IN PARTNERSHIP WITH:
Université Haute Bretagne (Rennes 2)

Université Rennes 1

École normale supérieure de Rennes

Activity Report 2019

Project-Team MIMETIC

Analysis-Synthesis Approach for Virtual Human Simulation

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Interaction and visualization

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Creation of the Team: 2011 January 01, updated into Project-Team: 2014 January 01

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2. Overall Objectives

2.1. Presentation

MimeTIC is a multidisciplinary team whose aim is to better understand and model human activity in order to simulate realistic autonomous virtual humans: realistic behaviors, realistic motions and realistic interactions with other characters and users. It leads to modeling the complexity of a human body, as well as of his environment where he can pick-up information and he can act on it. A specific focus is dedicated to human physical activity and sports as it raises the highest constraints and the highest complexity when addressing these problems. Thus, MimeTIC is composed of experts in computer science whose research interests are computer animation, behavioral simulation, motion simulation, crowds and interaction between real and virtual humans. MimeTIC is also composed of experts in sports science, motion analysis, motion sensing, biomechanics and motion control. Hence, the scientific foundations of MimeTIC are motion sciences (biomechanics, motion control, perception-action coupling, motion analysis), computational geometry (modeling of the 3D environment, motion planning, path planning) and design of protocols in immersive environments (use of virtual reality facilities to analyze human activity).

Thanks to these skills, we wish to reach the following objectives: to make virtual humans behave, move and interact in a natural manner in order to increase immersion and to improve knowledge on human motion control. In real situations (see Figure 1), people have to deal with their physiological, biomechanical and neurophysiological capabilities in order to reach a complex goal. Hence MimeTIC addresses the problem of modeling the anatomical, biomechanical and physiological properties of human beings. Moreover these characters have to deal with their environment. Firstly they have to perceive this environment and pick-up relevant information. MimeTIC thus addresses the problem of modeling the environment including its geometry and associated semantic information. Secondly, they have to act on this environment to reach their goals. It leads to cognitive processes, motion planning, joint coordination and force production in order to act on this environment.

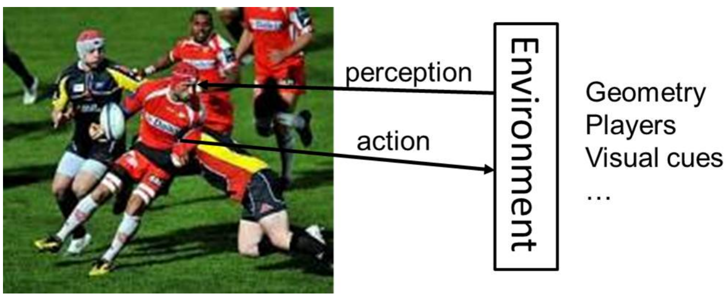

Figure 1. Main objective of MimeTIC: to better understand human activity in order to improve virtual human simulations. It involves modeling the complexity of human bodies, as well as of environments where to pick-up information and act upon.

In order to reach the above objectives, MimeTIC has to address three main challenges:

- dealing with the intrinsic complexity of human beings, especially when addressing the problem of interactions between people for which it is impossible to predict and model all the possible states of the system,

- making the different components of human activity control (such as the biomechanical and physical, the reactive, cognitive, rational and social layers) interact while each of them is modeled with completely different states and time sampling,
- and being able to measure human activity while balancing between ecological and controllable protocols, and to be able to extract relevant information in wide databases of information.

Contrary to many classical approaches in computer simulation, which mostly propose simulation without trying to understand how real people do, the team promotes a coupling between human activity analysis and synthesis, as shown in Figure 2.

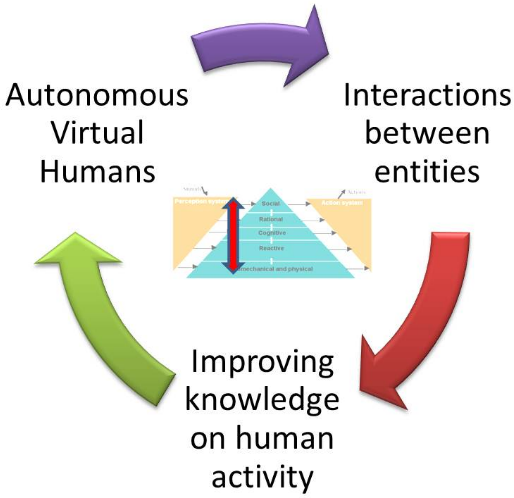

Figure 2. Research path of MimeTIC: coupling analysis and synthesis of human activity enables us to create more realistic autonomous characters and to evaluate assumptions about human motion control.

In this research path, **improving knowledge on human activity** enables us to highlight fundamental assumptions about natural control of human activities. These contributions can be promoted in e.g. biomechanics, motion sciences, neurosciences. According to these assumptions we propose new algorithms for controlling **autonomous virtual humans**. The virtual humans can perceive their environment and decide of the most natural action to reach a given goal. This work is promoted in computer animation, virtual reality and has some applications in robotics through collaborations. Once autonomous virtual humans have the ability to act as real humans would in the same situation, it is possible to make them **interact with others**, i.e., autonomous characters (for crowds or group simulations) as well as real users. The key idea here is to analyze to what extent the assumptions proposed at the first stage lead to natural interactions with real users. This process enables the validation of both our assumptions and our models.

Among all the problems and challenges described above, MimeTIC focuses on the following domains of research:

- **motion sensing** which is a key issue to extract information from raw motion capture systems and thus to propose assumptions on how people control their activity,
- **human activity & virtual reality**, which is explored through sports application in MimeTIC. This domain enables the design of new methods for analyzing the perception-action coupling in human activity, and to validate whether the autonomous characters lead to natural interactions with users,

- **interactions** in small and large groups of individuals, to understand and model interactions with lot of individual variability such as in crowds,
- **virtual storytelling** which enables us to design and simulate complex scenarios involving several humans who have to satisfy numerous complex constraints (such as adapting to the real-time environment in order to play an imposed scenario), and to design the coupling with the camera scenario to provide the user with a real cinematographic experience,
- **biomechanics** which is essential to offer autonomous virtual humans who can react to physical constraints in order to reach high-level goals, such as maintaining balance in dynamic situations or selecting a natural motor behavior among the whole theoretical solution space for a given task,
- and **autonomous characters** which is a transversal domain that can reuse the results of all the other domains to make these heterogeneous assumptions and models provide the character with natural behaviors and autonomy.

3. Research Program

3.1. Biomechanics and Motion Control

Human motion control is a highly complex phenomenon that involves several layered systems, as shown in Figure 3. Each layer of this controller is responsible for dealing with perceptual stimuli in order to decide the actions that should be applied to the human body and his environment. Due to the intrinsic complexity of the information (internal representation of the body and mental state, external representation of the environment) used to perform this task, it is almost impossible to model all the possible states of the system. Even for simple problems, there generally exists an infinity of solutions. For example, from the biomechanical point of view, there are much more actuators (i.e. muscles) than degrees of freedom leading to an infinity of muscle activation patterns for a unique joint rotation. From the reactive point of view there exists an infinity of paths to avoid a given obstacle in navigation tasks. At each layer, the key problem is to understand how people select one solution among these infinite state spaces. Several scientific domains have addressed this problem with specific points of view, such as physiology, biomechanics, neurosciences and psychology.

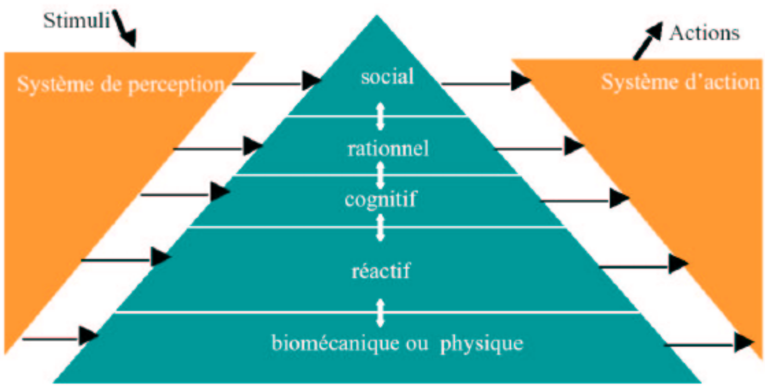

Figure 3. Layers of the motion control natural system in humans.

In biomechanics and physiology, researchers have proposed hypotheses based on accurate joint modeling (to identify the real anatomical rotational axes), energy minimization, force and torques minimization, comfort maximization (i.e. avoiding joint limits), and physiological limitations in muscle force production. All these constraints have been used in optimal controllers to simulate natural motions. The main problem is thus to define how these constraints are composed altogether such as searching the weights used to linearly combine these criteria in order to generate a natural motion. Musculoskeletal models are stereotyped examples for which there exists an infinity of muscle activation patterns, especially when dealing with antagonist muscles. An unresolved problem is to define how to use the above criteria to retrieve the actual activation patterns, while optimization approaches still leads to unrealistic ones. It is still an open problem that will require multidisciplinary skills including computer simulation, constraint solving, biomechanics, optimal control, physiology and neuroscience.

In neuroscience, researchers have proposed other theories, such as coordination patterns between joints driven by simplifications of the variables used to control the motion. The key idea is to assume that instead of controlling all the degrees of freedom, people control higher level variables which correspond to combinations of joint angles. In walking, data reduction techniques such as Principal Component Analysis have shown that lower-limb joint angles are generally projected on a unique plane whose angle in the state space is associated with energy expenditure. Although knowledge exists for specific motions, such as locomotion or grasping, this type of approach is still difficult to generalize. The key problem is that many variables are coupled and it is very difficult to objectively study the behavior of a unique variable in various motor tasks. Computer simulation is a promising method to evaluate such type of assumptions as it enables to accurately control all the variables and to check if it leads to natural movements.

Neuroscience also addresses the problem of coupling perception and action by providing control laws based on visual cues (or any other senses), such as determining how the optical flow is used to control direction in navigation tasks, while dealing with collision avoidance or interception. Coupling of the control variables is enhanced in this case as the state of the body is enriched by the large amount of external information that the subject can use. Virtual environments inhabited with autonomous characters whose behavior is driven by motion control assumptions is a promising approach to solve this problem. For example, an interesting problem in this field is navigation in an environment inhabited with other people. Typically, avoiding static obstacles together with other people displacing into the environment is a combinatory problem that strongly relies on the coupling between perception and action.

One of the main objectives of MimeTIC is to enhance knowledge on human motion control by developing innovative experiments based on computer simulation and immersive environments. To this end, designing experimental protocols is a key point and some of the researchers in MimeTIC have developed this skill in biomechanics and perception-action coupling. Associating these researchers to experts in virtual human simulation, computational geometry and constraints solving enable us to contribute to enhance fundamental knowledge in human motion control.

3.2. Experiments in Virtual Reality

Understanding interactions between humans is challenging because it addresses many complex phenomena including perception, decision-making, cognition and social behaviors. Moreover, all these phenomena are difficult to isolate in real situations, and it is therefore highly complex to understand their individual influence on these human interactions. It is then necessary to find an alternative solution that can standardize the experiments and that allows the modification of only one parameter at a time. Video was first used since the displayed experiment is perfectly repeatable and cut-offs (stop the video at a specific time before its end) allow having temporal information. Nevertheless, the absence of adapted viewpoint and stereoscopic vision does not provide depth information that are very meaningful. Moreover, during video recording session, the real human is acting in front of a camera and not of an opponent. The interaction is then not a real interaction between humans.

Virtual Reality (VR) systems allow full standardization of the experimental situations and the complete control of the virtual environment. It is then possible to modify only one parameter at a time and to observe its influence on the perception of the immersed subject. VR can then be used to understand what information is picked up to make a decision. Moreover, cut-offs can also be used to obtain temporal information about when information is picked up. When the subject can moreover react as in a real situation, his movement (captured in real time) provides information about his reactions to the modified parameter. Not only is the perception studied, but the complete perception-action loop. Perception and action are indeed coupled and influence each other as suggested by Gibson in 1979.

Finally, VR allows the validation of virtual human models. Some models are indeed based on the interaction between the virtual character and the other humans, such as a walking model. In that case, there are two ways to validate it. First, they can be compared to real data (e.g. real trajectories of pedestrians). But such data are not always available and are difficult to get. The alternative solution is then to use VR. The validation of the realism of the model is then done by immersing a real subject in a virtual environment in which a virtual character is controlled by the model. Its evaluation is then deduced from how the immersed subject reacts when interacting with the model and how realistic he feels the virtual character is.

3.3. Computer animation

Computer animation is the branch of computer science devoted to models for the representation and simulation of the dynamic evolution of virtual environments. A first focus is the animation of virtual characters (behavior and motion). Through a deeper understanding of interactions using VR and through better perceptive, biomechanical and motion control models to simulate the evolution of dynamic systems, the Mimetic team has the ability to build more realistic, efficient and believable animations. Perceptual study also enables us to focus computation time on relevant information (i.e. leading to ensure natural motion from the perceptual points of view) and save time for unperceived details. The underlying challenges are (i) the computational efficiency of the system which needs to run in real-time in many situations, (ii) the capacity of the system to generalise/adapt to new situations for which data was not available or for which models were not defined for, and (iii) the variability of the models, i.e. their ability to handle many body morphologies and generate variations in motions that would be specific to each virtual character.

In many cases, however, these challenges cannot be addressed in isolation. Typically character behaviors also depend on the nature and the topology of the environment they are surrounded by. In essence, a character animation system should also rely on smarter representations of the environments, in order to better perceive the environment, and take contextualised decisions. Hence the animation of virtual characters in our context often requires to be coupled with models to represent the environment, reason, and plan both at a geometric level (can the character reach this location), and at a semantic level (should it use the sidewalk, the stairs, or the road). This represents the second focus. Underlying challenges are the ability to offer a compact, yet precise representation on which efficient path and motion planning can be performed, and on which high-level reasonning can be achieved.

Finally, a third scientific focus tied to the computer animation axis is digital storytelling. Evolved representations of motions and environments enable realistic animations. It is yet equally important to question how these event should be portrayed, when and under which angle. In essence, this means integrating *discourse models* into *story models*, the story representing the sequence of events which occur in a virtual environment, and the discourse representing how this story should be displayed (ie which events to show in which order and with which viewpoint). Underlying challenges are pertained to (i) narrative discourse representations, (ii) projections of the discourse into the geometry, planning camera trajectories and planning cuts between the viewpoints and (iii) means to interactively control the unfolding of the discourse.

By therefore establishing the foundations to build bridges between the high-level narrative structures, the semantic/geometric planning of motions and events, and low-level character animations, the Mimetic team adopts a principled and all-inclusive approach to the animation of virtual characters.

4. Application Domains

4.1. Animation, Autonomous Characters and Digital Storytelling

Computer Animation is one of the main application domain of the research work conducted in the MimeTIC team, in particular in relation to the entertainment and game industries. In these domains, creating virtual characters that are able to replicate real human motions and behaviours still highlights unanswered key challenges, especially as virtual characters are becoming more and required to populate virtual worlds. For instance, virtual characters are used to replace secondary actors and generate highly populated scenes that would be hard and costly to produce with real actors, which requires to create high quality replicas that appear, move and behave both individually and collectively like real humans. The three key challenges for the MimeTIC team are therefore (i) to create natural animations (i.e., virtual characters that move like real humans), (ii) to create autonomous characters (i.e., that behave like real humans) and (iii) to orchestrate the virtual characters so as to create interactive stories.

First, our challenge is therefore to create animations of virtual characters that are natural, in the largest sense of the term of moving like a real human real would. This challenge covers several aspects of Character Animation depending on the context of application, e.g., producing visually plausible or physically correct motions, producing natural motion sequences, etc. Our goal is therefore to develop novel methods for animating virtual characters, e.g., based on motion capture, data-driven approaches, or learning approaches. However, because of the complexity of human motion (e.g., the number of degrees of freedom that can be controled), resulting animations are not necessarily physically, biomechanically, or visually plaisible. For instance, current physics-based approaches produce physically correct motions but not necessarily perceptually plausible ones. All these reasons are why most entertainment industries still mainly rely on manual animation, e.g., in games and movies. Therefore, research in MimeTIC on character animation is also conducted with the goal of validating objective (e.g., physical, biomechanical) as well as subjective (e.g., visual plausibility) criteria.

Second, one of the main challenges in terms of autonomous characters is to provide a unified architecture for the modeling of their behavior. This architecture includes perception, action and decisional parts. This decisional part needs to mix different kinds of models, acting at different time scale and working with different nature of data, ranging from numerical (motion control, reactive behaviors) to symbolic (goal oriented behaviors, reasoning about actions and changes). For instance, autonomous characters play the role of actors that are driven by a scenario in video games and virtual storytelling. Their autonomy allows them to react to unpredictable user interactions and adapt their behavior accordingly. In the field of simulation, autonomous characters are used to simulate the behavior of humans in different kind of situations. They enable to study new situations and their possible outcomes. In the MimeTIC team, our focus is therefore not to reproduce the human intelligence but to propose an architecture making it possible to model credible behaviors of anthropomorphic virtual actors evolving/moving in real time in virtual worlds. The latter can represent particular situations studied by psychologists of the behavior or to correspond to an imaginary universe described by a scenario writer. The proposed architecture should mimic all the human intellectual and physical functions.

Finally, interactive digital storytelling, including novel forms of edutainment and serious games, provides access to social and human themes through stories which can take various forms and contains opportunities for massively enhancing the possibilities of interactive entertainment, computer games and digital applications. It provides chances for redefining the experience of narrative through interactive simulations of computer-generated story worlds and opens many challenging questions at the overlap between computational narratives, autonomous behaviours, interactive control, content generation and authoring tools. Of particular interest for the MimeTIC research team, virtual storytelling triggers challenging opportunities in providing effective models for enforcing autonomous behaviours for characters in complex 3D environments. Offering both low-level capacities to characters such as perceiving the environments, interacting with the environment and reacting to changes in the topology, on which to build higher-levels such as modelling abstract representations for efficient reasoning, planning paths and activities, modelling cognitive states and behaviours requires the provision of expressive, multi-level and efficient computational models. Furthermore virtual storytelling requires the seamless control of the balance between the autonomy of characters and the unfolding of the story through the narrative discourse. Virtual storytelling also raises challenging questions on the conveyance of a narrative through interactive or automated control of the cinematography (how to stage the characters, the lights and the cameras). For example, estimating visibility of key subjects, or performing motion planning for cameras and lights are central issues for which have not received satisfactory answers in the literature.

4.2. Fidelity of Virtual Reality

VR is a powerful tool for perception-action experiments. VR-based experimental platforms allow exposing a population to fully controlled stimuli that can be repeated from trial to trial with high accuracy. Factors can be isolated and objects manipulations (position, size, orientation, appearance, ..) are easy to perform. Stimuli can be interactive and adapted to participants' responses. Such interesting features allow researchers to use VR to perform experiments in sports, motion control, perceptual control laws, spatial cognition as well as person-person interactions. However, the interaction loop between users and their environment differs in virtual conditions in comparison with real conditions. When a user interact in an environment, movement from action and perception are closely related. While moving, the perceptual system (vision, proprioception,..) provides feedback about the users' own motion and information about the surrounding environment. That allows the user to adapt his/her trajectory to sudden changes in the environment and generate a safe and efficient motion. In virtual conditions, the interaction loop is more complex because it involves several material aspects.

First, the virtual environment is perceived through a numerical display which could affect the available information and thus could potentially introduce a bias. For example, studies observed a distance compression effect in VR, partially explained by the use of Head Mounted Display with reduced field of view and exerting a weight and torques on the user's head. Similarly, the perceived velocity in a VR environment differs from the real world velocity, introducing an additional bias. Other factors, such as the image contrast, delays in the displayed motion and the point of view can also influence efficiency in VR. The second point concerns the user's motion in the virtual world. The user can actually move if the virtual room is big enough or if wearing a head mounted display. Even with a real motion, authors showed that walking speed is decreased, personal space size is modified and navigation in VR is performed with increased gait instability. Although natural locomotion is certainly the most ecological approach, the physical limited size of VR setups prevents from using it most of the time. Locomotion interfaces are therefore required. Locomotion interfaces are made up of two components, a locomotion metaphor (device) and a transfer function (software), that can also introduce bias in the generated motion. Indeed, the actuating movement of the locomotion metaphor can significantly differ from real walking and the simulated motion depends on the transfer function applied. Locomotion interfaces cannot usually preserve all the sensory channels involved in locomotion.

When studying human behavior in VR, the aforementioned factors in the interaction loop potentially introduce bias both in the perception and in the generation of motor behavior trajectories. MimeTIC is working on the mandatory step of VR validation to make it usable for capturing and analyzing human motion.

4.3. Motion Sensing of Human Activity

Recording human activity is a key point of many applications and fundamental works. Numerous sensors and systems have been proposed to measure positions, angles or accelerations of the user's body parts. Whatever the system is, one of the main problems is to be able to automatically recognize and analyze the user's performance according to poor and noisy signals. Human activity and motion are subject to variability: intra-variability due to space and time variations of a given motion, but also inter-variability due to different styles and anthropometric dimensions. MimeTIC has addressed the above problems in two main directions.

Firstly, we have studied how to recognize and quantify motions performed by a user when using accurate systems such as Vicon (product of Oxford Metrics), Qualisys, or Optitrack (product of Natural Point) motion capture systems. These systems provide large vectors of accurate information. Due to the size of the state vector (all the degrees of freedom) the challenge is to find the compact information (named features) that enables the automatic system to recognize the performance of the user. Whatever the method used, finding these relevant features that are not sensitive to intra-individual and inter-individual variability is a challenge. Some researchers have proposed to manually edit these features (such as a Boolean value stating if the arm is moving forward or backward) so that the expertise of the designer is directly linked with the success ratio. Many proposals for generic features have been proposed, such as using Laban notation which was introduced to encode dancing motions. Other approaches tend to use machine learning to automatically extract these features. However most of the proposed approaches were used to seek a database for motions which properties correspond to the features of the user's performance (named motion retrieval approaches). This does not ensure the retrieval of the exact performance of the user but a set of motions with similar properties.

Secondly, we wish to find alternatives to the above approach which is based on analyzing accurate and complete knowledge on joint angles and positions. Hence new sensors, such as depth-cameras (Kinect, product of Microsoft) provide us with very noisy joint information but also with the surface of the user. Classical approaches would try to fit a skeleton into the surface in order to compute joint angles which, again, lead to large state vectors. An alternative would be to extract relevant information directly from the raw data, such as the surface provided by depth cameras. The key problem is that the nature of these data may be very different from classical representation of human performance. In MimeTIC, we try to address this problem in specific application domains that require picking specific information, such as gait asymmetry or regularity for clinical analysis of human walking.

4.4. Sports

Sport is characterized by complex displacements and motions. One main objective is to understand the determinants of performance through the analysis of the motion itself. In the team, different sports have been studied such as the tennis serve, where the goal was to understand the contribution of each segment of the body in the performance but also the risk of injuries as well as other situation in cycling, swimming, fencing or soccer. Sports motions are dependent on visual information that the athlete can pick up in his environment, including the opponent's actions. Perception is thus fundamental to the performance. Indeed, a sportive action, as unique, complex and often limited in time, requires a selective gathering of information. This perception is often seen as a prerogative for action, it then takes the role of a passive collector of information. However, as mentioned by Gibson in 1979, the perception-action relationship should not be considered sequentially but rather as a coupling: we perceive to act but we must act to perceive. There would thus be laws of coupling between the informational variables available in the environment and the motor responses of a subject. In other words, athletes have the ability to directly perceive the opportunities of action directly from the environment. Whichever school of thought considered, VR offers new perspectives to address these concepts by complementary using real time motion capture of the immersed athlete.

In addition to better understand sports and interactions between athletes, VR can also be used as a training environment as it can provide complementary tools to coaches. It is indeed possible to add visual or auditory information to better train an athlete. The knowledge found in perceptual experiments can be for example used to highlight the body parts that are important to look at to correctly anticipate the opponent's action.

4.5. Ergonomics

The design of workstations nowadays tends to include assessment steps in a Virtual Environment (VE) to evaluate ergonomic features. This approach is more cost-effective and convenient since working directly on the Digital Mock-Up (DMU) in a VE is preferable to constructing a real physical mock-up in a Real Environment (RE). This is substantiated by the fact that a Virtual Reality (VR) set-up can be easily modified, enabling quick adjustments of the workstation design. Indeed, the aim of integrating ergonomics evaluation tools in VEs is to facilitate the design process, enhance the design efficiency, and reduce the costs.

The development of such platforms asks for several improvements in the field of motion analysis and VR. First, interactions have to be as natural as possible to properly mimic the motions performed in real environments. Second, the fidelity of the simulator also needs to be correctly evaluated. Finally, motion analysis tools have to be able to provide in real-time biomechanics quantities usable by ergonomists to analyse and improve the working conditions.

In real working condition, motion analysis and musculoskeletal risks assessment raise also many scientific and technological challenges. Similarly to virtual reality, fidelity of the working process may be affected by the measurement method. Wearing sensors or skin markers, together with the need of frequently calibrating the assessment system may change the way workers perform the tasks. Whatever the measurement is, classical ergonomic assessments generally address one specific parameter, such as posture, or force, or repetitions..., which makes it difficult to design a musculoskeletal risk factor that actually represent this risk. Another key scientific challenge is then to design new indicators that better capture the risk of musculoskeletal disorders. However, this indicator has to deal with the tradeoff between accurate biomechanical assessment and the difficulty to get reliable and the required information in real working conditions.

4.6. Locomotion and Interactions between walkers

Modeling and simulating locomotion and interactions between walkers is a very active, complex and competitive domain, interesting various disciplines such as mathematics, cognitive sciences, physics, computer graphics, rehabilitation etc. Locomotion and interactions between walkers are by definition at the very core of our society since they represent the basic synergies of our daily life. When walking in the street, we should produce a locomotor movement while taking information about our surrounding environment in order to interact with people, move without collision, alone or in a group, intercept, meet or escape to somebody. MimeTIC is an international key contributor in the domain of understanding and simulating locomotion and interactions between walkers. By combining an approach based on Human Movement Sciences and Computer Sciences, the team focuses on locomotor invariants which characterize the generation of locomotor trajectories, conducts challenging experiments focusing on visuo-motor coordination involved during interactions between walkers both using real and virtual set-ups. One main challenge is to consider and model not only the "average" behaviour of healthy younger adult but also extend to specific populations considering the effect of pathology or the effect of age (kids, older adults). As a first example, when patients cannot walk efficiently, in particular those suffering from central nervous system affections, it becomes very useful for practitioners to benefit from an objective evaluation of their capacities. To facilitate such evaluations, we have developed two complementary indices, one based on kinematics and the other one on muscle activations. One major point of our research is that such indices are usually only developed for children whereas adults with these affections are much more numerous. We extend this objective evaluation by using person-person interaction paradigm which allows studying visuo-motor strategies deficit in these specific populations.

Another fundamental question is the adaptation of the walking pattern according to anatomical constraints, such as pathologies in orthopedics, or adaptation to various human and non-human primates in paleoanthropoly. Hence, the question is to predict plausible locomotion according to a given morphology. This question raises fundamental questions about the variables that are regulated to control gait: balance control, minimum energy, minimum jerk...In MimeTIC we develop models and simulators to efficiently test hypothesis on gait control for given morphologies.

5. Highlights of the Year

5.1. Highlights of the Year

Members of the MimeTIC team / M2S laboratory carried out a PIA3 EUR (Ecole Universitaire de Recherche) project (DIGISPORT project) for the University of Rennes, which brings together the universities and Grandes Ecoles of the Rennes site. This project, with a total budget of €86 million, is funded by the Ministry of Higher Education, Research and Innovation to the tune of €5.9 million. The objective of DIGISPORT is to create a unique graduate school of international excellence in interdisciplinary training and research in digital sport sciences. This project aims to offer students in initial and continuing training an opportunity to build a study strategy suited to their professional goals and to the labor market. The digital revolution in sports and exercise is indeed already underway, at the confluence of the fast-growing markets of sport (€80 billion worldwide) and digital technology and connected objects (€207 billion worldwide). It leads to the emergence of new

professions at the interface of these domains requiring skills in sports science, digital, electronics, and human and social sciences. Currently, education system is not designed to train this type of multi-skilled and agile students able to integrate an evolving labor market. DIGISPORT aims to link and structure training courses and research to promote a transversal approach uniting teaching and research staff around the new discipline of digital sport science and to address the new skills generated by the entry of sport into the digital age. The EUR will provide a coordinated training offer, from masters to doctoral level, that is resolutely interdisciplinary and strongly linked to research and innovation.
Based on previous scientific results in dynamic motion analysis, MimeTIC has developed an efficient software platform to carry-out biomechanical analysis based on motion capture data. "Customizable Toolbox for Musculoskeletal simulation" (CusToM) was delivered as an open source software available on a repository (https://github.com/anmuller/CusToM) and documented in [22]. CusToM is a MATLAB toolbox aiming at performing inverse dynamics-based musculoskeletal analyzes. This type of analysis is essential to access mechanical quantities of human motion in different fields such as clinic, ergonomics and sports. CusToM exhibits several features. It can generate a personalized musculoskeletal model, and can solve from motion capture data inverse kinematics, external forces estimation, inverse dynamics and muscle forces estimation problems with a high level of customization for research purposes. It is also designed for non-expert users interested in motion analysis. CusToM is an OpenSource Software available with no restriction.

The Immersia VR platform has celebrated its 20 years of existence at Inria Rennes/IRISA center, within the “20ans d’Immersia” event (November 2019).

6. New Software and Platforms

6.1. AsymGait

Asymmetry index for clinical gait analysis based on depth images

KEYWORDS: Motion analysis - Kinect - Clinical analysis

SCIENTIFIC DESCRIPTION: The system uses depth images delivered by the Microsoft Kinect to retrieve the gait cycles first. To this end it is based on a analyzing the knees trajectories instead of the feet to obtain more robust gait event detection. Based on these cycles, the system computes a mean gait cycle model to decrease the effect of noise of the system. Asymmetry is then computed at each frame of the gait cycle as the spatial difference between the left and right parts of the body. This information is computed for each frame of the cycle.

FUNCTIONAL DESCRIPTION: AsymGait is a software package that works with Microsoft Kinect data, especially depth images, in order to carry-out clinical gait analysis. First it identifies the main gait events using the depth information (footstrike, toe-off) to isolate gait cycles. Then it computes a continuous asymmetry index within the gait cycle. Asymmetry is viewed as a spatial difference between the two sides of the body.

- Participants: Edouard Auvinet and Franck Multon
- Contact: Franck Multon

6.2. Cinematic Viewpoint Generator

KEYWORD: 3D animation

FUNCTIONAL DESCRIPTION: The software, developed as an API, provides a mean to automatically compute a collection of viewpoints over one or two specified geometric entities, in a given 3D scene, at a given time. These viewpoints satisfy classical cinematographic framing conventions and guidelines including different shot scales (from extreme long shot to extreme close-up), different shot angles (internal, external, parallel, apex), and different screen compositions (thirds,fifths, symmetric of di-symmetric). The viewpoints allow to cover the range of possible framings for the specified entities. The computation of such viewpoints relies on a database of framings that are dynamically adapted to the 3D scene by using a manifold parametric representation and guarantee the visibility of the specified entities. The set of viewpoints is also automatically annotated with cinematographic tags such as shot scales, angles, compositions, relative placement of entities, line of interest.

- Participants: Christophe Lino, Emmanuel Badier and Marc Christie
- Partners: Université d'Udine - Université de Nantes
- Contact: Marc Christie

6.3. Directors Lens Motion Builder

KEYWORDS: Previzualisation - Virtual camera - 3D animation

FUNCTIONAL DESCRIPTION: Directors Lens Motion Builder is a software plugin for Autodesk's Motion Builder animation tool. This plugin features a novel workflow to rapidly prototype cinematographic sequences in a 3D scene, and is dedicated to the 3D animation and movie previsualization industries. The workflow integrates the automated computation of viewpoints (using the Cinematic Viewpoint Generator) to interactively explore different framings of the scene, proposes means to interactively control framings in the image space, and proposes a technique to automatically retarget a camera trajectory from one scene to another while enforcing visual properties. The tool also proposes to edit the cinematographic sequence and export the animation. The software can be linked to different virtual camera systems available on the market.

- Participants: Christophe Lino, Emmanuel Badier and Marc Christie
- Partner: Université de Rennes 1
- Contact: Marc Christie

6.4. Kimea

Kinect IMprovement for Egronomics Assessment

KEYWORDS: Biomechanics - Motion analysis - Kinect

SCIENTIFIC DESCRIPTION: Kimea consists in correcting skeleton data delivered by a Microsoft Kinect in an ergonomics purpose. Kimea is able to manage most of the occlultations that can occur in real working situation, on workstations. To this end, Kimea relies on a database of examples/poses organized as a graph, in order to replace unreliable body segments reconstruction by poses that have already been measured on real subject. The potential pose candidates are used in an optimization framework.

FUNCTIONAL DESCRIPTION: Kimea gets Kinect data as input data (skeleton data) and correct most of measurement errors to carry-out ergonomic assessment at workstation.

- Participants: Franck Multon, Hubert Shum and Pierre Plantard
- Partner: Faurecia
- Contact: Franck Multon
- Publications: hal-01612939v1 - hal-01393066v1 - hal-01332716v1 - hal-01332711v2 - hal-01095084v1

6.5. Populate

KEYWORDS: Behavior modeling - Agent - Scheduling

SCIENTIFIC DESCRIPTION: The software provides the following functionalities:

- A high level XML dialect that is dedicated to the description of agents activities in terms of tasks and sub activities that can be combined with different kind of operators: sequential, without order, interlaced. This dialect also enables the description of time and location constraints associated to tasks.

- An XML dialect that enables the description of agent's personal characteristics.

- An informed graph describes the topology of the environment as well as the locations where tasks can be performed. A bridge between TopoPlan and Populate has also been designed. It provides an automatic analysis of an informed 3D environment that is used to generate an informed graph compatible with Populate.

- The generation of a valid task schedule based on the previously mentioned descriptions.

With a good configuration of agents characteristics (based on statistics), we demonstrated that tasks schedules produced by Populate are representative of human ones. In conjunction with TopoPlan, it has been used to populate a district of Paris as well as imaginary cities with several thousands of pedestrians navigating in real time.

FUNCTIONAL DESCRIPTION: Populate is a toolkit dedicated to task scheduling under time and space constraints in the field of behavioral animation. It is currently used to populate virtual cities with pedestrian performing different kind of activities implying travels between different locations. However the generic aspect of the algorithm and underlying representations enable its use in a wide range of applications that need to link activity, time and space. The main scheduling algorithm relies on the following inputs: an informed environment description, an activity an agent needs to perform and individual characteristics of this agent. The algorithm produces a valid task schedule compatible with time and spatial constraints imposed by the activity description and the environment. In this task schedule, time intervals relating to travel and task fulfillment are identified and locations where tasks should be performed are automatically selected.

- Participants: Carl-Johan Jorgensen and Fabrice Lamarche
- Contact: Fabrice Lamarche

6.6. The Theater

KEYWORDS: 3D animation - Interactive Scenarios

FUNCTIONAL DESCRIPTION: The Theater is a software framework to develop interactive scenarios in virtual 3D environements. The framework provides means to author and orchestrate 3D character behaviors and simulate them in real-time. The tools provides a basis to build a range of 3D applications, from simple simulations with reactive behaviors, to complex storytelling applications including narrative mechanisms such as flashbacks.

- Participant: Marc Christie
- Contact: Marc Christie

6.7. CusToM

Customizable Toolbox for Musculoskeletal simulation

KEYWORDS: Biomechanics - Dynamic Analysis - Kinematics - Simulation - Mechanical multi-body systems

SCIENTIFIC DESCRIPTION: The present toolbox aims at performing a motion analysis thanks to an inverse dynamics method.

Before performing motion analysis steps, a musculoskeletal model is generated. Its consists of, first, generating the desire anthropometric model thanks to models libraries. The generated model is then kinematical calibrated by using data of a motion capture. The inverse kinematics step, the inverse dynamics step and the muscle forces estimation step are then successively performed from motion capture and external forces data. Two folders and one script are available on the toolbox root. The Main script collects all the different functions of the motion analysis pipeline. The Functions folder contains all functions used in the toolbox. It is necessary to add this folder and all the subfolders to the Matlab path. The Problems folder is used to contain the different study. The user has to create one subfolder for each new study. Once a new musculoskeletal model is used, a new study is necessary. Different files will be automaticaly generated and saved in this folder. All files located on its root are related to the model and are valuable whatever the motion considered. A new folder will be added for each new motion capture. All files located on a folder are only related to this considered motion.

FUNCTIONAL DESCRIPTION: Inverse kinematics Inverse dynamics Muscle forces estimation External forces prediction

- Participants: Antoine Muller, Charles Pontonnier, Georges Dumont, Pierre Puchaud, Anthony Sorel, Claire Livet and Louise Demestre
- Contact: Charles Pontonnier
- Publications: Motion-based prediction of external forces and moments and back loading during manual material handling tasks - A case study with custom : a comparison of normal and altered gait with an ankle brace - Motion-based prediction of hands and feet contact efforts during asymmetric handling tasks - MusIC method enhancement by a sensitivity study of its performance: application to a lower limbs musculoskeletal model - Ground Reaction Forces and Moments Prediction of Challenging Motions: Fencing Lunges - CusToM: a Matlab toolbox for musculoskeletal simulation - The MusIC method: a fast and quasi-optimal solution to the muscle forces estimation problem

6.8. Immerstar Platform

Participants: Georges Dumont [contact], Ronan Gaugne, Anthony Sorel, Richard Kulpa.

With the two platforms of virtual reality, Immersia (http://www.irisa.fr/immersia/) and Immermove (http://m2slab.com/index.php/facilities-4/), 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 2015-2019 that enables important evolutions of the equipment. In 2016, the first technical evolutions have been decided and, in 2017, these evolutions have been implemented. On one side, for Immermove, the addition of a third face to the immersive space, and the extension of the Vicon tracking system have been realized and continued this year with 23 new cameras. And, on the second side, for Immersia, the installation of WQXGA laser projectors with augmented global resolution, of a new tracking system with higher frequency and of new computers for simulation and image generation in 2017. In 2018, a Scale One haptic device has been installed. It allows, as in the CPER proposal, one or two handed haptic feedback in the full space covered by Immersia and possibility of carrying the user.

We celebrated the twentieth anniversary of the Immersia platform in November 2019 by inaugurating the new haptic equipment. We proposed scientific presentations and received 150 participants, and visits for support services where we received 50 persons.

7. New Results

7.1. Outline

In 2019, MimeTIC has maintained his activity in motion analysis, modelling and simulation, to support the idea that these approaches are strongly coupled in a motion analysis-synthesis loop. This idea has been applied to the main application domains of MimeTIC:

- Animation, autonomous characters and Digital Storytelling,
- Fidelity of Virtual Reality,
- Motion sensing of Human Activity,
- Sports,
- Ergonomics,
- and Locomotion and Interactions between walkers.

7.2. Animation, Autonomous Characters and Digital Storytelling

MimeTIC main research path consists in associating motion analysis and synthesis to enhance the naturalness in computer animation, with applications in movie previsualisation, and autonomous virtual character control. Thus, we pushed example-based techniques in order to reach a good tradeoff between simulation efficiency and naturalness of the results. In 2019, to achieve this goal, MimeTIC continued to explore the use of perceptual studies and model-based approaches, but also began to investigate deep learning, for example to control cameras in Movie previsualization.

7.2.1. VR as a Content Creation Tool for Movie Previsualisation

Participants: Marc Christie [contact], Quentin Galvane.

This work proposes a VR authoring system which provides intuitive ways of crafting visual sequences in 3D environments, both for expert animators and expert creatives. It is designed in mind to be applied animation and film industries, but can find broader applications (eg. in multimedia content creation). Creatives in animation and film productions have forever been exploring the use of new means to prototype their visual sequences before realizing them, by relying on hand-drawn storyboards, physical mockups or more recently 3D modelling and animation tools. However these 3D tools are designed in mind for dedicated animators rather than creatives such as film directors or directors of photography and remain complex to control and master. The proposed system is designed to reflect the traditional process through (i) a storyboarding mode that enables rapid creation of annotated still images, (ii) a previsualisation mode that enables the animation of the characters, objects and cameras, and (iii) a technical mode that enables the placement and animation of complex camera rigs (such as cameras cranes) and light rigs. Our methodology strongly relies on the benefits of VR manipulations to re-think how content creation can be performed in this specific context, typically how to animate contents in space and time. As a result, the proposed system is complimentary to existing tools, and provides a seamless back-and-forth process between all stages of previsualisation. We evaluated the tool with professional users to gather experts' perspectives on the specific benefits of VR in 3D content creation [36].

7.2.2. Deep Learning Techniques for Camera Trajectories

Participant: Marc Christie [contact].

Designing a camera motion controller which places and moves virtual cameras in relation with contents in a cinematographic way is a complex and challenging task. Many cinematographic rules exist, yet practice shows there are significant stylistic variations in how these can be applied. While contributions have attempted to encode rules by hand, this work is the very first to propose an end-to-end framework that automatically learns from real and synthetic movie sequences how the camera behaves in relation with contents. Our deep-learning framework extracts cinematic features of movies through a novel feature estimator trained on synthetic data, and learns camera behaviors from those extracted features, through the design of a Recurrent Neural Network (RNN) with a Mixture of Experts (MoE) gating mechanism. This cascaded network is designed to capture important variations in camera behaviors while ensuring the generalization capacity in the learning of similar behaviors. We demonstrate the features of our framework through experiments that highlight (i) the quality of our cinematic feature extractor (ii) the capacity to learn ranges of behaviors through the gating mechanism, and (iii) the ability to analyse the camera behaviors from a given input sequence, and automatically re-apply these behaviors on new virtual contents, offering exciting new possibilities towards a deeper understanding of cinematographic style and enhanced possibilities in transferring style from real to virtual. The work is a collaboration with the Beijing Film Academy in China.

7.2.3. Efficient Visibility Computation for Camera Control

Participants: Marc Christie [contact], Ludovic Burg.

Efficient visibility computation is a prominent requirement when designing automated camera control techniques for dynamic 3D environments; computer games, interactive storytelling or 3D media applications all need to track 3D entities while ensuring their visibility and delivering a smooth cinematographic experience. Addressing this problem requires to sample a very large set of potential camera positions and estimate visibility for each of them, which in practice is intractable. In this work, we introduce a novel technique to perform efficient visibility computation and anticipate occlusions. We first propose a GPU-rendering technique to sample visibility in Toric Space coordinates – a parametric space designed for camera control. We then rely on this visibility evaluation to compute an anticipation map which predicts the future visibility of a large set of cameras over a specified number of frames. We finally design a camera motion strategy that exploits this anticipation map to maximize the visibility of entities over time. The key features of our approach are demonstrated through comparison with classical ray-casting techniques on benchmark environments, and through an integration in multiple game-like 3D environment with heavy sparse and dense occluders.

7.2.4. Analysing and Predicting Inter-Observer Gaze Congruency

Participant: Marc Christie [contact].

In trying to better understand film media, we have been recently exploring the relation between the distribution of gaze states and the features of images, with the objective of establishing correlations to understand how films manipulate users gaze (and how gaze can be manipulated be re-editing film sequences). According to the literature regarding visual saliency, observers may exhibit considerable variations in their gaze behaviors. These variations are influenced by aspects such as cultural background, age or prior experiences, but also by features in the observed images. The dispersion between the gaze of different observers looking at the same image is commonly referred as inter-observer congruency (IOC). Predicting this congruence can be of great interest when it comes to study the visual perception of an image. We introduce a new method based on deep learning techniques to predict the IOC of an image [31]. This is achieved by first extracting features from an image through a deep convolutional network. We then show that using such features to train a model with a shallow network regression technique significantly improves the precision of the prediction over existing approaches.

7.2.5. Deep Saliency Models: the Quest for the Loss Function

Participant: Marc Christie [contact].

Following our idea of understanding gaze patterns in movie watching, and predicting these gaze patterns on sequences, we have been exploring the influence of loss functions in learning the visual saliency. Indeed, numerous models in the literature present new ways to design neural networks, to arrange gaze pattern data, or to extract as much high and low-level image features as possible in order to create the best saliency representation. However, one key part of a typical deep learning model is often neglected: the choice of the loss function. In this work, we explore some of the most popular loss functions that are used in deep saliency models [49]. We demonstrate that on a fixed network architecture, modifying the loss function can significantly improve (or depreciate) the results, hence emphasizing the importance of the choice of the loss function when designing a model. We also introduce new loss functions that have never been used for saliency prediction to our knowledge. And finally, we show that a linear combination of several well-chosen loss functions leads to significant improvements in performances on different datasets as well as on a different network architecture, hence demonstrating the robustness of a combined metric.

7.2.6. Contact Preserving Shape Transfer For Rigging-Free Motion Retargeting

Participants: Franck Multon [contact], Jean Basset.

In 2018, we introduced the idea of context graph to capture the relationship between body parts surfaces and enhance the quality of the motion retargetting problem. Hence, it becomes possible to retarget the motion of a source character to a target one while preserving the topological relationship between body parts surfaces. However this approach implies to strictly satisfy distance constraints between body parts, whereas some of them could be relaxed to preserve naturalness. In 2019, we introduced a new paradigm based on transfering the shape instead of encoding the pose constraints to tackle this problem [29].

Hence, retargeting a motion from a source to a target character is an important problem in computer animation, as it allows to reuse existing rigged databases or transfer motion capture to virtual characters. Surface based pose transfer is a promising approach to avoid the trial-and-error process when controlling the joint angles. The main contribution of this work is to investigate whether shape transfer instead of pose transfer would better preserve the original contextual meaning of the source pose. To this end, we propose an optimization-based method to deform the source shape+pose using three main energy functions: similarity to the target shape, body part volume preservation, and collision management (preserve existing contacts and prevent penetrations). The results show that our method is able to retarget complex poses, including several contacts, to very different morphologies. In particular, we introduce new contacts that are linked to the change in morphology, and which would be difficult to obtain with previous works based on pose transfer that aim at distance preservation between body parts. These preliminary results are encouraging and open several perspectives, such as decreasing computation time, and better understanding how to model pose and shape constraints.

7.2.7. The Influence of Step Length to Step Frequency Ratio on the Perception of Virtual Walking Motions

Participants: Ludovic Hoyet [contact], Benjamin Niay, Anne-Hélène Olivier.

Synthesizing walking motions that look realistic and diverse is a challenging task in animation, and even more when the target is to create realistic motions for large group of characters. Indeed, in order to keep a good trade-off between computational costs and realism, biomechanical constraints of human walk are not always fulfilled. In pilot experiments [38], [46], we have therefore started to investigate the ability of viewers to identify an invariant parameter of human walking named the walk ratio, representing the ratio between step length and step frequency of an individual, when applied to virtual humans. To this end, we recorded 4 actors (2 males, 2 females) walking at different freely chosen speeds, as well as at different combinations of step frequency and step length. We then performed pilot perceptual studies to identify the ability of viewers to detect the range of walk ratios considered as natural and compared it to the walk ratio freely chosen by the actor when performing walks at the same speeds. Our results will provide new considerations to drive the animation of walking virtual characters using the walk ratio as a parameter, which we believe could enable animators to control the speed of characters through simple parameters while retaining the naturalness of the locomotion.

7.3. Fidelity of Virtual Reality

MimeTIC wishes to promote the use of Virtual Reality to analyze and train human motor performance. It raises the fundamental question of the transfer of knowledge and skills acquired in VR to real life. In 2019, we put efforts in better understanding the potential fidelity of Virtual Reality experiences compared to real life experiences. It has been applied to various aspects of the interaction between pedestrians, but also the biomechanical fidelity of using haptic devices in highly constrainted conditions, such as hammering tasks.

7.3.1. Influence of Motion Speed on the Perception of Latency in Avatar Control

Participants: Ludovic Hoyet [contact], Richard Kulpa, Anthony Sorel, Franck Multon.

With the dissemination of Head Mounted Display devices in which users cannot see their body, simulating plausible avatars has become a key challenge. For fullbody interaction, avatar simulation and control involves several steps, such as capturing and processing the motion (or intentions) of the user using input interfaces, providing the resulting user state information to the simulation platform, computing a plausible adaptation of the virtual world, rendering the scene, and displaying the multisensory feedback to the user through output interfaces. All these steps imply that the displayed avatar motion appears to users with a delay (or latency) compared to their actual performance. Previous works have shown an impact of this delay on the perception-action loop, with possible impact on Presence and embodiment. We have explored [37] how the speed of the motion performed when controlling a fullbody avatar can impact the way people perceive and react to such a delay. We conducted an experiment where users were asked to follow a moving object with their finger, while embodied in a realistic avatar. We artificially increased the latency by introducing different levels of delays (up to 300ms) and measured their performance in the mentioned task, as well as their feeling about the perceived latency. Our results show that motion speed influenced the perception of latency: we found critical latencies of 80ms for medium and fast motion speeds, while the critical latency reached 120ms for a slow motion speed. We also noticed that performance is affected by both latency and motion speed, with higher speeds leading to decreased performance. Interestingly, we also found that performance was affected by latency before the critical latency for medium and fast speeds, but not for a slower speed. These findings could help to design immersive environments to minimize the effect of latency on the performance of the user, with potential impacts on Presence and embodiment.

7.3.2. Influence of Personality Traits and Body Awareness on the Sense of Embodiment in Virtual Reality

Participants: Ludovic Hoyet [contact], Rebecca Fribourg, Diane Dewez.

With the increasing use of avatars (i.e. the virtual representation of the user in a virtual environment) in virtual reality, it is important to identify the factors eliciting the sense of embodiment or the factors that can disrupt this feeling. This paper [35] reports an exploratory study aiming at identifying internal factors (personality traits and body awareness) that might cause either a resistance or a predisposition to feel a sense of embodiment towards a virtual avatar. To this purpose, we conducted an experiment (n=123) in which participants were immersed in a virtual environment and embodied in a gender-matched generic virtual avatar through a head-mounted display. After an exposure phase in which they had to perform a number of visuomotor tasks (during 2 minutes) a virtual character entered the virtual scene and stabbed the participants' virtual hand with a knife. The participants' sense of embodiment was measured, as well as several personality traits (Big Five traits and locus of control) and body awareness, to evaluate the influence of participants' personality on the acceptance of the virtual body. The major finding of the experiment is that the locus of control is linked to several components of embodiment: the sense of agency is positively correlated with an internal locus of control and the sense of body ownership is positively correlated with an external locus of control. Interestingly, both components are not influenced by the same traits, which confirms that they can appear independently. Taken together our results suggest that the locus of control could be a good predictor of the sense of embodiment when the user embodies an avatar with a similar physical appearance.

7.3.3. Gaze Behaviour During Person-Person Interaction in VR

Participants: Ludovic Hoyet, Anne-Hélène Olivier [contact], Florian Berton.

Simulating realistic interactions between virtual characters has been of interest to research communities for years, and is particularly important to automatically populate virtual environments. This problem requires to accurately understand and model how humans interact, which can be difficult to assess. In this context, Virtual Reality (VR) is a powerful tool to study human behaviour, especially as it allows assessing conditions which are both ecological and controlled. While VR was shown to allow realistic collision avoidance adaptations, in the frame of the ecological theory of perception and action, interactions between walkers can not solely be characterized through motion adaptations but also through the perception processes involved in such interactions. The objective of this study [30] is therefore to evaluate how different VR setups influence gaze behaviour during collision avoidance tasks between walkers. In collaboration with Julien Pettré in Rainbow

Figure 4. Conditions used in this work to understand the effect of VR setup on gaze beaviour in a collision avoidance task.

team, we designed an experiment involving a collision avoidance task between a participant and another walker (real confederate or virtual character). During this task, we compared both the participant's locomotion and gaze behaviour in a real environment and the same situation in different VR setups (including a CAVE, a screen and a Head-Mounted Display) as illustrated on Figure4. Our results show that even if some quantitative differences exist, gaze behaviour is qualitatively similar between VR and real conditions. Especially, gaze behaviour in VR setups including a HMD is more in line with the real situation than the other setups. Furthermore, the outcome on motion adaptations confirms previous work, where collision avoidance behaviour is qualitatively similar in VR and real conditions. In conclusion, our results show that VR has potential for qualitative analysis of locomotion and gaze behaviour during collision avoidance. This opens perspectives in the design of new experiments to better understand human behaviour, in order to design more realistic virtual humans.

7.3.4. Gaze Anticipation in Curved Path in VR

Participants: Anne-Hélène Olivier [contact], Hugo Brument.

This work was performed in collaboration with Ferran Argelaguet-Sanz and Maud Marchal from Hybrid team [32]. We investigated whether the body anticipation synergies in real environments (REs) are preserved during navigation in virtual environments (VEs). Experimental studies related to the control of human locomotion in REs during curved trajectories report a top-down reorientation strategy with the reorientation of the gaze anticipating the reorientation of head, the shoulders and finally the global body motion. This anticipation behavior provides a stable reference frame to the walker to control and reorient whole-body according to the future direction. To assess body anticipation during navigation in VEs, we conducted an experiment where participants, wearing a head-mounted display, were asked to perform a lemniscate trajectory in a virtual environment (VE) using five different navigation techniques, including walking, virtual steering (hand, head or torso steering) and passive navigation. For the purpose of this experiment, we designed a new control law based on the powerlaw relation between speed and curvature during human walking. Taken together our results showed that a similar ordered top-down sequence of reorientation of the gaze, head and shoulders during curved trajectories between walking in REs and in VEs (for all the evaluated techniques). However, this anticipation mechanism significantly differs between physical walking in VE, where the anticipation is higher, and the other virtual navigation techniques. The results presented in this paper pave the way to the better understanding of the underlying mechanisms of human navigation in VEs and to the design of navigation techniques more adapted to humans

7.3.5. Validity of VR to Study Social Norms During Person-Person Interaction

Participants: Anne-Hélène Olivier [contact], Ludovic Hoyet, Florian Berton.

The modelling of virtual crowds for major events, such as the Oympics in Paris in 2024, takes into account the global proxemics standards of individuals without questioning the possible variability of these standards according to the space in which the interactions are performed. We know that body interactions (Goffman, 1974) are subject to rules whose variability is, at least in part, cultural (Hall, 1971). Obviously, these proxemics standards also address practical issues such as available space and space occupancy density. Our objective in this study was to understand the conditions which can explain that the discomfort felt and the adaptive behaviour performed differ when the interaction takes place in the same city and in spaces with identical occupancy densities. Especially, we focused on the effect of the social context of the environement. We aim at estimating the extent to which the prospect of attending a sports performance alters sensitivity to the transgression of proxemics norms. An additional objective was to evaluate whether virtual reality can help us to provide new insights in such a social context, where objective measures out-of-the lab are complex to perform. To answer this question, we designed in collaboration with Julien Pettré (Rainbow team) and colleagues in the field of sociology François Le Yondre, Théo Rougant and Tristan Duverne (Univ Rennes II) an experiment (in real context and then in virtual reality) in two different locations: a train station and the surroundings of a stadium before a league 1 football match) but with similar densities. The task performed by a confederate was to walk and stand excessively close to men aged 20 to 40. The individual's behaviour (not conscious of being a subject of the experiment) was observed by ethnography and explanatory interviews were conducted immediately afterwards. This same experiment was carried out in virtual reality conditions on the same type of population, modelling the two spaces and making it possible to acquire more precise and quantifiable data than in real conditions such as distances, travel time and eye fixations. The results show that the discomfort shown is much higher in the train station. The sporting context seems to participate in a form of relaxation of the norms of bodily interaction. Such a gap is not observable in virtual reality. From a methodological point of view, explicit interviews make it possible to usefully identify the reasons why virtual reality does not generate the same reactions, although it sometimes provokes the same sensitivity. Future work is needed to evaluate the effect of an increased immersion on such Social Science studies.

7.4. Motion Sensing of Human Activity

MimeTIC has a long experience in motion analysis in laboratory condition. In the MimeTIC project, we proposed to explore how these approaches could be transferred to ecological situations, with a lack of control on the experimental conditions. In the continuation of 2018, we have proposed to explore the use of cheap depth cameras solution for on-site motion analysis in ergonomics.

7.4.1. Motion Analysis of Work Conditions Using Commercial Depth Cameras in Real Industrial Conditions

Participant: Franck Multon [contact].

Based on a former PhD thesis (of Pierre Plantard) we have demonstrated the use of depth sensors in industry to assess risks of musculoskeletal disorders ar work. It has leaded to the creation of the the KIMEA software and of the Moovency start-up company in November 2018. In 2019 we published a synthesis work with new results [48] to demonstrate that such an approach can actually support the work of ergonomists in their goal to enhance the quality of life of workers in industry.

Hence, measuring human motion activity in real work condition is challenging as the environment is not controlled, while the worker should perform his/her task without perturbation. Since the early 2010s, affordable and easy-to-use depth cameras, such as the Microsoft Kinect system, have been applied for in-home entertainment for the general public. In this work, we evaluated such a system for the use in motion analysis in work conditions and propose software algorithms to enhance the tracking accuracy. Firstly, we highlighted the high performance of the system when used under the recommended setup without occlusions. However, when the position/orientation of the sensor changes, occlusions may occur and the performance of the system may decrease, making it difficult to be used in real work conditions. Secondly, we propose a software algorithm to adapt the system to challenging conditions with occlusions to enhance the robustness and accuracy. Thirdly, we show that real work condition assessment using such an adapted system leads to similar results comparing with those performed manually by ergonomists. These results show that such adapted systems could be used to support the ergonomists work by providing them with reproducible and objective information about the human movement. It consequently saves ergonomists time and effort and allows them to focus on high-level analysis and actions.

7.5. Sports

MimeTIC promotes the idea of coupling motion analysis and synthesis in various domains, especially sports. More specifically, we have a long experience and international leadership in using Virtual Reality for analyzing and training sports performance. In 2019, we continued to explore 1) how enhancing on-site sports motion analysis using models inspired from motion simulation techniques, and 2) how Virtual Reality could be used to analyze and train motor and perceptual skills in sports.

7.5.1. *Analysis of Fencing Lunge Accuracy and Response Time in Uncertain Conditions With an Innovative Simulator*

Participants: Anthony Sorel [contact], Richard Kulpa, Nicolas Bideau, Charles Pontonnier.

We conducted a study evaluating the motor control strategies implied by the introduction of uncertainty in the realization of lunge motions [27]. Lunge motion is one of the fundamental attacks used in modern fencing, asking for a high level of coordination, speed and accuracy to be efficient. The aim of the current paper was the assessment of fencer's performance and response time in lunge attacks under uncertain conditions. For this study, an innovative fencing lunge simulator was designed. The performance of 11 regional to national-level fencers performing lunges in Fixed, Moving and Uncertain conditions was assessed. The results highlighted notably that i) Accuracy and success decreased significantly in Moving and Uncertain conditions with regard to Fixed ones ii) Movement and Reaction times were also affected by the experimental conditions iii) Different fencer profiles were distinguishable among subjects. In conclusion, the hypothesis that fencers may privilege an adaptation to the attack conditions and preserve accuracy instead of privileging quickness was supported by the results. Such simulators may be further used to analyze in more detail the motor control strategies of fencers through the measure and processing of biomechanical quantities and a wider range of fencing levels. It has also a great potential to be used as training device to improve fencer's performance to adapt his attack to controlled opponent's motion.

7.5.2. *Enactive Approach to Assess Perceived Speed Error during Walking and Running in Virtual Reality*

Participants: Théo Perrin, Richard Kulpa [contact], Charles Faure, Anthony Sorel, Benoit Bideau.

The recent development of virtual reality (VR) devices such as head mounted displays (HMDs) increases opportunities for applications at the confluence of physical activity and gaming. Recently, the fields of sport and fitness have turned to VR, including for locomotor activities, to enhance motor and energetic resources, as well as motivation and adherence. For example, VR can provide visual feedbacks during treadmill running, thereby reducing monotony and increasing the feeling of movement and engagement with the activity. However, the relevance of using VR tools during locomotion depends on the ability of these systems to provide natural immersive feelings, specifically a coherent perception of speed. The objective of this study is to estimate the error between actual and perceived locomotor speed in VE using an enactive approach, i.e. allowing an active control of the environment. Sixteen healthy individuals participated in the experiment, which consisted in walking and running on a motorized treadmill at speeds ranging from 3 to 11 km/h with 0.5 km/h increments, in a randomized order while wearing a HMD device (HTC Vive) displaying a virtual racetrack. Participants were instructed to match VE speed with what they perceived was their actual locomotion speed (LS), using a handheld Vive controller. They were able to modify the optic flow speed (OFS) with a 0.02 km/h increment/decrement accuracy. An optic flow multiplier (OFM) was computed based on the error between OFS and LS. It represents the gain that exists between the visually perceived speed and the real locomotion speed experienced by participants for each trial. For all conditions, the average of OFM was 1.00 $\pm .25$ to best match LS. This finding is at odds with previous works reporting an underestimation of speed perception in VR. It could be explained by the use of an enactive approach allowing an active and accurate matching of visually and proprioceptively perceived speeds by participants. But above all, our study showed that the perception of speed in VR is strongly individual, with some participants always overestimating and others constantly underestimating. Therefore, a general OFM should not be used to correct speed in VE to ensure congruence in speed perception, and we propose the use of individual models as recommendations for setting up locomotion-based VR applications.

7.5.3. Acting Together, Acting Stronger? Interference Between Participants During Face-to-Face Cooperative Interception Task

Participants: Charles Faure, Théo Perrin, Richard Kulpa [contact], Anthony Sorel, Anabelle Limballe, Benoit Bideau.

People generally coordinate their action to be more effective. However, in some cases, interference between them occur, resulting in an inefficient collaboration. The main goal of this study [16], [16] is to explore the way two persons regulate their actions when performing a cooperative task of ball interception, and how interference between them may occur. Starting face to face, twenty-four participants (twelve teams of two) had to physically intercept balls moving down from the roof to the floor in a virtual room. To this end, they controlled a virtual paddle attached to their hand moving along the anterior-posterior axis, and were not allowed to communicate. Results globally showed participants were often able to intercept balls without collision by dividing the interception space in two equivalent parts. However, an area of uncertainty (where many trials were not intercepted) appeared in the center of the scene highlighting the presence of interference between participants. The width of this area increased when situation became more complex and when less information was available. Moreover, participants often interpreted balls starting above them as balls they should intercept, even when these balls were in fine intercepted by their partner. Overall, results showed that team coordination emerges from between-participants interactions in this ball interception task and that interference between them depends on task complexity (uncertainty on partner's action and visual information available).

7.5.4. Detection of Deceptive Motions in Rugby from Visual Motion Cues

Participants: Richard Kulpa [contact], Anne-Hélène Olivier, Benoit Bideau.

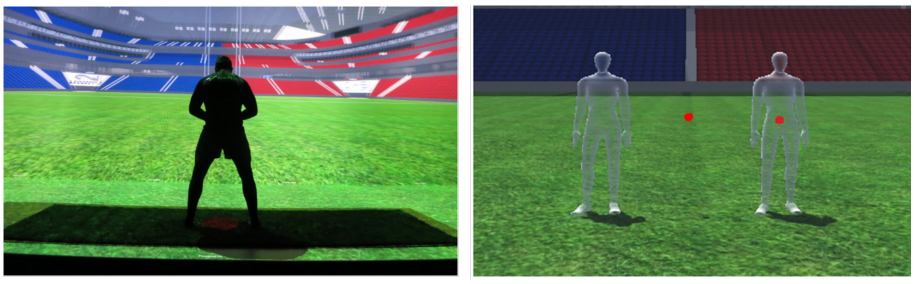

Figure 5. Illustration of a rugby player interacting in VR with 3 representations of a virtual attacker.

Frequently, in rugby, players incorporate deceptive motions (e.g., a side-step) in order to pass their opponent. Previous works showed that expert defenders are more efficient in detecting deceptive motions. Performance was shown to be correlated with the evolution of the center of gravity of the attacker, suggesting that experts may rely on global motion cues. This study [19] aims at investigating whether a representation of center of gravity can be useful for training purposes, by using this representation alone or by combining it with the local motion cues given by body parts. We designed an experiment in virtual reality to control the motion cues available to the defenders. Sixteen healthy participants (seven experts and nine novices) acted as defenders while a virtual attacker approached. Participants completed two separate tasks. The first was a time occlusion perception task, occlusion after 100ms, 200ms or 300ms after the initial change in direction, thereafter participants indicated the passing direction of the attacker. The second was a perception-action task Figure 5, participants were instructed to intercept the oncoming attacker by displacing medio-laterally. The attacker performed either a non-deceptive motion, directly toward the final passing direction or a deceptive motion, initially toward a false direction before quickly reorienting to the true direction. There was a main effect of expertise, appearance, cut off times and motion on correct responses during both tasks. There was an interaction between visual appearance and expertise, and between motion type and expertise during the perception task, however, this interaction was not present during the perception-action task. We observed that experts maintained superiority in the perception of deceptive motion; however when the visual appearance is reduced to global motion alone the difference between novices and experts is reduced. We further explore the interactions and discuss the effects observed for the visual appearance and expertise.

7.5.5. IMU-based Motion Capture for Cycling Performance

Participants: Nicolas Bideau [contact], Guillaume Nicolas, Benoit Bideau, Sebastien Cordillet, Erwan Delhaye.

The quantification of 3D kinematical parameters such as body segment orientations and joint angles is important in the monitoring of cycling to provide relevant biomechanical parameters associated with performance optimization and/or injury prevention. Numerous experiments based on optoelectronic motion capture have been conducted in the laboratory to analyze kinematical variables (e.g., joint angles) during cycling. However, the assessment of kinematics in real conditions during training or competition is a challenging task, especially since conventional optoelectronic motion capture systems suffer from major drawbacks (restricted fields of view, cumbersome and time consuming) in this regard. To overcome these limitations, inertial measurement units (IMU) is a relevant solution for in situ cycling analysis as they allow a continuous data acquisition process throughout a cycling exercise. Beyond the common problem of the drift related to the integration of gyroscope data, one of the major issues in joint kinematics assessment using IMU devices lies is the misalignment of sensor axes with the anatomical body segment axis, which is not straightforward. Thus, we developed a novel sensor-to-segment calibration procedure for inertial sensor-based knee joint kinematics analysis during cycling. This procedure was designed to be feasible in-field, autonomously, and without any external operator or device. It combines a static standing up posture and a pedaling task. In comparison with conventional calibration methods commonly employed in gait analysis, the new method we proposed significantly improved the accuracy of 3D knee joint angle measurement when applied to cycling analysis [14]. As a second step related to the in-field application to track cycling, we estimated lower limb joint angles during a time trial on a velodrome. This integrative measurement exhibited the evolution of kinematic parameters in relation with distance but also with the track curvature [43].

7.6. Ergonomics

Ergonomics has become an important application domains in MimeTIC: being able to capture, analyze, and model human performance at work. In this domain, key challenge consists in using limited equipment to capture the physical activity of workers in real conditions. Hence, in 2019, we have designed a new approach to predict external forces using mainly motion capture data, and to personnalize the biomechanical capabilities (maximum feasible force/torque) of specific population.

7.6.1. Motion-based Prediction of External Forces

Participants: Charles Pontonnier [contact], Georges Dumont, Claire Livet, Anthony Sorel, Nicolas Bideau.

We proposed [21] a method to predict the external efforts exerted on a subject during handling tasks, only with a measure of his motion. These efforts are the contacts forces and moments on the ground and on the load carried by the subject. The method is based on a contact model initially developed to predict the ground reaction forces and moments. Discrete contact points are defined on the biomechanical model at the feet and the hands. An optimization technique computes the minimal forces at each of these points satisfying the dynamic equations of the biomechanical model and the load. The method was tested on a set of asymmetric handling tasks performed by 13 subjects and validated using force platforms and an instrumented load. For each task, predictions of the vertical forces obtained a RMSE of about 0.25 N/kg for the feet contacts and below 1 N/kg for the hands contacts. This method enables to quantitatively assess asymmetric handling tasks on the basis of kinetics variables without additional instrumentation such as force sensors and thus improve the ecological aspect of the studied tasks. We evaluated this method [23] on manual material handling (MMH) tasks. From a set of hypothesized contact points between the subject and the environment (ground and load), external forces were calculated as the minimal forces at each contact point while ensuring the dynamics equilibrium. Ground reaction forces and moments (GRF&M) and load contact forces and moments (LCF&M) were computed from motion data alone. With an inverse dynamics method, the predicted data were then used to compute kinetic variables such as back loading. On a cohort of 65 subjects performing MMH tasks, the mean correlation coefficients between predicted and experimentally measured GRF for the vertical, antero-posterior and medio-lateral components were 0.91 (0.08), 0.95 (0.03) and 0.94 (0.08), respectively. The associated RMSE were 0.51 N/kg, 0.22 N/kg and 0.19 N/kg. The correlation coefficient between L5/S1 joint moments computed from predicted and measured data was 0.95 with a RMSE of 14 Nm for the flexion / extension component. This method thus allows the assessment of MMH tasks without force platforms, which increases the ecological aspect of the tasks studied and enables performance of dynamic analyses in real settings outside the laboratory.

This method was successfully applied [24] on lunge motion that is a fundamental attack of modern fencing, asking for a high level of coordination, speed and accuracy. It consists in an explosive extension of the front leg accompanying an extension of the sword arm. In such motions, the direction of action and the way feet are oriented – guard position - are particularly challenging for a GRF&M prediction method. These methods are avalaible in CusToM software [22].

7.6.2. *Biomechanics for Motion Analysis-Synthesis and Analysis of Torque Generation Capacities*

Participants: Charles Pontonnier [contact], Georges Dumont, Nicolas Bideau, Guillaume Nicolas, Pierre Puchaud.

Characterization of muscle mechanism through the torque-angle and torque-velocity relationships [17] is critical for human movement evaluation and simulation. In-vivo determination of these relationships through dynamometric measurements and modelling is based on physiological and mathematical aspects. However, no investigation regarding the effects of the mathematical model and the physiological parameters underneath these models was found. The purpose of the current study was to compare the capacity of various torque-angle and torque-velocity models to fit experimental dynamometric measurement of the elbow and provide meaningful mechanical and physiological information. Therefore, varying mathematical function and physiological muscle parameters from the literature were tested. While a quadratic torque-angle model seemed to increase predicted to measured elbow torque fitting, a new power-based torque-velocity parametric model gave meaningful physiological values with similar fitting results to a classical torque-velocity model. This model is of interest to extract modelling and clinical knowledge characterizing the mechanical behavior the joint. Based on the same kind of methods, we proposed [25] to analyse torque generation capacities of a human knee. The torque generation capacities are often assessed for human performance, as well as for prediction of internal forces through musculoskeletal modelling. Scaling individual strength generation capacities is challenging but can provide physiologically meaningful perspectives. We propose to fit the models to isokinetic measurements of joint torques in different angle and angular velocity conditions. Assuming muscles are viscoelastic actuators, their entire architectures contribute to Joint Torque-Angle and Torque-Velocity Relationships (JTAR and JTVR respectively, and their coupling JTAVR) at the joint level. Experimental observation at different scales (muscle sarcomere, muscle fibre and joint) resulted in various JTAR models available in the literature. On the other side, JVTR models are often modelled without obvious physiological consistency. The above mentionned JTVR model was shown to increase physiological transparency of the elbow JTAVR. As those results might be joint-specific, we extended it to evaluate five JTAR and two JTVR models on the knee flexion and extension.

7.7. Locomotion and Interactions between Walkers

MimeTIC is a leader in the study and modeling of walkers' visuo-motor strategies. This implies to understand how humans generate their walking trajectories within an environment. This year, one main focus was to consider how the interaction models change with specific populations (including kids, older adults, concussed athletes or person on a wheelchair) as well as in specific environment (including narrow sidewalk, or environment with varying social context).

7.7.1. Effect of Foot Stimulation on Locomotion

Participants: Anne-Hélène Olivier, Armel Crétual [contact], Carole Puil.

Medio-Intern Element (EMI®) is a thin plantar insert used by podiatrists to treat postural deficiency. It was shown an influence of a 3 mm high EMI on Medio-Lateral (ML) displacement of the Centre of Pressure (CoP) of healthy participants in quasi-static standing. Recently it has been demonstrated that EMI has an impact on eyes vergence, and especially in population with plantar postural dysfunction. These effects were weakly assessed however and only using static tasks. Therefore, the objective of this work [53], [52], [41], was to evaluate the effect of the EMI while performing a locomotor task. We expected a controlateral deviation of the trajectory when this insert was located under one foot. Indeed, in previous studies dealing with bottom-up control of locomotion, it was shown that a 30 min podokinetic stimulation leads to a ML deviation of the trajectory when participants were asked to walk in a straight line with eyes closed. 20 healthy participants volunteered for this study. They participated into 3 different sessions in random order: either without EMI, with EMI under the right foot or under the left foot. Each session involved first, static tasks (with and without vision) to compare with previous work, then, dynamic locomotor tasks with 6 different conditions mixing trajectory (straight walking, 90° left or right turn) and vision (with and without vision) in random order. In static conditions, we computed the average ML position of the CoP. In dynamic conditions, we analyzed the difference in the final orientation of the locomotor trajectory with and without vision with an EMI with respect to this difference without the EMI. No significant effect of the EMI was observed for either static or dynamic conditions. Our results do not confirm the previous work in static conditions. Future work is needed to better understand the effect of this insert. In particular, our participants were healthy and it could be interesting to evaluate this effect in participants with postural deficiencies. These results would have an application in the design of new clinical tests.

7.7.2. Collision Avoidance between Walkers on a Curvilinear Path

Participants: Anne-Hélène Olivier [contact], Armel Crétual, Richard Kulpa, Anthony Sorel.

Crowded public spaces require humans to interact with what the environment affords to regulate interpersonal distance to avoid collisions. In the case of rectilinear trajectories, the collision avoidance behaviours have been extensively studied. It has been shown that the perceived action-opportunities of the walkers might be afforded based on a future distance of closest approach (also coined ‘Minimal Predicted Distance’, MPD). However, typical daily interactions do not always follow rectilinear but also curvilinear trajectories. In that context, it has been shown that a ball following a curvilinear trajectory can be successfully intercepted. However, it remains unclear whether the collision avoidance strategies in the well-studied linear trajectories can be transferred to curvilinear trajectories. Therefore, the aim of this work [44] was to examine collision avoidance behaviours when interacting with walkers following curvilinear trajectories. An experiment was designed using virtual reality in which 22 participants navigated toward a goal in a virtual environment with a joystick. A Virtual Human (VH) crossed the path of the participant from left and right with varying risks of collision. The VH followed either a curvilinear path with a fixed radius of 5 m or 10 m, approaching from in-front of and behind the participant, or a control rectilinear path. The final crossing distance, the number of collisions and inversions of initial crossing order were analysed to determine the success of the task. Further, MPD evolution over time and specific timing events was analysed across conditions. For a curvilinear path with a 5 m radius there were significantly more collisions when the VH approached from behind the participant, and significantly more inversions of the initial crossing order when the VH approached from in-front than the control rectilinear path. Final crossing distance was shorter when the VH followed a path with a 5 m radius from behind the participant. Finally, the evolution of the MPD over time was similar for paths with a 10 m radius when compared to the control rectilinear path, whereas the 5 m curvilinear paths had significant differences during the interaction. Overall, with few collisions and few inversions of crossing order we can conclude that participants were capable of interacting with virtual walkers on curvilinear trajectories. Further, the task was solved with similar avoidance adaptations to those observed for rectilinear interactions. However, paths with a smaller radius had more reported collisions and inversions. Future work should address how a curved trajectory during collision avoidance is perceived.

7.7.3. Collision Avoidance in Person-Specific Populations

Participants: Anne-Hélène Olivier [contact], Armel Crétual.

In the frame of the Inria BEAR associate team, we have used our 90° crossing paradigm to understand visuo-motor coordination in specific population. This is important, not only from a theoretical point of view but also to design more individual model of human locomotion in a dynamic environment.

Figure 6. Illustration of person-person interaction experiments in a) kids, b) older adults, c) previously concussed athletes, d) a person on an electric powered wheelchair

We first investigated the effect of age on visuo-motor coordination by considering a collision avoidance task in kids (8-12 years) and older adults (65-74 years) as illustrated on Figure 6a,b. On one hand, middle-aged children have been shown to have poor perception-action coupling during static and dynamic collision avoidance tasks. Research has yet to examine whether perception-action coupling deficits persist in a dynamic collision avoidance task involving a child and another walker. In this work [26], [54], we invesigated whether the metric MPD(t) be used to examine collision avoidance strategies between children and adults. To this end, eighteen children (age: 10 ± 1.5 years) and eighteen adults (34 ± 9.6 years) walked while avoiding another participant (child or adult). Groups of three children and three adults were recruited per session. The results demonstrated that (1) MPD(t) can be used to predict future collisions in children, (2) MPD(t) is an absolute measure that is consistently lower when a child is involved compared to two adult walkers, (3) the individual passing second, even when it is a child, contributes more to MPD(t) than the walker passing first. It then appears that children have developed adult-like strategies during a collision avoidance task involving two walkers. Body anthropometrics should be considered when determining collision avoidance strategies between children and adults. On the other hand, every year, 1 in 3 older adults are likely to fall at least once and many falls occurs while walking where an individual needs to adapt to environmental hazards. Studies with older adults interacting within an environment showed difficulties in estimating time to arrival of vehicles, larger critical ratio and more variability in door aperture task as well as larger clearance distance when avoiding a moving object. The current study [51] aims to identify whether differences in collision avoidance behaviours of older adults during a person-person collision avoidance task are the result of age-related visuomotor processing deficits. Results showed that no collision occurred, where older and younger adults were able to act appropriately. However, larger threshold were needed to trigger avoidance when an older adult is second in crossing order, possibly due to visuomotor delays. Moreover, we observed more crossing inversions with older adults, which may suggest a poor visumotor processing. Finally, the clearance distance was samller when to older adults interact with each others, resulting in “risky” behaviours. Interestingly, social factors seems to be involved since when a young and an older adults interact, the young adult contribute more to solve the collision avoidance task.

In close relation with the Application Domain "Sports", we also investigated visuo-motor coordination during locomotion in previously concussed rugby-players (Figure 6c). Despite adherence to return-to-play guidelines, athletes with previous concussion exhibit persistent visuomotor deficits during static balance and visuomotor integration tasks such as collision avoidance months after returning to sport. Previous research in collision avoidance was done in a static setting, however less is known about visuomotor strategies utilized in dynamic scenarios, such as person-person interactions. In this context, during a collision avoidance locomotor task, individuals make adjustments to their path and/or their velocity in response to a risk of collision. These adjustments ensure that the clearance distance would be large enough such that no collision occurs. However, athletes with previous concussion may demonstrate impaired performance during a collision avoidance task requiring path adjustments based on visual information. The purpose of this study [55] was to investigate collision avoidance strategies when avoiding another walker between previously concussed athletes and healthy athletes. We hypothesized that previously concussed athletes would demonstrate altered trajectory adaptation and changes in individual contribution to the avoidance compared to healthy athletes. Preliminary results show that individuals with previous concussion demonstrated trajectory adaptation behaviours consistent with healthy athletes and young adults. However, previously concussed athletes passed with a reduced distance between themselves and the other walker when they are second in passage order at the crossing point. Athletes who have sustained a previous concussion show decreased collision avoidance behaviour. This behaviour results in a higher risk of a collision occurring, as individuals showed reduced contributions (i.e. creating physical space) to the avoidance of the collision. This change in typical behaviour on a visuomotor task may indicate a persistent deficit in perceptual abilities following concussion. Although trajectory adaptations were consistent with healthy athletes, these results suggest that athletes with previous concussion remain at an elevated risk of collision and possible injury following concussion recovery. This study provides novel insights and additional evidence that visuomotor and perceptual impairments persist following return to play in previously concussed athletes. Additionally, this protocol has important implications for the assessment and rehabilitation of visuomotor processes that are affected following a concussion. Future research could further develop this protocol to be used in sideline assessment, and guide treatment of concussions past clinical recovery.

7.7.4. Collision Avoidance between a Walker and an Electric Powered Wheelchair: Towards Smart Wheelchair

Participants: Anne-Hélène Olivier [contact], Armel Crétual.

In collaboration with Marie Babel and Julien Pettré from Inria Rainbow team, we are interested in the development of smart electric powered wheelchairs (EPW), which provide driver assistance. Developing smart assistance requires to better understand interactions between walkers and such vehicles. We focus on collision avoidance task between an EPW (fully operated by a human) and a walker, where the difference in the nature of the agents (weight, maximal speed, acceleration profiles) results into asymmetrical physical risk in case of a collision, for example due to the protection EPW provides to its driver, or the higher energy transferred to the walker during head-on collision. In this work [39], [47], our goal is to demonstrate that this physical risk asymmetry results into differences in the walker's behavior during collision avoidance in comparison to human-human situations. 20 participants (15 walkers and 5 EPW drivers) volunteered to this study. The experiment was performed in a 30mx20m gymnasium. We designed a collision avoidance task, where an EPW and a human walker moved towards a goal with orthogonal crossing trajectories (Figure6d). We recorded their trajectory among 246 trials (each trial being 1 collision avoidance). We compared the predicted passage order when they can first see each other with the one observed at the crossing point to identify if inversions occur during the interaction. Note that during walker-walker interactions it was shown that the initial passage order is almost systematically preserved all along the interaction up to the crossing point. We also computed the shape-to-shape clearance distance. We observed 23.7% of passage order inversion, specifically in 20.8% of trials where walkers were supposed to cross first, they crossed second. This means that walkers were more likely to pass behind the EPW than in front. On average, human walkers crossed first when having sufficient advance on the wheelchair to reach the crossing point. We estimated this advance up to 0.91m. The shape-to-shape clearance distance was influenced by the passage order at the crossing point, with larger distance when the walker cross first (M=0.78m) than second (M=0.34m). Results show that walkers set more conservative strategies when interacting with an EPW. By passing more frequently behind the EPW, they avoid risks of collisions that would lead to high energy transfer. Also, when they pass in front, they significantly increase the clearance distance, compared to cases where they pass behind. These results can then be linked to the difference in the physical characteristics of the walkers and EPW where asymmetry in the physical risks raised by collisions influence the strategies performed by the walkers in comparison with a similar walker-walker situation. This gives interesting insights in the task of modeling such interactions, indicating that geometrical terms are not sufficient to explain behaviours, physical terms linked to collision momentum should also be considered.

7.7.5. Collision Avoidance on a Narrow Sidewalk

Participant: Anne-Hélène Olivier [contact].

In the context of transportation research and a collaboration with the colleagues of Ifsttar (LEPSIS, LESCOT), we investigate person-person interaction when walking on a narrow sidewalk [34]. Narrow sidewalks are not the result of imagination nor a heritage of the former urban planning in the oldest cities. They exist in many modern cities, a simple web query provides a lot of examples in the world. In most cases, two pedestrians walking in opposite way cannot stay both on the sidewalk when they cross: one has to give a free way on the curb by stepping down on the road, which can generate risky situations for pedestrians. These situations are nowadays underestimated and so are the associated risk. In this context, driving simulators and walking simulators are useful tools to conduct studies in a safe environment with controlled conditions. Therefore, they can allow improving our knowledge on the way pedestrians interact on a narrow sidewalk and how drivers can react when facing this situation. This contribution aims to model the behaviours of simulated pedestrians, Non Player Characters (NPC). Using an interdisciplinary framework, we first identified from the literature psychosocial factors that should be involved in such interactions. Then, we designed a questionnaire to evaluate the impact of these factors on the perception of these interaction. Based on the main factors, we developed a perception model, and we modified the ORCA model, which is one of the most used for pedestrian collision avoidance simulation. Finally, we assessed the consistency of all our simulated interactions with a user study.

7.7.6. Shared Effort Model During Collision Avoidance

Participants: Anne-Hélène Olivier [contact], Armel Crétual.

In collaboration with Jose Grimaldo da Silva and Thierry Fraichard (Inria Grenoble), we finally designed a shared-effort model during interaction between a moving robot and a human relying on walker-walker collision avoidance data. [33]. Recent works in the domain of Human-Robot Motion (HRM) attempted to plan collision avoidance behavior that accounts for cooperation between agents. Cooperative collision avoidance between humans and robots should be conducted under several factors such as speed, heading and also human attention and intention. Based on some of these factors, people decide their crossing order during collision avoidance. However, whenever situations arise in which the choice crossing order is not consistent for people, the robot is forced to account for the possibility that both agents will assume the same role, a decision detrimental to collision avoidance. In our work we evaluate the boundary that separates the decision to avoid collision as first or last crosser. Approximating the uncertainty around this boundary allows our collision avoidance strategy to address this problem based on the insight that the robot should plan its collision avoidance motion in such a way that, even if agents, at first, incorrectly choose the same crossing order, they would be able to unambiguously perceive their crossing order on their following collision avoidance action.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Cifre Faurecia - Monitoring of gestual efficiency at work

Participants: Franck Multon [contact], Georges Dumont, Charles Pontonnier, Olfa Haj Mahmoud.

This Cifre contract has started in September 2018 for three years and is funding the PhD thesis of Olfa Haj Mamhoud. It consists in designing new methods based on depth cameras to monitor the activity of workers in production lines, compute the potential risk of musculoskeletal disorders, and efficiency compared to reference workers. It raises several fundamental questions, such as adapting previous methods to assess the risk of musculoskeletal disorders, as they generally rely on static poses whereas the worker is performing motion. Based on previous works in the team (previous Cifre PhD thesis of Pierre Plantard) we will provide 30Hz motion capture of the worker, that will enable us to evaluate various time-dependent assessment methods.

We will also explore how to estimate joint forces based and torques on such noisy and low-sampling motion data. We will then define a new assessment method based on these forces and torques.

The Cifre contracts funds the PhD salary and 10K€ per year for the supervision and management of the PhD thesis.

8.1.2. Cifre InterDigitial - Adaptive Avatar Customization for Immersive Experiences

Participants: Franck Multon [contact], Ludovic Hoyet, Nicolas Olivier.

This Cifre contract has started in February 2019 for three years and is funding the PhD thesis of Nicolas Olivier. The aim of the project is to design stylized avatars of users in immersive environment and digital arts such as videogames or cinema.

To this end, we will design a pipeline from motion and shape capture of the user to the simulation of the 3D real-time and stylized avatar. It will take hairs, eyes, face, body shape and motion into account. The key idea is to stylized both appaearance and motion to make avatar better correspond to the style of the movie of immersive experience. We will carry-out perceptual studies to better understand the expectation of the users when controlling stylized avatars, to maximize embodiment. The Cifre contracts funds the PhD salary and 15K€ per year for the supervision and management of the PhD thesis. This contract is also in collaboration with Hybrid team.

8.2. Bilateral Grants with Industry

8.2.1. Collaboration with company SolidAnim (Bordeaux, France)

Participants: Marc Christie [contact], Xi Wang.

Thsi contract started in November 2019 for three years. Its purpose is to explore novel means of performing depth detection for augmented reality applied to the film and broadcast industries. The grant serves to fund the PhD of Xi Wang.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Liv-Lab Breizh Digital Sport

Participants: Richard Kulpa [contact], Benoit Bideau, Franck Multon.

Our project aims, through new virtual reality and augmented reality technologies, to bring people who do not practice physical activity back into sport, whether for economic reasons, or for issues related to social and/or geographical isolation. To achieve this, the Brittany Region, accompanied by identified partners with complementary skills, proposes the development and networking of dedicated rooms at regional level. These existing rooms are chosen to be as close as possible to the target population, i.e. in priority areas: in the City Political District (QPV) for Rennes and Brest, and in the Rural Area to be Revitalized (ZRR) for Auray and Rostrenen. They will be redesigned to integrate these new technologies and attract target populations through the development of remote entertainment and collaborative applications. Indeed, the rooms will be connected to each other allowing participants to train together and create a community of practitioners. They will be equipped with simple sensors to evaluate their practices using a multidisciplinary cross-disciplinary approach, with biomechanical, physiological and psychological analyses (M2S/MimeTIC, CREAD and VIPS[2] laboratories). These evaluations will be used to propose physical activities that are progressive and adapted to the level of the practitioner. Access to objective data on their performance will be an additional motivating factor to keep these target audiences active. Support to local structures will allow them to extend their sporting experience after leaving Liv-Lab. Finally, subjects suffering from pathologies that are too disabling will be redirected to a health network, such as Rennes in the Living Lab ISAR (Innovation Santé Autonomie Rennes).

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR PRCE Cineviz

Participants: Marc Christie [contact], Quentin Galvane.

Cineviz is a 3-year ANR LabCom project (2016-2019). Amount: 300kE. Parnters: SolidAnim, UR1.

The project is a bilateral collaboration with the SolidAnim company. The objective is to jointly progress on the design and implementation of novel tools for the preproduction in the film industry. The project will address the challenges related to (i) proposing expressive framing tools, (ii) integrating the technical aspects of shooting (how to place the cameras, lights, green sets) directly at the design stage), and (iii) novel interaction metaphors for designing and controlling the staging of lights in preproduction, using an example-based approach.

9.2.1.2. ANR PRC Capacities

Participants: Charles Pontonnier [contact], Georges Dumont, Pierre Puchaud, Claire Livet, Anthony Sorel.

This project is leaded by Christophe Sauret, from INI/CERAH. The project objective is to build a series of biomechanical indices characterizing the biomechanical difficulty for a wide range of urban environmental situations. These indices will rely on different biomechanical parameters such as proximity to joint limits, forces applied on the handrims, mechanical work, muscle and articular stresses, etc. The definition of a more comprehensive index, called Comprehensive BioMechanical (CBM) cost, including several of the previous indices, will also be a challenging objective. The results of this project would then be used in the first place in VALMOBILE application to assist MWC users in selecting optimal route in Valenciennes agglomeration (project founded by the French National Agency for Urban Renewal and the North Department of France). The MimeTIC team is involved on the musculoskeletal simulation issues and the biomechanical costs definition.

9.2.1.3. ANR JCJC Per2

Participants: Ludovic Hoyet [contact], Benjamin Niay, Anne-Hélène Olivier, Richard Kulpa, Franck Multon.

Per2 is a 42-month ANR JCJC project (2018-2022) entitled *Perception-based Human Motion Personalisation* (Budget: 280kE; website: https://project.inria.fr/per2/)

The objective of this project is to focus on how viewers perceive motion variations to automatically produce natural motion personalisation accounting for inter-individual variations. In short, our goal is to automate the creation of motion variations to represent given individuals according to their own characteristics, and to produce natural variations that are perceived and identified as such by users. Challenges addressed in this project consist in (i) understanding and quantifying what makes motions of individuals perceptually different, (ii) synthesising motion variations based on these identified relevant perceptual features, according to given individual characteristics, and (iii) leveraging even further the synthesis of motion variations and to explore their creation for interactive large-scale scenarios where both performance and realism are critical.

This work is performed in collaboration with Julien Pettré from Rainbow team.

9.2.1.4. ANR PRCI HoBis

Participants: Franck Multon [contact], Armel Crétual, Georges Dumont, Charles Pontonnier, Anthony Sorel.

Hobis is a 42-month ANR collaborative (PRCI) project (2018-2022) entitled *Hominin BipedalismS: Exploration of bipedal gaits in Hominins thanks to Specimen-Specific Functional Morphology*. HoBis is leaded by the Museum Nationale d'Histoires Naturelles (CNRS), with CNRS/LAAS, and Antwerpen University (Belgium), with a total of 541KE budget (140KE for MimeTIC).

HoBiS (Hominin BipedalismS) is a pluridisciplinary research project, fundamental in nature and centred on palaeoanthropological questions related to habitual bipedalism, one of the most striking features of the human lineage. Recent discoveries (up to 7 My) highlight an unexpected diversity of locomotor anatomies in Hominins that lead palaeoanthropologists to hypothesize that habitual bipedal locomotion took distinct shapes through our phylogenetic history. In early Hominins, this diversity could reveal a high degree of locomotor plasticity which favoured their evolutionary success in the changing environments of the late Miocene and Pliocene. Furthermore, one can hypothesize based on biomechanical theory that differences in gait characteristics, even slight, have impacted the energy balance of hominin species and thus their evolutionary success. However, given the fragmented nature of fossil specimens , previous morphometric and anatomo-functional approaches developed by biologists and palaeoanthropologists, do not allow the assessment of the biomechanical and energetic impacts of such subtle morphological differences, and the manners in which hominin species walked still remains unknown. To tackle this problem, HoBiS proposes as main objective a totally new specimen-specific approach in evolutionary anthropology named Specimen-Specific Functional Morphology: inferring plausible complete locomotor anatomies based on fossil remains, to link these reconstructed anatomies and corresponding musculoskeletal models (MSM) with plausible gaits using simulations. Both sub-objectives will make use of an extensive comparative anatomical and gait biomechanical data bases (challenges). To this end, we will integrate anatomical and functional studies, tools for anatomical modelling, optimization and simulation rooted in informatics, biomechanics, and robotics, to build an in-silico decision-support system (DSS). This DSS will provide biomechanical simulations and energetic estimations of the most plausible bipedal gaits for a variety of hominin species based on available remains, from partial to well-preserved specimens. To achieve this main objective, the project will address the following sub-objectives and challenges

MimeTIC is Leader of WP3 "Biomechanical simulation", aiming at predicting plausible bipedal locomotion based on paleoanthropological heuristics and a given MSM.

9.2.1.5. Labex CominLabs : Moonlight

Participants: Guillaume Nicolas [contact], Nicolas Bideau.

Moonlight is a 2-year Labex Cominlabs project (2018-2019). Amount: 55kE (including a one-year postdoctoral fellowship). Partners: Granit Team IRISA (http://www-granit.irisa.fr/fr/), M2S Lab.

The Moonlight project is part of an effort to transpose the tools and methodologies used in motion capture from optoelectronic equipment to inertial unit devices. More specifically, the overall objective of Moonlight project is to design a new embedded system in order to analyze cyclists' movements in real conditions, i.e. outside of the laboratory. This requires to estimate reliable 3D joint angles, lower limb kinematics and pedals orientation. IMUs are used as an alternative to optoelectronical motion capture but some challenges have to be addressed as regards to sensor-to-segment misalignment and drift. Indeed, a real time accurate orientation of the crank is necessary to get limb position. To achieve this goal, data fusion algorithms between IMU data and pedal orientation are implemented. A wireless sensor network with accurate time synchronization mechanism is needed to process data fusion from all sensor's nodes on a tablet. Finally, the system deals with size, energy consumption and ease-to-use constraints.

9.2.2. National scientific collaborations

9.2.2.1. Cavaletic

Participant: Franck Multon [contact].

The Cavaletic collaborative project is leaded by University Bretagne Sud and also involves University Rennes2 (CREAD Lab.). It has been funded by the National IFCE (Institut Français du Cheval et de l'Equitation) in order to develop and evaluate technological assistance in horse riding learning, thanks to a user-centered approach. MimeTIC is involved in measuring expert and non-expert horse riders' motions in standardized situations in order to develop metrics to measure riders' performance. It will be used to develop a technological system embedded on users to evaluate their performance and provide them with real-time feedback to correct potential errors.

The project funded by IFCE ended in 2018 but we got a 30K€ budget from SATT Ouest Valorisation in order to finish the development of the technological prototype, and to evaluate the possibility to patent the process, and transfer it to private companies. This project is in collaboration with LEGO lab. in University Bretagne Sud, and CAIRN Inria team.

9.2.2.2. French Federation of Tennis

Participants: Richard Kulpa [contact], Benoit Bideau, Pierre Touzard.

An exclusive contract has been signed between the M2S laboratory and the French Federation of Tennis for three years. The goal is to perform biomechanical analyses of 3D tennis serves on a population of 40 players of the Pôle France. The objective is to determine the link between injuries and biomechanical constraints on joints and muscles depending on the age and gender of the players. At the end, the goal is to evaluate their training load.

9.2.3. Chaire Safran-Saint-Cyr "the enhanced soldier in the digital battlefield"

Participants: Charles Pontonnier [contact], Pierre Puchaud.

The chaire has the goal to answer to scientific questions accompanying the evolution of the technologies equipping the soldiers in mission. In this scheme, the MimeTIC team is involved in generic and specific musculoskeletal models for the prototyping of load carriage assistive devices (exoskeletons). Chair sponsored by SAFRAN group, led by Yvon Erhel (Professor, Ecoles de Sainr-Cyr Coëtquidan).

9.2.4. AUTOMA-PIED

Participants: Anne-Hélène Olivier [contact], Armel Crétual, Anthony Sorel.

The AUTOMA-PIED project is driven by IFSTTAR. Using a set-up in virtual reality, the first objective of the project aims at comparing pedestrian behaviour (young and older adults) when interacting with traditional or autonomous vehicles in a street crossing scenario. The second objective is to identify postural cues that can predict whether or not the pedestrian is about to cross the street.

9.2.5. IPL Avatar

Participants: Ludovic Hoyet [contact], Franck Multon.

This project aims at design avatars (i.e., the user's representation in virtual environments) that are better embodied, more interactive and more social, through improving all the pipeline related to avatars, from acquisition and simulation, to designing novel interaction paradigms and multi-sensory feedback. It involves 6 Inria teams (GraphDeco, Hybrid, Loki, MimeTIC, Morpheo, Potioc), Prof. Mel Slater (Uni. Barcelona), and 2 industrial partners (InterDigitak and Faurecia).

Website: http://avatar.inria.fr

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. H2020 ICT-25 PRESENT

Participants: Marc Christie, Ludovic Hoyet [contact], Anne-Hélène Olivier, Alberto Jovane, Adèle Colas.

This European project aims at creating virtual characters that are realistic in looks and behaviour, and who can act as trustworthy guardians and guides in the interfaces for AR, VR and more traditional forms of media. It is conducted in collaboration with industrial partners The Framestore Ltd, Cubic Motion Ltd, InfoCert Spa, Brainstorm Multimedia S.L., Creative Workers - Createieve Werkers VZW, and academic partners Universidad Pompeu Fabra and Universität Augsburg.

9.3.1.2. JPI-CH SCHEDAR

Participants: Franck Multon [contact], Richard Kulpa.

SCHEDAR (Safeguarding the Cultural HEritage of Dance through Augmented Reality) is a Joint Program Initiative for preserving immaterial cultural heritage. The project started in June 2018 and will finish December 2021. It is coordinated by University of Cyprus, in collaboration with Algolysis LTD (Cyprus), University of Warwick (UK), University of Reims Champagne Ardennes (France).

Dance is an integral part of any culture. Through its choreography and costumes dance imparts richness and uniqueness to that culture. Over the last decade, technological developments have been exploited to record, curate, remediate, provide access, preserve and protect tangible CH. However, intangible assets, such as dance, has largely been excluded from this previous work. Recent computing advances have enabled the accurate 3D digitization of human motion. Such systems provide a new means for capturing, preserving and subsequently re-creating ICH which goes far beyond traditional written or imaging approaches. However, 3D motion data is expensive to create and maintain, encompassed semantic information is difficult to extract and formulate, and current software tools to search and visualize this data are too complex for most end-users. SCHEDAR will provide novel solutions to the three key challenges of archiving, re-using and re-purposing, and ultimately disseminating ICH motion data. In addition, we will devise a comprehensive set of new guidelines, a framework and software tools for leveraging existing ICH motion databases. Data acquisition will be undertaken holistically; encompassing data related to the performance, the performer, the kind of the dance, the hidden/untold story, etc. Innovative use of state-of-the-art multisensory Augmented Reality technology will enable direct interaction with the dance, providing new experiences and training in traditional dance which is key to ensure this rich culture asset is preserved for future generations. MimeTIC is responsible for WP3 "Dance Data Enhancement".

9.4. International Initiatives

9.4.1. Inria Associate Teams Not Involved in an Inria International Labs

9.4.1.1. BEAR

Title: from BEhavioral Analysis to modeling and simulation of interactions between walkeRs

International Partner: Michael Cinelli (Wilfrid Laurier University, Canada) and Michael Barnett Cowann (University of Waterloo, Canada)

Start year: 2019

See also: https://sites.google.com/view/inriabearproject/home

Interactions between individuals are by definition at the very core of our society since they represent the basic synergies of our daily life. When walking in the street or in more dynamical and strategic situations such as sports motion, we take in information about our surrounding environment in order to interact with people, move without collision, alone or in a group, intercept, meet or escape other people. In this context, the BEAR project is a collaboration between researchers from Inria Rennes (Computer Sciences) and Waterloo universities (Kinesiology-Neuroscience). The project aims at providing more realistic models and simulations of interactions between pedestrians, for various applications such as rehabilitation, computer graphics, or robotics. The originality of the project is to investigate the complexity of human interactions from a human motor control perspective, considering the strong coupling between pedestrians' visual perception and their locomotor adaptations. We will investigate how people gather the relevant information to control their motion. To provide generic models considering the inter-individual variability of humans, we will consider both normal populations and specific populations (children, older adults, injured, diseased ...) for whom an altered perception can modify their motion. The strength of this project is the complementarity of theinvolved teams. While all researchers will equally perform experiments on interactions between pedestrians, the researchers from Waterloo will take the lead to identify the relevant behavioral variables that will be used mainly by the researchers from Rennes to design the new models and simulations.

9.4.2. International Mobility Grant

- Mitacs Globalink grant: Perception-Action Integration in Collision Avoidance in Older Adults, Robyn Grundberg, University Wilfrid Laurier, Canada (April-July 2019)
- Mitacs Globalink grant: Influence of walking speed and trunk sway on collision avoidance with a virtual human, Sheryl Bourgaize, University Wilfrid Laurier, Canada (April-July 2019).

9.4.3. Inria International Partners

9.4.3.1. Informal International Partners

- Dr. Rachel McDonnell, Trinity College Dublin, Ireland (on-going collaboration with Ludovic Hoyet)
- Prof. Carol O Sullivan, Trinity College Dublin, Ireland (on-going collaboration with Ludovic Hoyet)
- Prof Michael Cinelli, University Wilfrid Laurier, Waterloo, Canada (on-going collaboration with Anne-Hélène Olivier)
- Prof Michael Barnet-Cowann, University of Waterloo, Waterloo, Canada (on-going collaboration with Anne-Hélène Olivier)
- Prof. Hui Huang, Shenzhen University (on-going collaboration with Marc Christie)
- Prof. Baoquan Chen, Pekin University (on-going collaboration with Marc Christie)
- Dr. Bin Wang, Beijing Film Academy University (on-going collaboration with Marc Christie)

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Michael Barnett-Cowan (from Waterloo University, Canada): Visiting Professor, Research Chair of America, Rennes 2 (September 2019): multisensory integration of perceptual information.
- Kristoffer Larsen Norheim (from Aalborg University, Denmark): Doctoral stay (September-November 2019): biomechanical analysis of virtual hammering tasks.

9.5.1.1. Internships

- Sheryl Bourgaize, PhD Student, Wilfrid Laurier University, Canada (April-July 2019)
- Robyn Grunberg, Master Student, Wilfrid Laurier University, Canada (April-July 2019)

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Simon Hilt: doctoral stay at Aalborg University Denmark (May-July 2019): biomechanical analysis of hammering tasks.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. Member of the Organizing Committees

- Marc Christie, Co-chair and co-organizer of the 8th Eurographics WICED event (Workshop on Intelligent Cinematography and Editing), 2019
- Anne-Hélène Olivier, Co-organizer of the workshop "Modeling and Animating Realistic Crowds and Humans (MARCH)" during the AIVR Conference, San Diego, USA, December 2019
- Anne-Hélène Olivier, Co-Organizer of the Symposium " Going from here to there and beyond: Fundamental theories and applications from what we have learned about human navigation of cluttered environments", ISPGR 2019, Edinburgh, Scotland, July 2019
- Anne-Hélène Olivier, Co-organizer of the workshop "Virtual Humans and Crowds in Immersive Environments" (VHCIE) during IEEE VR Conference Osaka Japan, March 2019

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

- Ludovic Hoyet, Co-Program Chair of the 19th ACM Symposium on Applied Perception, Barcelona, September 2019
- Ludovic Hoyet, Co-Workshop Chair for of the 32nd International Conference on Computer Animation and Social Agents, Paris, July 2019
- Ludovic Hoyet, Animation & Simulation Area Program Chair, International Conference on Computer Graphics Theory and Applications 2019, Prague, Czech Republic, Feb. 2019
- Marc Christie, Area Chair, ACM TVX 2019, International Conference on Interactive Experiences for Television and Online Video
- Anne-Hélène Olivier, Conference Paper co-chair, IEEE Virtual Reality Conference, Osaka Japan, March 2019

10.1.2.2. Member of the Conference Program Committees

- Ludovic Hoyet, ACM Motion Interaction in Games MIG 2019
- Marc Christie, ACM Motion Interaction in Games MIG 2019
- Marc Christie, ACM Interactive Experiences for Television and Online Video TVX 2019
- Anne-Hélène Olivier, ACM Motion Interaction in Games MIG 2019
- Anne-Hélène Olivier, ACM Symposium on Applied Perception SAP 2019
- Anne-Hélène Olivier, ACM Symposium on Virtual Reality Software and Technology VRST, Technical Papers 2019
- Franck Multon, ACM Motion Interaction in Games MIG 2019
- Franck Multon, Computer Animation and Social Agents CASA2019

10.1.2.3. Reviewer

- Ludovic Hoyet, ISVC 2019, JFIG 2019, CRDH Workshop (AIVR 2019), VHCIE Workshop (IEEE VR 2019)
- Franck Multon, CASA 2019, MIG 2019

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Anne-Hélène Olivier, Review Editor in Frontiers in Virtual Reality - Technologies for VR
- Franck Multon, Presence, MIT Press
- Franck Multon, Computer Animation and Virtual Worlds CAVW, John Wiley
- Georges Dumont, Review Editor in Frontiers in Virtual Reality - Technologies for VR

10.1.3.2. Reviewer - Reviewing Activities

- Charles Pontonnier - Applied Science, Applied ergonomics, Multibody Systems Dynamics, Sensors, Complexity
- Marc Christie, ACM SIGGRAPH 2019, ACM SIGGRAPH ASIA 2019, TVCG
- Ludovic Hoyet, IEEE Transactions on Visualization and Computer Graphics, Neuroscience, Journal of Virtual Reality and Broadcasting, Journal on Multimodal User Interfaces
- Anne-Hélène Olivier, Virtual Reality, Gait and Posture
- Franck Multon, Virtual Reality, The Visual Computer, IEEE Robotics and Automation, International Journal of Industrial Ergonomics, Journal of Sports Sciences, Journal of Ergonomics
- Armel Crétual, Clinical Biomechanics, Medical and Biological Engineering and Computing, PlosONE, Sensors
- Georges Dumont, Journal of Biomechanics

10.1.4. Invited Talks

- Marc Christie, Workshop AI in Media at European Broadcast Union, Manchester 2019.
- Anne-Hélène Olivier, Sport Unlimitech, Lyon, September 2019.

10.1.5. Scientific Expertise

- Franck Multon, expertise for I-Site NExT from Nantes for the "International Research Partnerships" call for projects
- Franck Multon, FRQNT (Canada) for the evaluation of 4 collaborative projects in Quebec on the topic "computer sciences - human-robot interaction"

10.1.6. Research Administration

- Ludovic Hoyet is an elected member of the Board of Managers for the French Computer Graphics Association (Association Française d'Informatique Graphique), since Oct. 2017
- Ludovic Hoyet is an elected member of the Inria Laboratory Board, since Sept. 2019.
- Franck Multon is the Inria national coordinator for digital sciences for Sports, since Sept 2018

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

- Master : Franck Multon, co-leader of the IEAP Master (1 and 2) "Ingénierie et Ergonomie de l'Activité Physique", STAPS, University Rennes2, France
- Master : Franck Multon, "Santé et Performance au Travail : étude de cas", leader of the module, 30H, Master 1 M2S, University Rennes2, France
- Master : Franck Multon, "Analyse Biomécanique de la Performance Motrice", leader of the module, 30H, Master 1 M2S, University Rennes2, France
- Master: Charles Pontonnier, "Numerical simulation of polyarticulated systems", leader of the module, 22H, M1 Mechatronics, Ecole Normale Supérieure de Rennes, France
- Master: Charles Pontonnier, Responsible of the internships of students (L3 and M1), 15H, Ecole Normale Supérieure de Rennes, France
- Master: Charles Pontonnier, Reearch projects, 20H, Ecole Normale Supérieure de Rennes, France
- Master : Georges Dumont, Responsible of the second year of the master Engineering of complex systems, École Normale Supérieure de Rennes and Rennes 1 University, France
- Master : Georges Dumont, Mechanical simulation in Virtual reality, 36H, Master Engineering of complex systems and Mechatronics, Rennes 1 University and École Normale Supérieure de Rennes, France

- Master : Georges Dumont, Mechanics of deformable systems, 40H, Master, École Normale Supérieure de Rennes, France
- Master : Georges Dumont, oral preparation to agregation competitive exam, 20H, Master, École Normale Supérieure de Rennes, France
- Master : Georges Dumont, Vibrations in Mechanics, 10H, Master, École Normale Supérieure de Rennes, France
- Master : Georges Dumont, Finite Element method, 12H, Master, École Normale Supérieure de Rennes, France
- Master : Ludovic Hoyet, Motion Analysis and Gesture Recognition, 12h, INSA Rennes, France
- Master : Ludovic Hoyet, Réalité Virtuelle pour l'Analyse Ergonomique, Master Ingénierie et Ergonomie des Activités Physique, 21h, University Rennes 2, France
- Master : Anne-Hélène Olivier, co-leader of the APPCM Master (1 and 2) "Activités Physiques et Pathologies Chroniques et Motrices", STAPS, University Rennes2, France
- Master : Anne-Hélène Olivier, "Biostatstiques", 21H, Master 2 APPCM/IEAP, University Rennes2, France
- Master : Anne-Hélène Olivier, "Evaluation fonctionnelle des pathologies motrices", 3H Master 2 APPCM, University Rennes2, France
- Master : Anne-Hélène Olivier, "Maladie neurodégénératives : aspects biomécaniques", 2H Master 1 APPCM, University Rennes2, France
- Master : Anne-Hélène Olivier, "Biostatstiques", 7H, Master 1 EOPS, University Rennes2, France
- Master : Anne-Hélène Olivier, "Méthodologie", 10H, Master 1 IEAP/APPCM, University Rennes2, France
- Master : Anne-Hélène Olivier, "Contrôle moteur : Boucle perceptivo-motrice", 3H, Master 1IEAP, Université Rennes 2, France
- Master: Fabrice Lamarche, "Compilation pour l'image numérique", 29h, Master 1, ESIR, University of Rennes 1, France
- Master: Fabrice Lamarche, "Synthèse d'images", 12h, Master 1, ESIR, University of Rennes 1, France
- Master: Fabrice Lamarche, "Synthèse d'images avancée", 28h, Master 1, ESIR, University of Rennes 1, France
- Master: Fabrice Lamarche, "Modélisation Animation Rendu", 36h, Master 2, ISTIC, University of Rennes 1, France
- Master: Fabrice Lamarche, "Jeux vidéo", 26h, Master 2, ESIR, University of Rennes 1, France
- Master: Fabrice Lamarche, "Motion for Animation and Robotics", 9h, Master 2 SIF, ISTIC, University of Rennes 1, France.
- Master : Armel Crétual, "Méthodologie", leader of the module, 20H, Master 1 M2S, University Rennes2, France
- Master : Armel Crétual, "Biostatstiques", leader of the module, 30H, Master 2 M2S, University Rennes2, France
- Master : Richard Kulpa, "Boucle analyse-modélisation-simulation du mouvement", 27h, leader of the module, Master 2, Université Rennes 2, France
- Master : Richard Kulpa, "Méthodes numériques d'analyse du geste", 27h, leader of the module, Master 2, Université Rennes 2, France
- Master : Richard Kulpa, "Cinématique inverse", 3h, leader of the module, Master 2, Université Rennes 2, France

- Master: Marc Christie, "Multimedia Mobile", Master 2, leader of the module, 32h, Computer Science, University of Rennes 1, France
- Master: Marc Christie, "Projet Industriel Transverse", Master 2, 32h, leader of the module, Computer Science, University of Rennes 1, France
- Master: Marc Christie, "Modelistion Animation Rendu", Master 2, 16h, leader of the module, Computer Science, University of Rennes 1, France
- Master: Marc Christie, "Advanced Computer Graphics", Master 1, 10h, leader of the module, Computer Science, ENS, France
- Licence : Franck Multon, "Ergonomie du poste de travail", Licence STAPS L2 & L3, University Rennes2, France
- Licence: Charles Pontonnier, "Lagrangian Mechanics" , leader of the module, 22H, L3 Mechatronics, Ecole Normale Supérieure de Rennes, France
- Licence: Charles Pontonnier, "Serial Robotics", leader of the module, 24H, L3 Mechatronics, , Ecole Normale Supérieure de Rennes, France
- Licence : Anne-Hélène Olivier, "Analyse cinématique du mouvement", 100H , Licence 1, University Rennes 2, France
- Licence : Anne-Hélène Olivier, "Anatomie fonctionnelle", 7H , Licence 1, University Rennes 2, France
- Licence : Anne-Hélène Olivier, "Effort et efficience", 12H , Licence 2, University Rennes 2, France
- Licence : Anne-Hélène Olivier, "Locomotion et handicap", 12H , Licence 3, University Rennes 2, France
- Licence : Anne-Hélène Olivier, "Biomécanique spécifique aux APA", 8H , Licence 3, University Rennes 2, France
- Licence : Anne-Hélène Olivier, "Biomécanique du viellissement", 12H , Licence 3, University Rennes 2, France
- Licence: Fabrice Lamarche, "Initiation à l'algorithmique et à la programmation", 56h, License 3, ESIR, University of Rennes 1, France
- License: Fabrice Lamarche, "Programmation en C++", 46h, License 3, ESIR, University of Rennes 1, France
- Licence: Fabrice Lamarche, "IMA", 24h, License 3, ENS Rennes, ISTIC, University of Rennes 1, France
- Licence : Armel Crétual, "Analyse cinématique du mouvement", 100H, Licence 1, University Rennes 2, France
- Licence : Richard Kulpa, "Biomécanique (dynamique en translation et rotation)", 48h, Licence 2, Université Rennes 2, France
- Licence : Richard Kulpa, "Méthodes numériques d'analyse du geste", 48h, Licence 3, Université Rennes 2, France
- Licence : Richard Kulpa, "Statistiques et informatique", 15h, Licence 3, Université Rennes 2, France

10.2.2. Supervision

PhD in progress (beginning September 2017): Pierre Puchaud, Développement d'un modèle musculo-squelettique générique du soldat en vue du support de son activité physique, Ecole normale supérieure, Charles Pontonnier & Nicolas Bideau & Georges Dumont

PhD in progress (beginning January 2019): Nils Hareng, simulation of plausible bipedal locomotion of human and non-human primate, University Rennes2, Franck Multon, & Bruno Watier (CNRS LAAS in Toulouse)

PhD in progress (beginning January 2019): Nicolas Olivier, Adaptive Avatar Customization for Immersive Experience, Cifre InterDigital, Franck Multon, Ferran Arguelaget (Hybrid team), Quentin Avril (InterDigital), Fabien Danieau (InterDigital)

PhD in progress (beginning September 2017): Lyse Leclerc, Intérêts dans les activités physiques du rétablissement de la fonction inertielle des membres supérieurs en cas d'amputation ou d'atrophie, Armel Crétual, Diane Haering

PhD in progress (beginning September 2018) : Jean Basset, Learning Morphologically Plausible Pose Transfer, Inria, Edmond Boyer (Morpheo Inria Grenoble), Franck Multon

PhD in progress (beginning October 2018): Hiep Pham Tuan, Heterogeneous data fusion for safeguarding of cultural heritage of dance, University Reims Champagne Ardennes, Celine Loscos (University Reims), Franck Multon

PhD in progress (beginning September 2017): Simon Hilt, Haptique Biofidèle pour l'Interaction en réalité virtuelle, Ecole normale supérieure, Georges Dumont, Charles Pontonnier

PhD in progress (beginning September 2018): Olfa Haj Mamhoud, Monitoring de l'efficience gestuelle d'opérateurs sur postes de travail, University Rennes 2, Franck Multon, Georges Dumont, Charles Pontonnier

PhD in progress (beginning September 2019) : Claire Livet, Dynamique contrainte pour l'analyse musculo-squelettique en temps rapide : vers des méthodes alternatives d'estimation des forces musculaires mises en jeu dans le mouvement humain, Ecole normale supérieure, Georges Dumont, Charles Pontonnier

PhD in progress (beginning september 2019) : Louise Demestre, simulation MUsculo-squelettique et Structure Elastique pour le Sport (MUSES), Ecole normale supérieure, Georges Dumont, Charles Pontonnier, Nicolas Bideau, Guillaume Nicolas

PhD in progress: Diane Dewez, Avatar-Based Interaction in Virtual Reality, Oct. 2018, Ferran Argelaguet, Ludovic Hoyet, Anatole Lécuyer. Coll. with Hybrid team.

PhD in progress: Rebecca Fribourg, Enhancing Avatars in Virtual Reality through Control, Interactions and Feedback, Sept. 2017, Ferran Argelaguet, Ludovic Hoyet, Anatole Lécuyer. Coll. with Hybrid team

PhD in progress: Florian Berton, Design of a virtual reality platform for studying immersion and behaviours in aggressive crowds, Nov. 2017, Ludovic Hoyet, Anne-Hélène Olivier, Julien Pettré. Coll with Rainbow team

PhD in progress: Benjamin Niay, A framework for synthezing personalised human motions from motion capture data and perceptual information, Oct. 2018, Ludovic Hoyet, Anne-Hélène Olivier, Julien Pettré. Coll. with Rainbow team

PhD in progress: Alberto Jovane, Modélisation de mouvements réactifs et comportements non verbaux pour la création d'acteurs digitaux pour la réalité virtuelle, Sept. 2019, Marc Christie, Ludovic Hoyet, Claudio Pacchierotti, Julien Pettré. Coll. with Rainbow team

PhD in progress: Adèle Colas, Modélisation de comportements collectifs réactifs et expressifs pour la réalité virtuelle, Nov. 2019, Ludovic Hoyet, Anne-Hélène Olivier, Claudio Pacchierotti, Julien Pettré. Coll. with Rainbow team

PhD in progress: Hugo Brument, Toward user-adapted interactions techniques based on human locomotion laws for navigating in virtual environments, Oct. 2018, Anne-Hélène Olivier, Ferran Argelaguet, Maud Marchal. Coll. with Hybrid team

PhD in progress: Lyse Leclercq, Intérêts dans les activités physiques du rétablissement de la fonction inertielle des membres supérieurs en cas d'amputation ou d'atrophie, Sep. 2017, Armel Crétual, Diane Haering

PhD in progress: Florence Gaillard, Validation d'un protocole d'analyse 3D du mouvement des membres supérieurs en situation écologique chez les enfants ayant une Hémiplégie Cérébrale Infantile, Armel Crétual, Isabelle Bonan

PhD in progress: Karim Jamal, Effets des stimulations sensorielles par vibration des muscles du cou sur les perturbations posturales secondaires aux troubles de la représentation spatiale après un accident vasculaire cérébral, Sep 2016, Isabelle Bonan, Armel Crétual

PhD in progress: Carole Puil, Impact d'une stimulation plantaire orthétique sur la posture d'individus sains et posturalement déficients au cours de la station debout, et lors de la marche, Sep. 2018, Armel Crétual, Anne-Hélène Olivier

PhD: Charles Faure, Analyse en réalité virtuelle de la coopération lors d'une interception de balle : interaction et interférence, Sep. 2016, defense 17/01/2019, Richard Kulpa, Benoit Bideau

PhD in progress: Théo Perrin, Evaluation de la perception de l'effort en réalité virtuelle pour l'entraînement sportif, Sep. 2017, Richard Kulpa, Benoit Bideau

PhD in progress: Annabelle Limballe, Anticipation dans les sports de combat : la réalité virtuelle comme solution innovante d'entraînement, Sep. 2019, Richard Kulpa & Benoit Bideau

PhD in progress: Alexandre Vu, Evaluation de l'influence des feedbacks sur la capacité d'apprentissage dans le cadre d'interactions complexes entre joueurs et influence de ces feedbacks en fonction de l'activité sportive , Sep. 2019, Richard Kulpa & Benoit Bideau

10.2.3. Juries

- PhD defense : École Nationale Supérieure d'Arts et Métiers, Samuel Hybois. « Approche numérique pour l'optimisation personnalisée des réglages d'un fauteuil roulant manuel ». 2019-10-14. Georges Dumont, President
- PhD defense : Université de Grenoble-Alpes, Chaowanan Khundam. « Évaluation de l'usage de la réalité virtuelle pour la promotion de patrimoine historique-Evaluation of the virtual reality usage for the promotion of historical heritage ». March 2019. Georges Dumont, President.
- PhD defense: University Toulouse 3, Guillaume Fumery, "Biomécanique du transport collectif de charges, vers une application clinique", january 2019. Franck Multon, Referee
- PhD defense: INSA Lyon, Samuel Carensac, "Contrôle physique de mouvement de personnages virtuels en environnement complexe", July 2019. Franck Multon, Referee
- HDR defense: Sorbonne University, Jonathan Savin, "Simulation de la variabilité du mouvement induite par la fatigue musculaire pour la conception ergonomique de postes de travail", november 2019, Franck Multon, Examiner
- HDR defense: University Lyon 1, Thomas Robert, "Analyse et simulation du maintien de l'équilibre debout chez l'humain", November 2019, Franck Multon, President

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

- Franck Multon is coordinating the national action of Inria in sports

10.3.2. Interventions

- Charles Pontonnier - "La simulation musculo-squelettique pour la robotique" - 4èmes rencontres interdisciplinaires Innovation, Robotique et Santé, December 2019
- Franck Multon - "fête de la Science" Rennes in Champs Libres for two days (October 4th and 5th) demos in the field of VR for sports for a wide public audience
- Franck Multon - "fête de la science" Paris (October 5th), stand-up talk about VR & Sports to the wide public audience, interview with "Esprit Sorcier" for a web-Tv diffusion
- Franck Multon - Sport Unlimitech Lyon, a large event about new technologies for sports (September 19-21), with keynote talks/round tables, managing the booths of Inria

- Armel Crétual - "La science sur les planches", Spectacle "Marcher!!!" avec le Collège Théophile Briant de Tinténiac et la compagnie Kali&Co
- Richard Kulpa - "La réalité virtuelle pour le sport, ludique mais encore ?", Mardis de l'Espace des Sciences, December 2019
- Richard Kulpa - Inria booth at Sport Unlimitech Lyon, a large event about new technologies for sports, September 2019
- Richard Kulpa - Booth at FIFA Women's World Cup 2019
- Anthony Sorel - Inria booth at Sport Unlimitech Lyon, a large event about new technologies for sports, September 2019

10.3.3. Internal action

- Franck Multon - "Journes scientifiques Inria", June 5-6th, plenary talk entitled "La réalité virtuelle pour le sport : un jeu vraiment sérieux ?"
- Franck Multon, Ronan Gaugne - "20 years of Immersia": Event organized by Inria Rennes/IRISA center, November 2019, plenary talks

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Major publications by the team in recent years

[1] S. Cordillet, N. Bideau, B. Bideau, G. Nicolas. *Estimation of 3D Knee Joint Angles during Cycling Using Inertial Sensors Accuracy of a Novel Sensor-to-Segment Calibration Procedure Based on Pedaling Motion*, in "Sensors", 2019, vol. 19, n^o^ 11, pp. 1-23 [*DOI :* 10.3390/s19112474], https://hal-univ-rennes1.archives-ouvertes.fr/hal-02160398

[2] C. Faure, A. Limballe, A. Sorel, T. Perrin, B. Bideau, R. Kulpa. *Dyadic Interference Leads to Area of Uncertainty During Face-to-Face Cooperative Interception Task*, in "Frontiers in information and communication technologies", October 2019, vol. 6, pp. 1-13 [*DOI :* 10.3389/fict.2019.00020], https://hal.inria.fr/hal-02407452

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[5] S. D. Lynch, A.-H. Olivier, B. Bideau, R. Kulpa. *Detection of deceptive motions in rugby from visual motion cues*, in "PLoS ONE", 2019, vol. 14, n^o^ 9, e0220878 p. [*DOI :* 10.1371/journal.pone.0220878], https://hal-univ-rennes1.archives-ouvertes.fr/hal-02308029

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[12] C. FAURE. *Analysis in virtual reality of cooperation during ball interception: interaction and interference*, Université Rennes 2, December 2019, https://hal.archives-ouvertes.fr/tel-02430381

[13] C. PONTONNIER. *Efficient motion analysis and virtual reality methods for preventive and corrective ergonomics*, ENS Rennes, November 2019, Habilitation à diriger des recherches, https://hal.archives-ouvertes.fr/tel-02392255

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[16] C. FAURE, A. LIMBALLE, A. SOREL, T. PERRIN, B. BIDEAU, R. KULPA. *Dyadic Interference Leads to Area of Uncertainty During Face-to-Face Cooperative Interception Task*, in "Frontiers in information and communication technologies", October 2019, vol. 6, pp. 1-13 [*DOI :* 10.3389/FICT.2019.00020], https://hal.inria.fr/hal-02407452

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