MR coil.

This work was done in collaboration with VISAGES team.

Unimodal Versus Bimodal EEG-fMRI Neurofeedback of a Motor Imagery Task

Participants: Lorraine Perronnet and Anatole Lécuyer

Neurofeedback is a promising tool for brain rehabilitation and peak performance training. Neurofeedback approaches usually rely on a single brain imaging modality such as EEG or fMRI. Combining these modalities for neurofeedback training could allow to provide richer information to the subject and could thus enable him/her to achieve faster and more specific self-regulation. Yet unimodal and multimodal neurofeedback have never been compared before. In [8] we introduced a simultaneous EEG-fMRI experimental protocol in which participants performed a motor-imagery task in unimodal and bimodal NF conditions (see Figure 15). With this protocol we were able to compare for the first time the effects of unimodal EEG-neurofeedback and fMRI-neurofeedback versus bimodal EEG-fMRI-neurofeedback by looking both at EEG and fMRI activations. We also proposed a new feedback metaphor for bimodal EEG-fMRI-neurofeedback that integrates both EEG and fMRI signal in a single bi-dimensional feedback (a ball moving in 2D). Such a feedback is intended to relieve the cognitive load of the subject by presenting the bimodal neurofeedback task as a single regulation task instead of two. Additionally, this integrated feedback metaphor gives flexibility on defining a bimodal neurofeedback target. Participants were able to regulate activity in their motor regions in all NF conditions. Moreover, motor activations as revealed by offline fMRI analysis were stronger during EEG-fMRI-neurofeedback than during EEG-neurofeedback. This result suggests that EEG-fMRI-neurofeedback could be more specific or more engaging than EEG-neurofeedback. Our results also suggest that during EEG-fMRI-neurofeedback, participants tended to regulate more the modality that was harder to control. Taken together our results shed first light on the specific mechanisms of bimodal EEG-fMRI-neurofeedback and on its added-value as compared to unimodal EEG-neurofeedback and fMRI-neurofeedback.

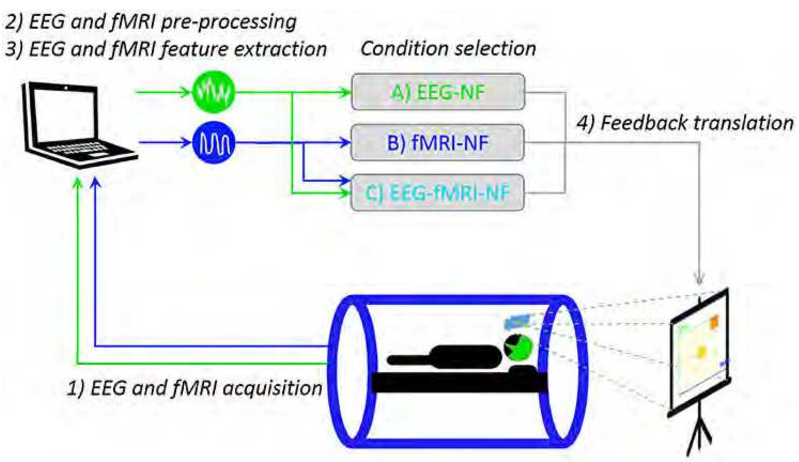

Figure 15. Real-time multimodal EEG/fMRI Neurofeedback experiment. The participant is lying in the MR tube with a 64-channel MR-compatible EEG cap. EEG and fMRI are simultaneously acquired then pre-processed with custom Matlab code. The EEG and fMRI laterality features are computed and eventually translated as a displacement of the ball on the stimulation screen, the image of which is projected on the mirror mounted on the head coil.

This work was done in collaboration with VISAGES team.

Investigating Neurophysiological Correlates of Covert Attention in Soccer Goalkeepers

Participants: Camille Jeunet, Ferran Argelaguet and Anatole Lécuyer

Soccer goalkeepers must process information from their peripheral vision at the same time they look towards the ball. This ability, committing attention to a position other than the fixation point, is called Covert Visuo-Spatial Attention or CVSA. CVSA being essential to reach high performances, it is primordial to find innovative and efficient ways of improving it. Neurofeedback, which consists in training specific brain features in order to enhance a cognitive ability, has been proven to increase attentional abilities. Also, different studies have suggested the existence of a neurophysiological marker specific to covert attention: a lateralised modulation of the alpha waves in the visual cortex. Moreover, it has been shown possible to compute this marker online, thus opening the door to a potential neurofeedback training procedure. In this view, we have proposed in a first instance to further investigate the relevance of this marker for soccer goalkeepers. The objective was here to answer the following questions: Is this marker transferrable to goalkeepers? How stable is it across athletes? Does it depend on their expertise?
This work was presented at the World Conference on Science and Soccer (Rennes, France, May 2017). It was done in collaboration with M2S Laboratory and EPFL.

7.5. Cultural Heritage

7.5.1. VR and AR tools for cultural heritage

EvoluSon: Walking Through an Interactive History of Music

Participants: Ronan Gaugne, Florian Nouviale and Valérie Gouranton

The EvoluSon project [4] proposes an immersive experience where the spectator explores an interactive visual and musical representation of the main periods of the history of Western music. The musical content is constituted of original musical compositions based on the theme of Bach's Art of Fugue to illustrate 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 (see Figure 16).

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

Immersive Point Cloud Manipulation for Cultural Heritage Documentation

Participants: Jean-Baptiste Barreau, Ronan Gaugne and Valérie Gouranton

Virtual reality combined with 3D digitisation allows to immerse archaeologists in 1:1 copies of monuments and sites. However, scientific communication of archaeologists is based on 2D representations of the monuments they study. In [2] we proposed a virtual reality environment with an innovative cutting-plan tool to dynamically produce 2D cuts of digitized monuments. A point cloud is the basic raw data obtained when digitizing cultural heritage sites or monuments with laser scans or photogrammetry. These data represent a rich and faithful record provided that they have adequate tools to exploit them. Their current analyses and visualizations on PC require software skills and can create ambiguities regarding the architectural dimensions. We conceived a toolbox to explore and manipulate such data in an immersive environment, and to dynamically generate 2D cutting planes usable for cultural heritage documentation and reporting (see Figure 17).

MAAP Annotate: When Archaeology meets Augmented Reality for Annotation of Megalithic Art

Participants: Jean-Marie Normand

Megalithic art is a spectacular form of symbolic representation found on prehistoric monuments. Carved by Europe's first farmers, this art allows an insight into the creativity and vision of prehistoric communities. As examples of this art continue to fade, it is increasingly important to document and study these symbols. In [12] we introduced MAAP Annotate, a Mixed Reality annotation tool from the Megalithic Art Analysis Project (MAAP). It provides an innovative method of interacting with megalithic art, combining cross-disciplinary research in digital heritage, 3D scanning and imaging, and augmented reality. The development of the tool

Figure 16. EvoluSon application in Immersia, Middle-Age era.

Figure 17. Immersive manipulation of the point cloud of the "Salle du Jeu de Paume" of Rennes, in Immersia room.

is described, alongside the results of an evaluation carried out on a group of archaeologists from University College Dublin, Ireland. It is hoped that such tools will enable archaeologists to collaborate worldwide, and non-specialists to experience and learn about megalithic art (see Figure 18).

This work was done in collaboration with the School of Computer Science and Informatics and the School of Archaeology of University College Dublin (UCD).

Figure 18. A real Irish megalith engraved with petroglyphs (Top-left) and a participant using the HoloLens to annotate the 3D scan of the megalith (Top-right). Overview of the MAAP Annotate user interface (Middle row), and two examples of manual AR annotations (Bottom row).

7.5.2. Multi-modal images and 3D printing for cultural heritage

Physical Digital Access Inside Archaeological Material

Participants: Théophane Nicolas, Ronan Gaugne and Valérie Gouranton

Traditionally, accessing the interior of an artefact or an archaeological material is a destructive activity. We proposed an alternative non-destructive technique, based on a combination of medical imaging and advanced transparent 3D printing. Our approach proposes combining a computed tomography (CT) scan and advanced 3D printing to generate a physical representation of an archaeological artefact or material [7]. This project is conducted with archaeologists from Inrap and computer scientists from Inria-IRISA. The goal of the project is to propose innovative practices, methods and tools for archaeology based on 3D digital techniques. We notably proposed a workflow (see Figure 19) where the CT scan images are used to produce volume and surface 3D data which serve as a basis for new evidence usable by archaeologists. This new evidence can be observed in interactive 3D digital environments or through physical copies of internal elements of the original material.

This work was done in collaboration with Inrap.

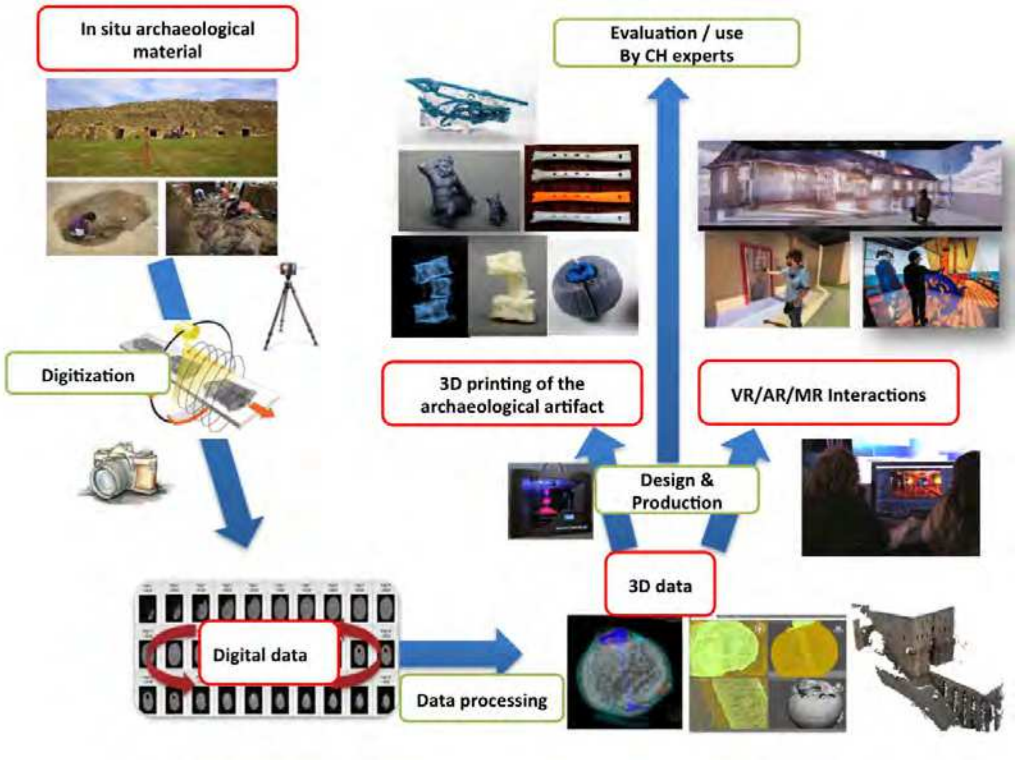

Figure 19. Our workflow for combining a computed tomography (CT) scan and advanced 3D printing to generate a physical representation of an archaeological artefact.

Combining CT-scan, Photogrammetry, 3D Printing and Mixed Reality

Participants: Théophane Nicolas, Ronan Gaugne, Bruno Arnaldi and Valérie Gouranton

Archaeological artefacts and the sediments that contain them constitute the sometimes tenuous evidence that requires analysis, preservation and showcasing. Different methods of digital analysis that provide non destructive solutions to preserve, analyse and showcase archaeological heritage have been developed over recent years. However these techniques are often restricted to the visible surface of the objects, monuments or sites. The techniques used in medical imaging are more and more frequently used in archaeology as they give non destructive access to the artefacts' internal and often fragile structure. This use is mostly limited to a simple visualisation. The information obtained by CT-scan is transcribed in a visual manner and its inherent detail can be used much more widely in the domain of the latest 3D technologies such as virtual reality, augmented reality, multimodal interactions and additive manufacturing. In combining these medical imaging techniques, it becomes possible to identify and scientifically analyse by efficient and non destructive methods non visible objects, to assess their fragility and their state of preservation. It is also possible to assess the restoration of a corroded artefact, to visualise, to analyse and to physically manipulate an inaccessible or fragile object (CT, 3D printing) and to observe the context of our hidden archaeological heritage (virtual reality, augmented reality or mixed, 3D). The development of digital technologies will hopefully lead to a democratisation of this type of analysis. We could illustrate our approach using the study of several artefacts from the recent excavation of the

Warcq chariot burial (Ardennes, France). We notably presented in [29] a physical interaction with inaccessible objects based on a transparent 3D printing of a horse's cranium (see Figure 20).

This work was done in collaboration with Inrap, Image ET and University Paris 1.

Figure 20. Original horse cranium (Top-left) and CT-scan of the cranium (Top-right), volume rendering from the CT scan (Bottom-left) and then transparent 3D printing of the same object (Bottom-right).

A Multimodal Digital Analysis of a Mesolithic Clavicle: Preserving and Studying the Oldest Human Bone in Brittany

Participants: Jean-Baptiste Barreau, Ronan Gaugne and Valérie Gouranton

The oldest human bone of Brittany was dug up from the mesolithic shell midden of Beg-er-Vil in Quiberon and dated about 8200 years. The low acid soils of these dump area represent exceptional sedimentary conditions. For these reasons, but also because these bones have a very particular patrimonial and symbolic value, their study goes altogether with concerns of conservation and museographic presentation. The clavicle is constituted of two pieces discovered separately at a one meter distance from each other. The two pieces match, so it can be assemble in a single fragment of approximately 7 centimeters. Cut-marks are clearly visible on the surface of these bones. They are bound to post- mortem processing which it is necessary to better qualify. The clavicle was studied through a process that combines advanced 3D image acquisition, 3D processing, and 3D printing with the goal to provide relevant support for the experts involved [25]. The bones were first scanned with a CT scan, and digitized with photogrammetry in order to get a high quality textured model. The CT scan appeared to be insufficient for a detailed analysis. The study was thus completed with a μCT providing a very accurate 3D model of the bone. Several 3D-printed copies of the collarbone were produced in order to constitute tangible support easy to annotate for sharing between the experts involved in the study. The 3D models generated from μCT and photogrammetry, were combined to provide an accurate and detailed 3D model. This model was used to study desquamation and the different cut marks. These cut marks were also studied with traditional binoculars and digital microscopy. This last technique allowed characterizing the cut marks, revealing a probable meat cutting process with a flint tool (see Figure 21). This work of crossed analyses allowed to document a fundamental patrimonial piece, and to ensure its preservation.

This work was done in collaboration with Inrap, UMR CReAAH, CNRS-INE and Université Paris 1.

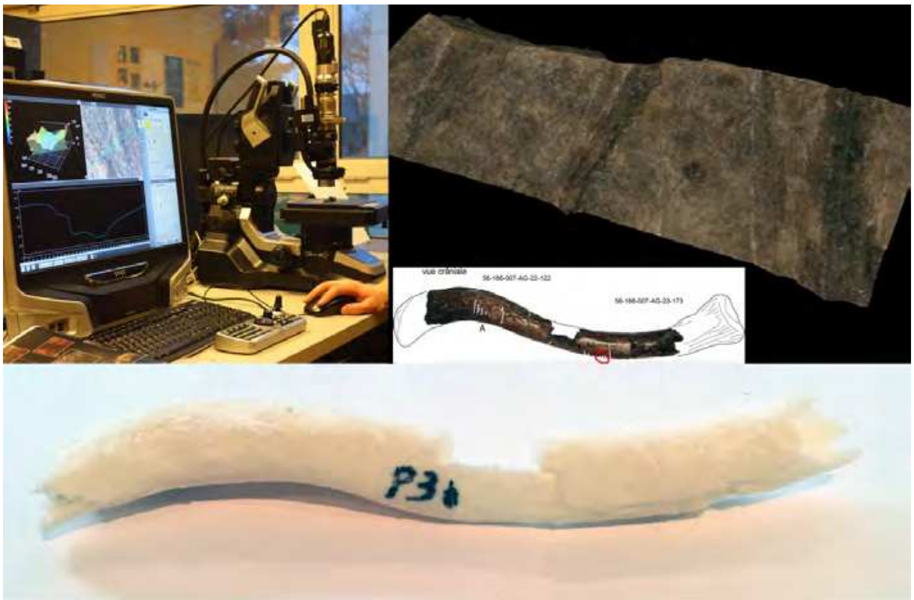

Figure 21. Digital microscopy of the clavicle (Top-left), and then detail of the cut marks in the digital model (Top-right), and annotated 3D printed clavicle (Bottom).

7.5.3. Generating 3D data for cultural heritage

3D Reconstruction of the Fortified Entrance of the Citadel of Aleppo from a few Sightseeing Photos

Participants: Jean-Baptiste Barreau and Ronan Gaugne

Built at the beginning of the 16th century by the final Mamluk sultan Al-Achraf Qânsûh Al-Ghûrî, the entrance to the Citadel of Aleppo was particularly affected by an earthquake in 1822, bombings during the Battle of Aleppo in August 2012, and a collapse of ramparts due to an explosion in July 2015. Even if compared to other Syrian sites, there are still enough vestiges to grasp the initial architecture, the civil war situation makes extremely difficult any "classic" process of digitization by photogrammetry or laser scanning. On this basis, we proposed in [26] a process to produce a 3D model "as relevant as possible" only from a few sightseeing photographs. This process combines fast 3D sketching by photogrammetry, 3D modeling and texture mapping and relies on a corpus based on pictures available on the net. Furthermore, it has the advantage to be applicable to destroyed monuments if sufficient pictures are available (see Figure 22).

This work was done in collaboration with UMR CReAAH and Inrap.

Raising the Elevations of a Megalithic Architecture: Methodological Developments

Participants: Jean-Baptiste Barreau, Quentin Petit and Ronan Gaugne

Figure 22. Rendering of the 3D model of Aleppo entrance.

Elevations have been little studied during explorations of megalithic architectures. For the past ten years, interest in these elevations has been growing in western France, particularly with the application of archeology of buildings and its tools to study them. Megalithic architecture, however, has its own characteristics that make manual surveys difficult. The first step presented in [27] was to acquire a 3D model, precise and manageable, of the whole architecture. Photogrammetry was tested, however the small space made it difficult to photograph. Laser scanner scanning has therefore been preferred. From the cloud of points obtained, a computer processing protocol was developed in order to obtain 2D images of the elevations according to the desired views. On these, a stone-to-stone design is possible in the laboratory and rectifiable directly in the field thanks to the use of a tablet computer. Our method has therefore met accessibility constraints. Above all, it allowed to increase the time devoted to the observation of ground, with a final result identical to a manual survey.

This work was done in collaboration with UMR CReAAH and SED Rennes.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Mensia Technologies

Participants: Anatole Lécuyer, Jussi Tapio Lindgren.

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

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

Figure 23. Inside the cairn of Barnenez in Immersia room.

8.2. Bilateral Grants with Industry

8.2.1. Technicolor

Participants: Antoine Costes, Anatole Lécuyer, Ferran Argelaguet.

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

8.2.2. Realyz

Participants: Guillaume Cortes, Anatole Lécuyer.

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

8.2.3. VINCI Construction

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

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

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, Guillaume Claude, Gautier Picard, 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 S3PM

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

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

9.1.3. Labex Cominlabs HEMISFER

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

HEMISFER is a 4-year project (2013-2017) 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).

9.1.4. Labex Cominlabs SABRE

Participants: Anatole Lécuyer [contact], Jussi Tapio Lindgren, Nataliya Kos’Myna.

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

9.1.5. IRT b<>com

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

b<>com is a French Institute of Research and Technology (IRT). The main goal of this IRT is to fasten the development and marketing of tools, products and services in the field of digital technologies. Our team has already collaborated with b<>com within two 3-year projects: ImData (on "Immersive Interaction") and GestChir (on "Augmented Healthcare") which both ended in 2016. A new 3-year project called NeedleWare (on "Augmented Healthcare") has started on October 2016.

9.1.6. CNPAO Project

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

9.1.7. Imag'In CNRS IRMA

Participants: Bruno Arnaldi, Jean-Baptiste Barreau, Ronan Gaugne, Valérie Gouranton [contact], Théophane Nicolas.

The IRMA project is an Imag'In project funded by CNRS which aims at developping innovative methodologies for research in the field of cultural heritage based on the combination of medical imaging technologies and interactive 3D technologies (virtual reality, augmented reality, haptics, additive manufacturing). It relies on close collaborations with the National Institute of Preventive Archaeological Research (Inrap), the Research Center Archaeology, and History Archéosciences (CReAAH UMR 6566) and the company Image ET. The developed tools are intended for cultural heritage professionals such as museums, curators, restorers, and archaeologists. We focus on a large number of archeological artefacts of different nature, and various time periods (Paleolithic, Mesolithic, and Iron Age Medieval) from all over France. We can notably mention the oldest human bones found in Brittany (clavicle Beg Er Vil), a funeral urn from Trebeurden (22), or a Bronze Cauldron from a burial of the Merovingian necropolis "Crassés Saint-Dizier" (51). This project involves a collaboration with Quentin Petit (SED Inria Rennes) and Grégor Marchand (CNRS/UMR CReAAH).

9.2. National Initiatives

9.2.1. ANR-FRQSC INTROSPECT

Participants: Valérie Gouranton [contact], Bruno Arnaldi, Ronan Gaugne, Jean-Baptiste Barreau, Flavien Lecuyer.

INTROSPECT is a 3-year project funded by French ANR and "Fonds de Recherche Société et Culture" (FRQSC) from Quebec region, Canada. The 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 partners in the project to spread our results among the general public.

9.2.2. Ilab CertiViBE

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

CertiViBE is a 2-year "Inria Innovation Lab" (2015-2017) funded by Inria for supporting the development of OpenViBE software, and notably its evolution in order to enable and fasten the medical transfer and the medical certification of products based on OpenViBE. This joint lab involves two partners: Hybrid and Mensia Technologies startup company. The project aims at setting up a quality environment, and developping a novel version of the software wich should comply with medical certification rules.

9.2.3. IPL BCI-LIFT

Participants: Anatole Lécuyer [contact], Jussi Tapio Lindgren, Hakim Si Mohammed, Lorraine Perronnet, Nataliya Kos'Myna.

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, Mjolnir, Demar; as well as external partners: INSERM-Lyon, and INSA Rouen. This project aims at improving several aspects of Brain-Computer Interfaces: learning and adaptation of BCI systems, user interfaces and feedback, training protocols, etc.

9.2.4. ATT CONSORVIBE

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

CONSORVIBE is 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.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. HAPPINESS

Title: HAptic Printed Patterned INtErfaces for Sensitive Surface

Programm: H2020

Duration: January 2015 - December 2017

Coordinator: CEA (France)

Partners:

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

Inria contact: Nicolas Roussel and Anatole Lécuyer

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

9.3.1.2. 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

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.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

This year, Hybrid team has welcomed for short periods:

- Gabriel Cirio, Universidad Rey Juan Carlos Madrid (Spain), May 2017
- Victoria Interrante, University of Minnesota (US), December 2017
- Geneviève Treyvaud and Pierre Francus, INRS (Canada), November 2017

9.4.2. Visits to International Teams

Ronan Gaugne and Valérie Gouranton made a short stay at University Laval (Canada) in August 2017

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, Scientific chair

- Bruno Arnaldi was General Chair of IGRV 2017 (journées du GDR IG-RV, Journées de l'AFRV, Journées de l'AFIG), Rennes, France.
- Anatole Lécuyer and Guillaume Moreau were General co-Chairs of IEEE Symposium on Mixed and Augmented Reality 2017 (IEEE ISMAR), Nantes, France.
- Maud Marchal was Program Chair of IEEE Symposium on 3D User Interfaces 2017 (IEEE 3DUI).
- Jean-Marie Normand was Deputy General Chair of IEEE Symposium on Mixed and Augmented Reality 2017 (IEEE ISMAR), Nantes, France.

10.1.1.2. Member of the organizing committees

- Anatole Lécuyer was Member of the organization committee of IGRV 2017.
- Ferran Argelaguet was Member of the organization committee of ISMAR 2017 and IGRV 2017.
- Ronan Gaugne was Member of the organization committee of ISMAR 2017 and IGRV 2017.
- Valérie Gouranton was Member of the steering committee of ISMAR 2017 and IGRV 2017.
- Maud Marchal was Member of the organization committee of IGRV 2017.
- Florian Nouviale was Member of the organization committee of ISMAR 2017 and IGRV 2017.

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

- Anatole Lécuyer was Member of the conference program committee of IEEE Conference on Virtual Reality 2017.
- Ferran Argelaguet was Member of the conference program committee of IEEE Symposium on 3D User Interfaces 2017, and ACM Symposium on Spatial User Interfaces 2017 and IHM 2017.
- Maud Marchal was Member of the conference program committee of Eurographics 2017, the best paper committee of "Journées Françaises de l'Informatique Graphique" 2017, the best Phd award committee of GDR-IGRV/EGFR/AFRV.
- Guillaume Moreau was Member of the program committee of IEEE Symposium on 3D User Interfaces 2017, Area Chair of IAPR Machine Vision Applications 2017.
- Jean-Marie Normand was Member of the program committee of Augmented Human 2017, Area Chair of IAPR Machine Vision Applications 2017.

10.1.2.2. Reviewer

- Ferran Argelaguet was Reviewer for IEEE VR 2017, ACM CHI 2017, ACM VRST 2017, ACM UIST 2017, WorldHaptics 2017.
- Maud Marchal was Reviewer for IEEE VR 2017, Eurographics 2017, IEEE ICRA 2017.
- Valérie Gouranton was Reviewer for IEEE VR 2017.
- Guillaume Moreau was Reviewer for IEEE 3DUI 2017, IEEE VR 2017, ACM AH 2017.
- Jean-Marie Normand was Reviewer for IEEE 3DUI 2017, IEEE VR 2017, IEEE ISMAR 2017, ACM CHI 2017, ACM MM 2017.

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- Anatole Lécuyer is Associate Editor of the IEEE Transactions on Visualization and Computer Graphics (since Dec 2017), Frontiers in Virtual Environments, and Presence journals. He is also Guest Editor of a Special Issue of IEEE Computer Graphics and Applications on "Virtual and Augmented Reality".
- Ferran Argelaguet is Review Editor of Frontiers in Virtual Environments.
- Maud Marchal is Review Editor of Frontiers in Virtual Environments.
- Guillaume Moreau is Associate Editor of a Special Issue of the Transactions of the Institute of Electronics, Information and Communication Engineers and for Applied Sciences.
- Jean-Marie Normand is Review Editor of Frontiers in Virtual Environments.

10.1.3.2. Reviewer - Reviewing activities

- Ferran Argelaguet was Reviewer for ACM Transactions on Graphics, IEEE Transactions on Visualization and Computer Graphics, International Journal on Human Computer Studies.
- Ronan Gaugne was Reviewer for Digital Applications in Archaeology and Cultural Heritage.
- Maud Marchal was Reviewer for IEEE Transactions on Visualization and Computer Graphics, IEEE Transactions on Haptics, The Visual Computer and Computers and Graphics Journal.
- Guillaume Moreau was reviewer for IEEE Transactions on Visualization and Computer Graphics and Computers, Environments and urban Systems.
- Jean-Marie Normand was Reviewer for Frontiers in Robotics and AI, IEEE Computer Graphics and Applications, IEEE Transactions on Visualization and Computer Graphics.

10.1.4. Invited talks

- Anatole Lécuyer was Keynote Speaker at EuroVR 2017.
- Guillaume Moreau was Keynote Speaker at "Journées de l'Association Française d'Histotechnologie".

10.1.5. Leadership within the scientific community

- Bruno Arnaldi is Member of Executive Committee of AFRV (French Association for Virtual Reality).
- Ronan Gaugne is Member of the Selection and Validation Committee for the French cluster "Pôle Images et Réseaux"
- Valérie Gouranton is Member of Executive Committee of AFRV.
- Maud Marchal is Member of Executive Committee of Eurographics French Chapter.

10.1.6. Scientific expertise

- Valérie Gouranton was Member of a selection committee for French ANR.
- Ronan Gaugne was Expert for "Atlanstic2020 Région Pays de la Loire".
- Maud Marchal was Expert for "Haute Ecole Specialisée de Suisse Occidentale" (Switzerland).
- Jean-Marie Normand was Expert for French ANR.

10.1.7. 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.
- Jean-Marie Normand is Head of the Minor "Virtual Reality" at ECN.

10.2. Teaching - Supervision - Juries

Anatole Lécuyer:

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

Ecole Centrale de Nantes : “Haptic Interaction and Brain-Computer Interfaces”, 4.5h, M1-M2, Ecole Centrale de Nantes, FR

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

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

Master VRI: "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 MITIC: "Techniques d’Interaction Avancées", 26h, M2, ISTIC, University of Rennes 1, FR

Master INSA Rennes: "Modeling and Engineering for Biology and Health Applications", 12h, M2, INSA Rennes, 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

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

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

Valérie Gouranton:

Licence: "Introduction to Virtual Reality", 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

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

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

Master CN: "Virtual Reality", 6h, M1, University of Rennes 2, FR

Ronan Gaugne:

INSA Rennes: Projects on "Virtual Reality", 47h, L3/M1/M2, Insa Rennes, FR

Master CN: "Virtual Reality", 3h, M1, University of Rennes 2, FR

Jean-Marie Normand:

Virtual Reality Minor, "Computer Graphics", 24h, M1/M2, Ecole centrale de Nantes, FR

Virtual Reality Minor, "Fundamentals of Virtual Reality", 14h, M1/M2, Ecole centrale de Nantes, FR

Virtual Reality Minor, "Computer Vision anf Augmented Reality", 24h, M1/M2, Ecole centrale de Nantes, FR

Virtual Reality Minor, "Projects on Virtual Reality", 20h, M1/M2, Ecole centrale de Nantes, FR

10.2.1. Supervision

10.2.1.1. PhD (defended)

- Jean-Baptiste Barreau, "Techniques of production, exploration and analysis of virtual archaeological environments", INSA Rennes, July 10th 2017, Supervised by Valérie Gouranton and Bruno Arnaldi
- Lorraine Perronnet, "Combining electroencephalography and functional magnetic resonance imaging for neurofeedback", University of Rennes 1, January 8th, 2017, Supervised by Anatole Lécuyer, Fabien Lotte (Potioc, Inria), Maureen Clerc (Athena, Inria) and Christian Barillot (Visages, Inria)
- Benoit Le Gouis, "Contribution to the study of haptic rendering and perception of virtual deformable objects", INSA Rennes, November 21th 2017, Supervised by Bruno Arnaldi, Maud Marchal and Anatole Lécuyer

10.2.1.2. PhD (in progress)

- Gwendal Le Moulec, "Automatic generation of VR applications", Started in October 2015, Supervised by Valérie Gouranton, Bruno Arnaldi and Arnaud Blouin (Diverse, Inria)
- Anne-Solène Dris-Kerdreux, "Training in virtual reality for construction applications", Started in November 2015, Supervised by Valérie Gouranton and Bruno Arnaldi
- Antoine Costes, "Haptic texturing", Started in November 2015, Supervised by Anatole Lécuyer, Philippe Guillotel (Technicolor), Fabien Danieau (Technicolor) and Ferran Argelaguet
- Guillaume Cortes, "Improving tracking in VR", Started in November 2015, Supervised by Anatole Lécuyer and Eric Marchand (Lagadic, Inria)
- 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
- Gautier Picard, "Collaborative VR", Started in October 2016, Supervised by Valérie Gouranton, Bernard Gibaud (Inserm) and Bruno Arnaldi
- Hadrien Gurnel, "Prise en compte de la déformation d'organe pour l'assistance robotisée d'insertion d'aiguille", Started in October 2016, Supervised by Alexandre Krupa (Lagadic, 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 (Lagadic, Inria) and Anatole Lécuyer
- Flavien Lecuyer, "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 (Lagadic, 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)

10.2.2. Juries

10.2.2.1. Selection committees

- Anatole Lécuyer was Member of selection committee of Assistant Professor Position at Ecole Centrale de Nantes.
- Valérie Gouranton was Member of selection committee of Assistant Professor Position at INSA Rennes, of Inria Junior Research Scientist (CR2 Inria) at Inria Rennes-Bretagne Atlantique
- Maud Marchal was Member of selection committee of Assistant Professor Position at Ecole Centrale de Nantes.
- Guillaume Moreau was Member of selection committee at Ecole Centrale de Nantes: Assistant Professor (2x), Full Professor (2x).

10.2.2.2. PhD and HDR juries

- Anatole Lécuyer was Referee of PhD theses of Paul Issartel (Univ Paris Saclay), Cephise Louison (Univ Mediterrannée) and Joan Sol Roo (Univ Bordeaux).
- Bruno Arnaldi was Referee of PhD thesis of Damien Clergeaud (Univ Bordeaux).
- Maud Marchal was Referee of PhD thesis of Fanny Morin (Univ Grenoble Alpes).
- Guillaume Moreau was Referee of PhD thesis of Judicaël Menant (INSA Rennes), and Member of PhD committee of Abdelkader Bellarbi (Univ Paris-Saclay).
- Jean-Marie Normand was Member of the committee of Barteld Postma (Univ. Paris Saclay).

10.3. Popularization

The results of the team have been disseminated in various media coverages in 2017:

- "XENIUS" TV channel Arte (02/17) : presentation of Immersia activity in Cultural Heritage applications
- “Sciences et Avenir” magazine (02/17) : article on "BCI, VR and videogames"
- France-Info radio (07/17) : 4-min interview of Anatole Lécuyer on Virtual Reality
- 20-minutes magazine (10/17) : article on Immersia activity
- Virgin Radio (10/17) : interview of Ronan Gaugne on Immersia
- France 3 Bretagne (10/17) : presentation of "Journée Science et Musique" in Immersia
- France 3 Centre (11/17) : presentation of INTROSPECT project

The team has also participated to several dissemination events in 2017 (chronological order):

- "Ma Thèse en 180 secondes" (Rennes, 03/17) : Lorraine Perronnet presented her PhD.
- "Semaine du Cerveau 2017" (Rennes, 03/17) : presentation and demo of BCI by Nataliya Kosmyna.
- Pint of Science (05/17): presentation on virtual incarnation by Ferran Argelaguet.
- "Journées Science et Musique 2017" (Rennes, 10/17) : co-organization of this event, and presentation of several demos.
- "Journées du Pôle Aerospace Valley" (Agen, 12/17) : presentation by Guillaume Moreau.

11. Bibliography

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