IN PARTNERSHIP WITH:
Université de Montpellier

Activity Report 2019

Project-Team CAMIN

Control of Artificial Movement & Intuitive Neuroprosthesis

IN COLLABORATION WITH: Laboratoire d'informatique, de robotique et de microélectronique de Montpellier (LIRMM)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Neuroscience and Medicine

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Project-Team CAMIN

Creation of the Team: 2016 January 01, updated into Project-Team: 2019 March 01

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A2.3. - Embedded and cyber-physical systems
A2.5.2. - Component-based Design
A4.4. - Security of equipment and software
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Other Research Topics and Application Domains:

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B2.2.1. - Cardiovascular and respiratory diseases
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1. Team, Visitors, External Collaborators

Research Scientists

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Daniel Simon [Inria, Researcher, HDR]

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Lucie William [Inria, PhD Student, from Oct 2019]

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Marion Holvoet [Univ de Montpellier, from Apr 2019 until Jul 2019]
Helene Moron [Univ de Montpellier, from March 2019 until June 2019]
Isabelle Mathieu [Inria, from Apr 2019 until may 2019]
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Sofiane Ramdani [Univ de Montpellier]

2. Overall Objectives

2.1. Overall Objectives

CAMIN research team is dedicated to the **design and development of realistic neuroprosthetic solutions for sensorimotor deficiencies** in collaboration with clinical partners. Our efforts are focused on clinical impact: improving the functional evaluation and/or quality of life of patients. Movement is at the center of our investigative activity, and the **exploration and understanding of the origins and control of movement** are one of our two main research priorities. Indeed, optimizing the neuroprosthetic solutions depends on a deeper understanding of the roles of the central and peripheral nervous systems in motion control. The second research priority is **movement assistance and/or restoration**. Based on the results from our first research focus, neuroprosthetic approaches are deployed (Figure 1).

Electrical stimulation (ES) is used to activate muscle contractions by recruiting muscle fibers, just as the action potentials initiated in motoneurons would normally do. When a nerve is stimulated, both afferent (sensitive) and efferent (motor) pathways are excited. ES can be applied externally using surface electrodes positioned on the skin over the nerves/muscles intended to be activated or by implantation with electrodes positioned at the contact with the nerves/muscles or neural structures (brain and spinal cord). ES is the only way to restore movement in many situations.

Yet although this technique has been known for decades, substantial challenges remain, including: (i) detecting and reducing the increased early fatigue induced by artificial recruitment, (ii) finding solutions to nonselective stimulation, which may elicit undesired effects, and (iii) allowing for complex amplitude and time modulations of ES in order to produce complex system responses (synergies, coordinated movements, meaningful sensory feedback, high-level autonomic function control).

We investigate functional restoration, as either a **neurological rehabilitation solution** (incomplete SCI, hemiplegia) or for **permanent assistance** (complete SCI). Each of these contexts imposed its own set of constraints on the development of solutions.

Functional ES (FES) rehabilitation mainly involves external FES, with the objective to increase neurological recuperation by activating muscle contractions and stimulating both efferent and afferent pathways. Our work in this area naturally led us to take an increasing interest in brain organization and plasticity, as well as central nervous system (brain, spinal cord) responses to ES. When the objective of FES is a permanent assistive aid, invasive solutions can be deployed. We pilot several animal studies to investigate neurophysiological responses to ES and validate models. We also apply some of our technological developments in the context of human per-operative surgery, including motor and sensory ES.

CAMIN research is focused on **exploring and understanding human movement** in order to propose neuroprosthetic solutions in sensorimotor deficiency situations to **assist or restore movement**. Exploration and understanding of human movement will allow us to propose assessment approaches and tools for diagnosis and evaluation purposes, as well as to improve FES-based solutions for functional assistance.

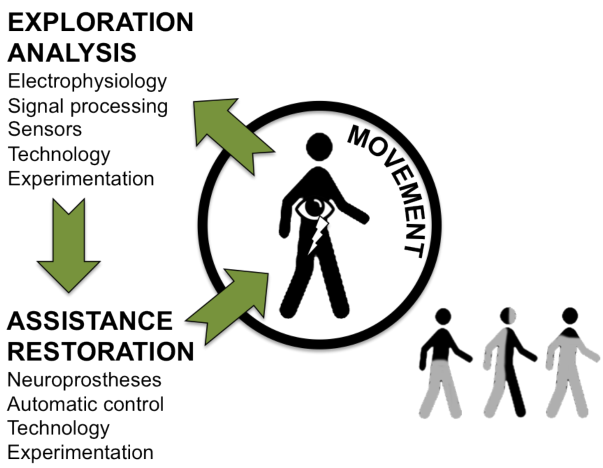

Figure 1. Overview of CAMIN *general scientific approach.*

We have chosen not to restrict our investigation spectrum to specific applications but rather to deploy our general approach to a variety of clinical applications in collaboration with our medical partners. **Our motivation and ambition is to have an effective clinical impact**.

3. Research Program

3.1. Exploration and understanding of the origins and control of movement

One of CAMIN's areas of expertise is **motion measurement, observation and modeling** in the context of **sensorimotor deficiencies**. The team has the capacity to design advanced protocols to explore motor control mechanisms in more or less invasive conditions in both animal and human.

Human movement can be assessed by several noninvasive means, from motion observation (MOCAP, IMU) to electrophysiological measurements (afferent ENG, EMG, see below). Our general approach is to develop solutions that are realistic in terms of clinical or home use by clinical staff and/or patients for diagnosis and assessment purposes. In doing so, we try to gain a better understanding of motor control mechanisms, including deficient ones, which in turn will give us greater insight into the basics of human motor control. Our ultimate goal is to optimally match a neuroprosthesis to the targeted sensorimotor deficiency.

The team is involved in research projects including:

- Peripheral nervous system (PNS) exploration, modeling and electrophysiology techniques

Electroneurography (ENG) and electromyography (EMG) signals inform about neural and muscular activities. The team investigates both natural and evoked ENG/EMG through advanced and dedicated signal processing methods. Evoked responses to ES are very precious information for understanding neurophysiological mechanisms, as both the input (ES) and the output (evoked EMG/ENG) are controlled. CAMIN has the expertise to perform animal experiments (rabbits, rats, earthworms and big animals with partners), design hardware and software setups to stimulate and record in harsh conditions, process signals, analyze results and develop models of the observed mechanisms. Experimental surgery is mandatory in our research prior to invasive interventions in humans. It allows us to validate our protocols from theoretical, practical and technical aspects.

- Central nervous system (CNS) exploration
  Stimulating the CNS directly instead of nerves allows activation of the neural networks responsible for generating functions. Once again, if selectivity is achieved the number of implanted electrodes and cables would be reduced, as would the energy demand. We have investigated **spinal electrical stimulation** in animals (pigs) for urinary track and lower limb function management. This work is very important in terms of both future applications and the increase in knowledge about spinal circuitry. The challenges are technical, experimental and theoretical, and the preliminary results have enabled us to test some selectivity modalities through matrix electrode stimulation. This research area will be further intensified in the future as one of ways to improve neuroprosthetic solutions.
  We intend to gain a better understanding of the electrophysiological effects of DES through electroencephalographic (EEG) and electrocorticographic (ECoG) recordings in order to optimize anatomo-functional brain mapping, better understand brain dynamics and plasticity, and improve surgical planning, rehabilitation, and the quality of life of patients.
- Muscle models and fatigue exploration
  Muscle fatigue is one of the major limitations in all FES studies. Simply, the muscle torque varies over time even when the same stimulation pattern is applied. As there is also muscle recovery when there is a rest between stimulations, modeling the fatigue is almost an impossible task. Therefore, it is essential to monitor the muscle state and assess the expected muscle response by FES to improve the current FES system in the direction of greater adaptive force/torque control in the presence of muscle fatigue.
- Movement interpretation
  We intend to develop ambulatory solutions to allow ecological observation. We have extensively investigated the possibility of using inertial measurement units (IMUs) within body area networks to observe movement and assess posture and gait variables. We have also proposed extracting gait parameters like stride length and foot-ground clearance for evaluation and diagnosis purposes.

3.2. Movement assistance and/or restoration

The challenges in movement restoration are: (i) improving nerve/muscle stimulation modalities and efficiency and (ii) global management of the function that is being restored in interaction with the rest of the body under voluntary control. For this, both local (muscle) and global (function) controls have to be considered.
Online modulation of ES parameters in the context of lower limb functional assistance requires the availability of information about the ongoing movement. Different levels of complexity can be considered, going from simple open-loop to complex control laws (Figure 2).

Real-time adaptation of the stimulation patterns is an important challenge in most of the clinical applications we consider. The modulation of ES parameters to adapt to the occurrence of muscular fatigue or to environement changes needs for advanced adaptive controllers based on sensory information. A special care in minimizing the number of sensors and their impact on patient motion should be taken.

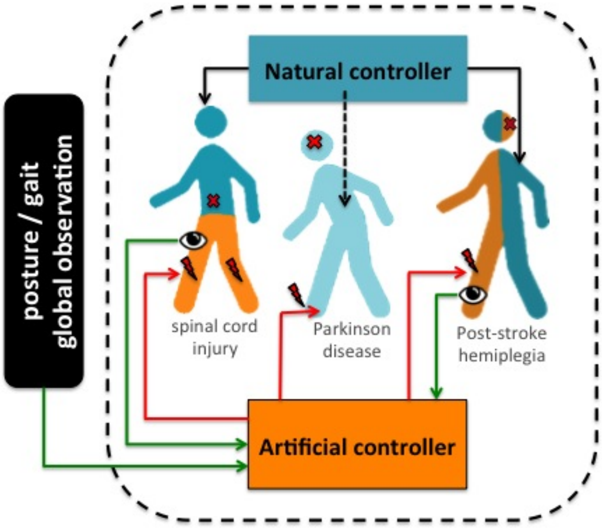

Figure 2. FES assistance should take into account the coexistence of artificial and natural controllers. Artificial controllers should integrate both global (posture/gait) and local (limb/joint) observations.

3.3. On-going clinical protocols

One specificity of CAMIN team is to be involved in Clinical protocols. At the moment we are involved in the following protocols:

- CYCLOSEF: Training spinal cord injured people pedaling a tricycle assisted by electric stimulation of sublesional muscles: case study - Protocol RCB 2019-A00808-49. CRF La Châtaigneraie.
- AGILIS - Functional evaluation of the recovery of prehension in quadriplegics by implanted neural stimulation - Protocol RCB 2019-A02037-50. APHP (Paris)
- E-PREHENSTROKE - Evaluation of optimal piloting modalities and their impact on the grasping capacity in Functional Electrical Stimulation of Finger Extensor Muscles in the Hemiplegic Patient in Chronic Phase - Protocol RCB 2018-A02144-51. CHU Nîmes.
- PBREATHLOOP - Recording tracheal sounds for the purpose of developing a breath control algorithm - Protocol RCB 2019-A01813-54. ADOREPS
- Variability and evolution of the single fiber potentials of a spastic muscle treated with botulinum toxin - Protocol RCB 2019-A01863-52A. CHU Nîmes
- Pilot study: measurement of evoked potentials in electroencephalography and electrocorticography by electrical stimulation of the brain during awake neuro-surgery of low-grade infiltrating gliomas - Protocol RCB 2014-A00056-43. CHU Montpellier

4. Highlights of the Year

4.1. Highlights of the Year

4.1.1. Awards

Student Paper price: X. Lu, D. Guiraud, S. Renaux, T. Similowski, C. Azevedo-Coste, "Monitoring phrenic nerve stimulation-induced breathing via tracheal sounds", the 58th International Spinal Cord Society Annual Scientific Meeting (ISCoS), Nice, France, 2019

Student Paper competition Finalist: L. Fonseca, A. Bo, D. Guiraud, B. Navarro, A. Gelis and C. Azevedo-Coste, "Investigating Upper Limb Movement Classification on Users with Tetraplegia as a Possible Neuroprosthesis Interface," 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Honolulu, USA, 2018, pp. 5053-5056.

5. New Software and Platforms

5.1. RT_Stim

Real-Time simulation for functional electrical Stimulation

KEYWORDS: Real time - Biomechanics - Control - Co-simulation

FUNCTIONAL DESCRIPTION: Hybrid simulation architecture gathering in a single framework and consistent time scales both the numerical integration of the continuous model of a bio-mechanical system (bones, joints and muscles) and a model of the hardware and software control architecture, including control tasks, communication protocols and real-time schedulers. Simulation run in real-time when possible, and otherwise consistent time scales are generated. The framework is intended to seamlessly evolve from purely software models to hardware-in-the-loop simulation.

- Authors: Daniel Simon and Samy Lafnoune
- Contact: Daniel Simon
- URL: https://gforge.inria.fr/projects/rtstim/trunk

5.2. Platforms

5.2.1. Platform : IMUSEF Modular embedded architecture for real time control of a FES system

Participants: Christine Azevedo Coste, Benoît Sijobert, Ronan Le Guillou, Martin Schmoll.

We have been working on the development of a new hardware and software architecture embedding a network of sensors and an electrical stimulator interfaced to a controller. The controller intends to be worn by the experiment participants.
A mini low-cost single board computer (Raspberry Pi3) was embedded in a 3D-printed case strapped around the waist of the subject. Using wireless inertial sensors connected as a WBAN, the sink node gets data from all the IMUs, therefore highly decreasing data flow when multiple IMUs are transmitting inside the network. To get rid of this limitation and guarantee an overall 100 Hz sampling rate no matter the number of IMUs, the wireless inertial sensors can be replaced by wired ones, low-cost with a high speed ARM Cortex-M0 based processor and a Kalman Filter directly providing quaternion estimation at 100 Hz for each IMU. The use of a multiplexer connected through an I2C interface (Inter Integrated Circuit) enabled to keep a 100 Hz rate using 4 IMUs.
The autonomous FES controller is able to acquire and process data, execute control algorithms and send the appropriate command to the stimulator. For safety reasons, in order to access to the FES controller and to enable a remote access to the stimulation from a computer, an ad-hoc Wi-Fi network is automatically provided by the Raspberry on start-up. The ad-hoc network enables to be independent from a network infrastructure where the connection is not always possible (e.g. Wi-Fi network from the hospital).

This scalable architecture (fig. 3), developed as a modular system, allowed us to implement new commands laws for Real Time closed loop control as well as giving us the possibility to use various types of sensors and stimulators to meet the needs of specific applications. To achieve this and in order for the FES architecture to directly control different electrical stimulators, Application Programming Interfaces (APIs) were developed for 3 main commercial stimulators in the team. They each corresponds to a specific need and use case. The Vivaltis Phoenix Stimulator allows for low-weight embedding, wireless network control, but only 2 stimulation channels are available at the moment, while being scalable, it is mainly used for experiments on gait. The BerkelBike Stimulator v2.0 presents a cumbersome but extended control compromise with 8 independent stimulation channels, which is an ideal solution for FES-assisted cycling. And finally the Hasomed Rehastim v1.0 allowing fine control but isn't battery powered in its commercial version, used mainly for upper limb experiments.

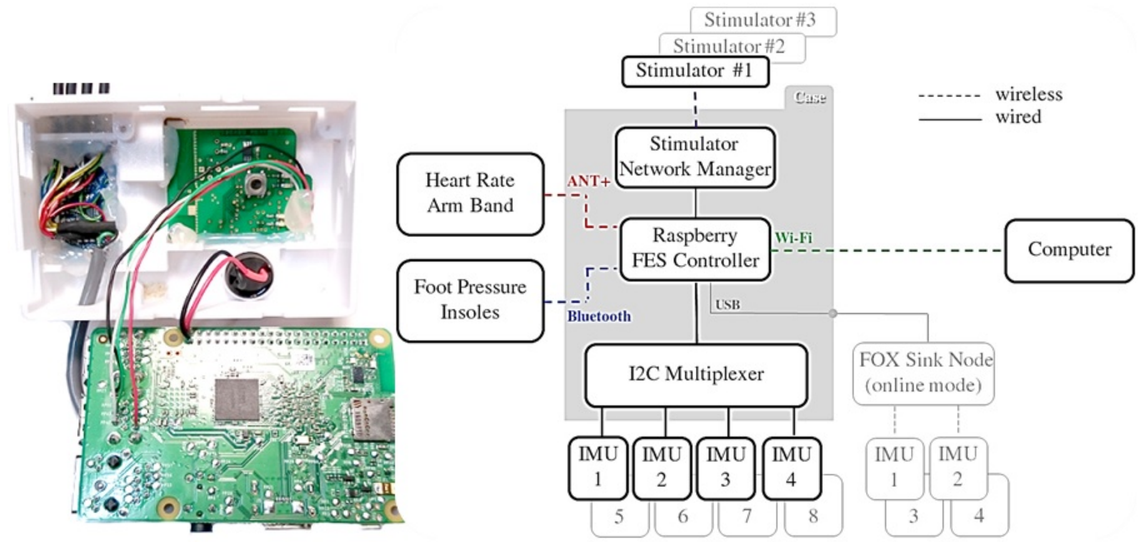

Figure 3. Experimental protocols have led to the development of a scalable hardware architecture decentralized on the subject.

This new architecture is currently used in clinical experiments and will continue to evolve with a goal of being easy to use, even by untrained clinicians (i.e. FES assisted cycling §6.8).

The software APP of this platform can be found at https://bil.inria.fr/fr/software/view/3520/tab as the *IMUSEF Project* with the Bil Id: Software_3520.

5.2.2. Platform : FESCYCLING FES-cycling platforms

Participants: Christine Azevedo Coste, Ronan Le Guillou, Martin Schmoll.

The embedded FES controller (IMUSEF) was reshaped for cycling application to improve modularity, performances and stability, using fully the capabilities of the Raspberry Pi 3B platform. These modifications now allow easier implementation, integration and usage of new control algorithms that could, in the future, be used for various end applications and contexts. Furthermore a Graphical User Interface (GUI) communicating with the embedded platform was developed, allowing on-the-fly modification of various parameters as well as safe control and monitoring of the running algorithms. An add-on relay box module allowing mechanical switching of the stimulating channels for more precise On/Off stimulation synchronization as well as more control and safety measures was also created. The two commercially available recumbent tricycles that we adapted for Spinal Cord Injured FES Cycling can be seen in Figure 4.

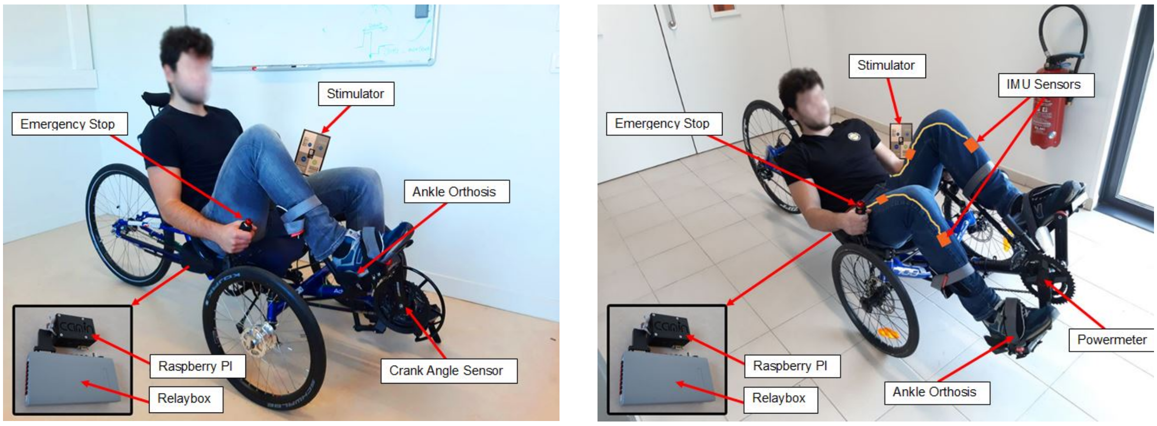

Figure 4. FES Cycling platforms developed in the CAMIN team. a) ICE Trike Adventure 26 setup adapted for Spinal Cord Injured FES Cycling b) CAT Trike 700 setup adapted for Spinal Cord Injured FES Cycling

5.2.3. Platform : MEDITAPARK Wearable Tremor monitoring system based on acceleration monitoring

Participants: Christine Azevedo Coste, Ronan Le Guillou, Marion Holvoet.

As part of a preliminary study on the effects of Mindfulness meditation on participants with Parkinson's Disease (PD) (§3), an application was developed to monitor at home tremor occurrence using a smartwatch Samsung Gear S3 and its newer model, the Samsung Galaxy Watch (Fig:5a). A Python program has been developed to process and format data and present characteristics of the tremor under a user friendly and comprehensible format for clinicians. The goal of this system being to identify Parkinson's tremors characteristics qualitatively and quantitatively to highlight global tendencies and help objectively determine effectiveness of diverse treatments against PD tremors. This system was tested on long duration acquisitions (2 and 4 days) with 2 volunteers subject to PD tremors of moderate and high severity and proved to be able to highlight tremor tendencies and characteristics in real conditions. These acquisitions were done in order to experimentally validate the inner-workings of the developed system in real conditions and its capacity to detect PD tremors of moderate and high severity as well as to refine the classification and processing of the data. An example of 4 days acquisition is presented in Figure 5b.

The created system allows qualification of tremors in punctual clinical check-ups in the Hospital as well as quantitative formatting of daily tendencies. This system should then allow to highlight the evolution of Parkinson's tremors characteristics throughout the MBSR (Mind-fullness Based Stress Reduction) meditation program which is yet to be undertaken. A protocol is still waiting for validation from the CPP to begin inclusions and conduct the MBSR meditation program, monitored with the developed system.

The software APP of this platform can be found at https://bil.inria.fr/fr/software/view/3565/tab as the *PARa-Keet Project* with the Bil Id: Software_3565.

5.2.4. Platform : AGILIS-EX software

Participants: Arthur Hiairrassary, Christine Azevedo Coste, David Guiraud.

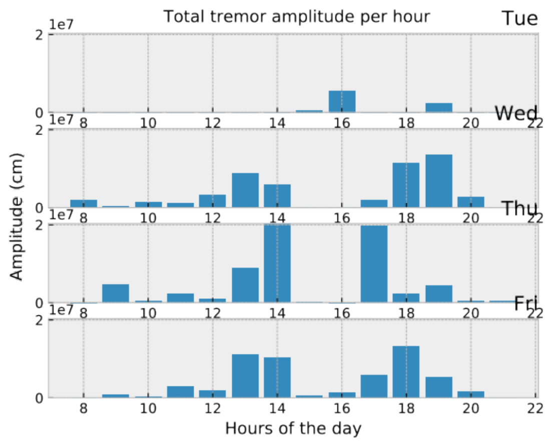

Figure 5. Meditapark figures. a) Smart watch used as the embedded platform for this monitoring application : Samsung Galaxy Watch b) Showcase of experimental data acquired in ecological conditions over 3.5 days presenting a quantitative and objective evaluation of the Parkinson's tremors under a daily format condensed hourly.

The AGILIS-EX software was specially developed as part of the AGILIS project for exploratory clinical trials governed by the ID RCB research protocol: 2019-A02037-50. It allows the configuration and triggering of the stimulation generated by the STIMEP (neural stimulator) or the VIVALTIS (external stimulator) (Fig.6). The stimulation parameters are automatically selected according to predefined configurations (frequency, current and pulse-width) in order to obtain the functional movements of the hand desired by the subject (Fig.7). To detect and interpret patient voluntary movement or contraction to infer the activation or deactivation of the pre-programmed stimulation, it uses measurements from the DELSYS acquisition system (EMG, FSR, trigger).

This medical grade software is compliant with the IEC 62304 (class B).

6. New Results

6.1. Selectivity of implanted neural electrical stimulation

Participants: Lucie William, David Guiraud, Charles Fattal, Christine Azevedo, Arthur Hiairrassary.

In the context of using a multi-contact cuff electrode positioned around a trunk nerve to activate selectively the fascicles leading to selective movements, a pre-clinical study was performed on the sciatic nerve of four rabbits (Lab. Chirurgie Experimentale, Institut de Biologie, University of Montpellier). The purpose was to compare and classify six different currents configuration (current ratios) (Fig.8) with a 12- contact cuff electrode using selectivity, robustness (i.e. ability to maintain selectivity within a range of current amplitudes) and efficiency (i.e. electrical consumption of the considered multipolar configuration *versus* the electrical consumption of the reference whole-ring configuration) indexes.

Results indicated that the optimal configuration depends on the weights applied to selectivity robustness and efficiency criteria. Tripolar transverse is the most robust configuration and the less efficient, whereas tripolar longitudinal ring is efficient but not robust. New configurations issued from a previous theoretical study we carried out such as steering current ring appears as good compromise between the 3 criteria [18].

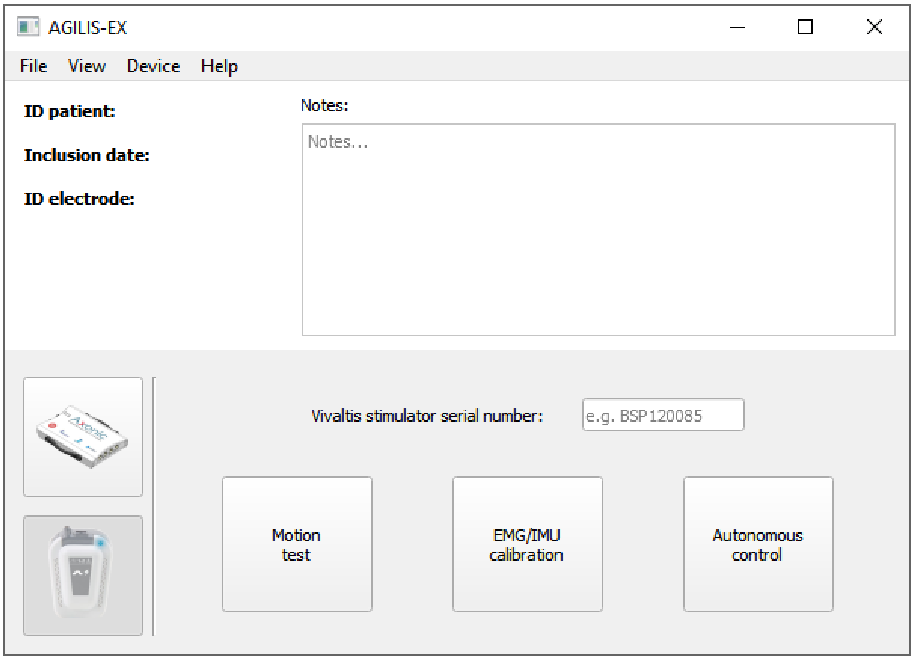

Figure 6. Main window of the AGILIS-EX software.

The PhD of Lucie William (started in October 2019) will be the continuation of this work in the context of neural electrical stimulation of complete quadriplegic human participants (AGILIS project).

6.2. Selective Neural Electrical Stimulation to restores Hand and Forearm Movements in Individuals with Complete Tetraplegia

Participants: David Guiraud, Charles Fattal, Christine Azevedo, Mélissa Dali, Jacques Teissier [Beau Soleil clinic, Montpellier], Anthony Gélys [Propara Rehab. Center, Montpellier].

Selective neural electrical stimulation of radial and median nerves enables the activation of functional movements in the paralyzed hand of individuals with tetraplegia. In eight participants (Clinique Beau Soleil and Propara Rehabilitation Center, Montpellier) with complete tetraplegia, during a programmed surgery and under complete anesthesia, we demonstrated that selective stimulation based on multicontact cuff electrodes and optimized current spreading over the active contacts provided isolated, compound, functional and strong movements. Several configurations were needed to target different areas within the nerve to obtain all the envisioned movements. We further confirmed that the upper limb nerves have muscle specific fascicles, which makes possible to activate isolated movements. The future goal is to provide patients with functional restoration of object grasping and releasing with a minimally invasive solution: only two cuff electrodes above the elbow. This will be the objective of AGILIS project supported by EIT Health.

6.3. Assisted Grasping in Individuals with Tetraplegia: Improving Control through Residual Muscle Contraction and Movement

Participants: Lucas Fonseca [UnB, Brazil], David Guiraud, Charles Fattal, Christine Azevedo, Arthur Hiairrassary, Camilo Silva, Anthony Gélys [Propara Rehab. Center, Montpellier].

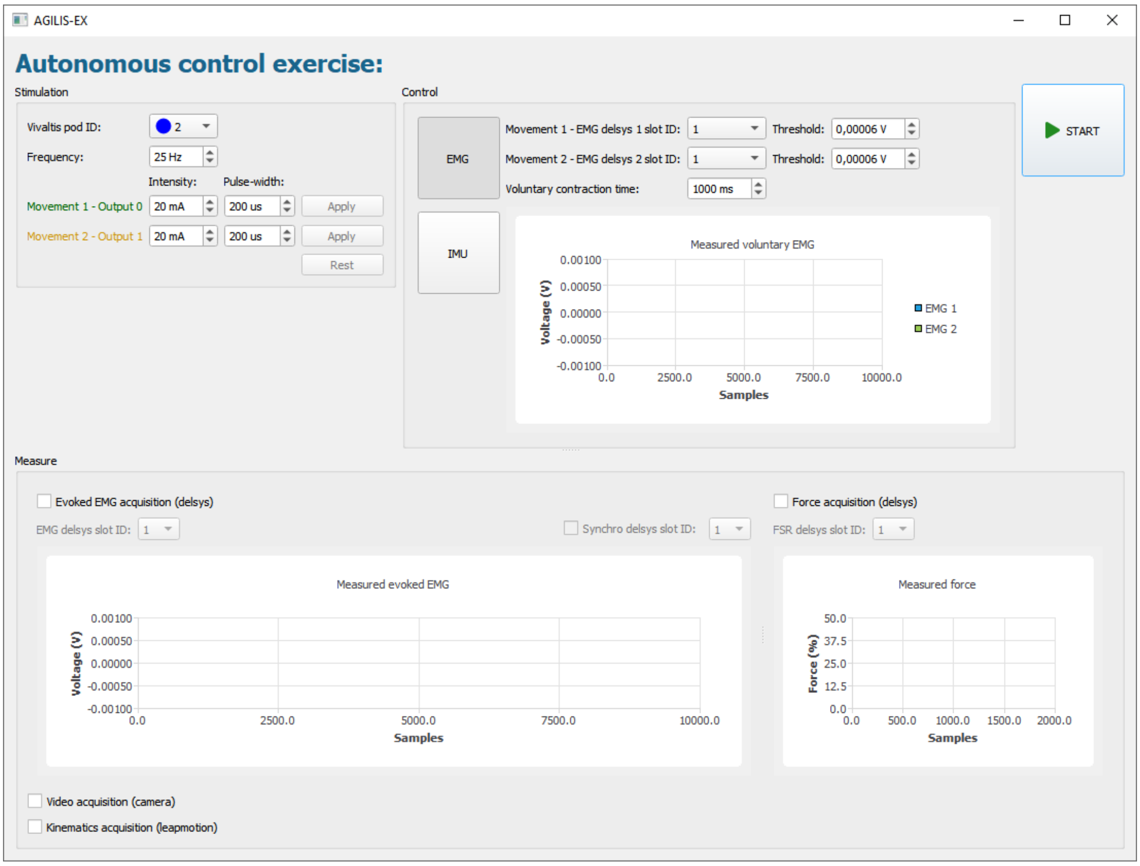

Figure 7. Autonomous control exercise window used for external stimulation

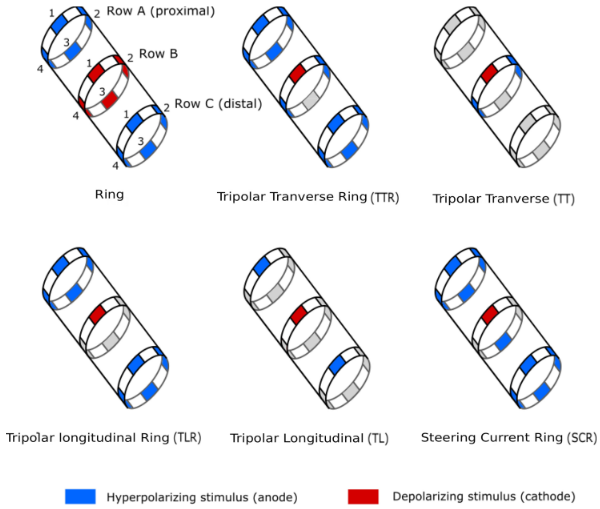

Figure 8. Six different configurations of the 12-contact electrode were tested: Ring, Tripolar Transverse Ring (TTR), Tripolar Transverse (TT), Tripolar Longitudinal Ring (TLR), Tripolar Longitudinal (TL), Steering Current Ring (SCR)

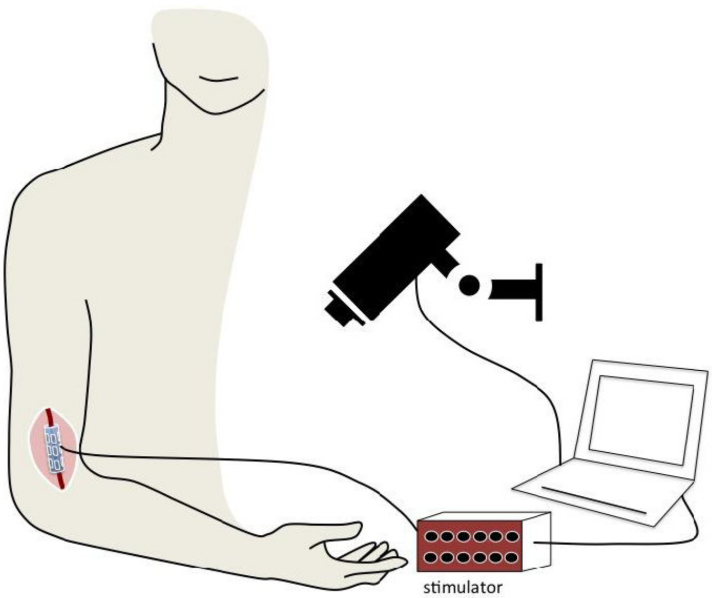

Figure 9. Neural electrical stimulation of radial or median nerve using a multi-contact cuff electrode allows to elicit different individual or grouped muscle contractions inducing different fingers and wrist movements.

Individuals who sustained a spinal cord injury often lose important motor skills, and cannot perform basic daily living activities. Several assistive technologies, including robotic assistance and functional electrical stimulation, have been developed to restore lost functions. However, designing reliable interfaces to control assistive devices for individuals with C4–C8 complete tetraplegia remains challenging. Although with limited grasping ability, they can often control upper arm movements via residual muscle contraction. We have explored the feasibility of drawing upon these residual functions to pilot two devices, a robotic hand and an electrical stimulator. We studied two modalities, supra-lesional electromyography (EMG), and upper arm inertial sensors (IMU). We interpreted the muscle activity or arm movements of subjects with tetraplegia attempting to control the opening/closing of a robotic hand, and the extension/flexion of their own contralateral hand muscles activated by electrical stimulation. Two groups of participants with quadriplegia were recruited (Clinique Propara, Montpellier): eight subjects issued EMG-based commands; nine other subjects issued IMU-based commands. For each participant, we selected at least two muscles or gestures detectable by our algorithms. Despite little training, all participants could control the robot's gestures or electrical stimulation of their own arm via muscle contraction or limb motion [20].

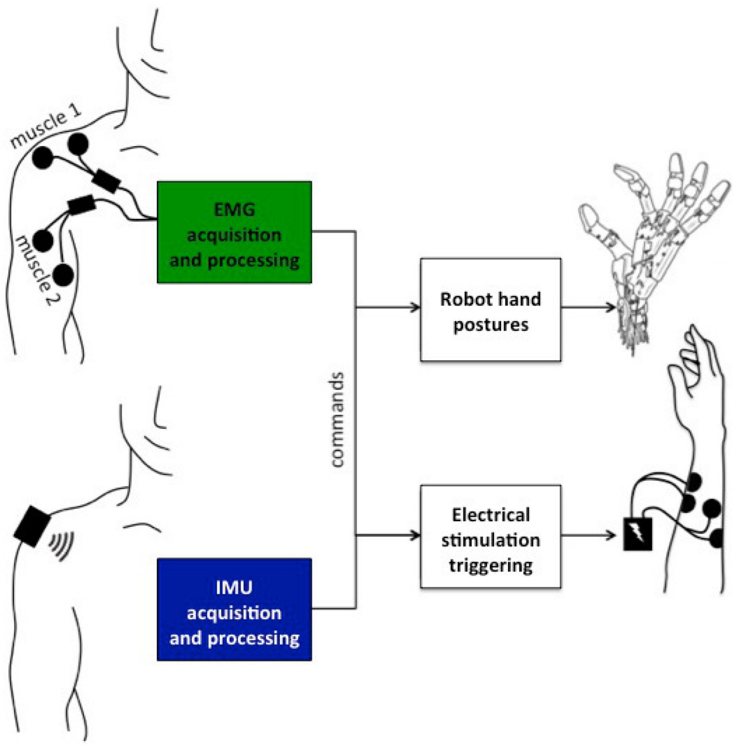

Figure 10. Protocol principle. EMG or IMU signals are converted into commands for the robotic hand or the electrical stimulator. The robotic hand has three possible gestures: at-rest, open and close. The electrical stimulator can receive three commands: no stimulation, stimulate channel 1 (wrist flexion) or stimulate channel 2 (wrist extension). Users are able to observe the outcome of their input and use it as biofeedback.

In the AGILIS project supported by EIT Health, we intend to extend this approach to participants with 2 implanted electrodes on median and radial nerves participating in a 30-days clinical study (APHP, Paris and Clinique La Châtaigneraie, Menucourt).

We are currently working on the software that is responsible for acquiring sensor data and controlling the stimulator (§5.2.4). The previous algorithms are being implemented in a single platform focusing on the 30-days clinical study. The residual motion based system was improved based on the results published in [20]. It is also faster and more efficient. The inertial sensors now have higher frequency, which leads to higher accuracy of movement classification, particularly with faster movements.

6.4. Modeling and simulation of a human hand

Participants: Daniel Simon, Ahmed Farek.

The AGILIS stimulation system is intended to generate grasping action on some objects such as balls and cans. A high-fidelity hand model and associated simulation software was developed to anticipate real experiments and help for the system identification and tuning [30]. The hand model uses 23 degrees of freedom for the wrist and fingers. 28 muscles are considered, including the 12 muscles which are expected to be activated using electrical stimulation of the median and radial nerves. Others are also considered in the model as, even if not stimulated, they contribute to the hand and fingers movements through passive forces when extended. Several actuation models are investigated to allow for the identification of muscles-to-movements relations.

The active forces provided by the stimulated muscles are computed thanks to the original model developed over the past years by the team, where the inputs are currents injected to muscles or nerves. The fingers are assumed to interact with the grasped object through elastic contacts and limited friction.

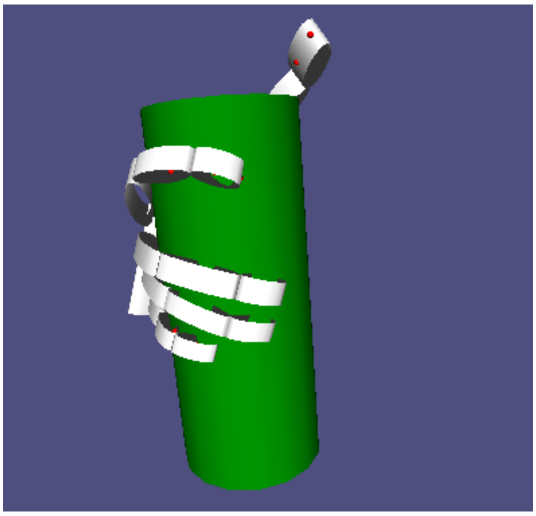

Figure 11. Simulation of a stimulated hand grasping a can

6.5. Functional impact of a self-triggered grasping neuroprosthesis in post-stroke subjects

Participants: David Gasq, Christine Azevedo, Ronan Le Guillou, Jérôme Froger [CHU Nîmes, France].

The improvement of the grasp abilities remains a challenge in the 50% of post-stroke subjects who have not recovered functional grasping due to paralysis of the finger's extensor muscles. The ePrehension-Stroke is a prospective, bicentric (promoted by the CHU de Nîmes), multi-crossover, blinded evaluation study which assesses the functional impact of a self-triggered grasping neuroprosthesis. We have developed a specific software, NeuroPrehens, which controls external electrical stimulations applied over finger's extensor muscles and was triggered by voluntary head movements or electromyography activity of leg muscles. The main objective is to assess the impact of the self-triggered grasping neuroprosthesis on the ability to perform a standardized task of grasping, moving and releasing either a glass (palmar grasp) or a spoon (key pinch), compared to the absence of neuroprosthesis use. Secondary objectives are to assess (1) the preferential modes of neuroprosthesis control, (2) the impact of the neuroprosthesis on a standardized unimanual grip scale (Action Arm Research Test), (3) the psycho-social impacts (Psychosocial Impact of Assistive Devices Scale questionnaire) and the subject's satisfaction and tolerance (Quebec User Assessment of Satisfaction with Assistive Technology questionnaire) related to neuroprosthesis use. Over 20 subjects planned to include until June 2020, we have included 8 subjects since July 2019. The prospects of this pilot study are to develop a fully wearable and self-piloted neuroprosthesis that can be used in daily life by the largest number of post-stroke subjects who have not recovered active grasping abilities.

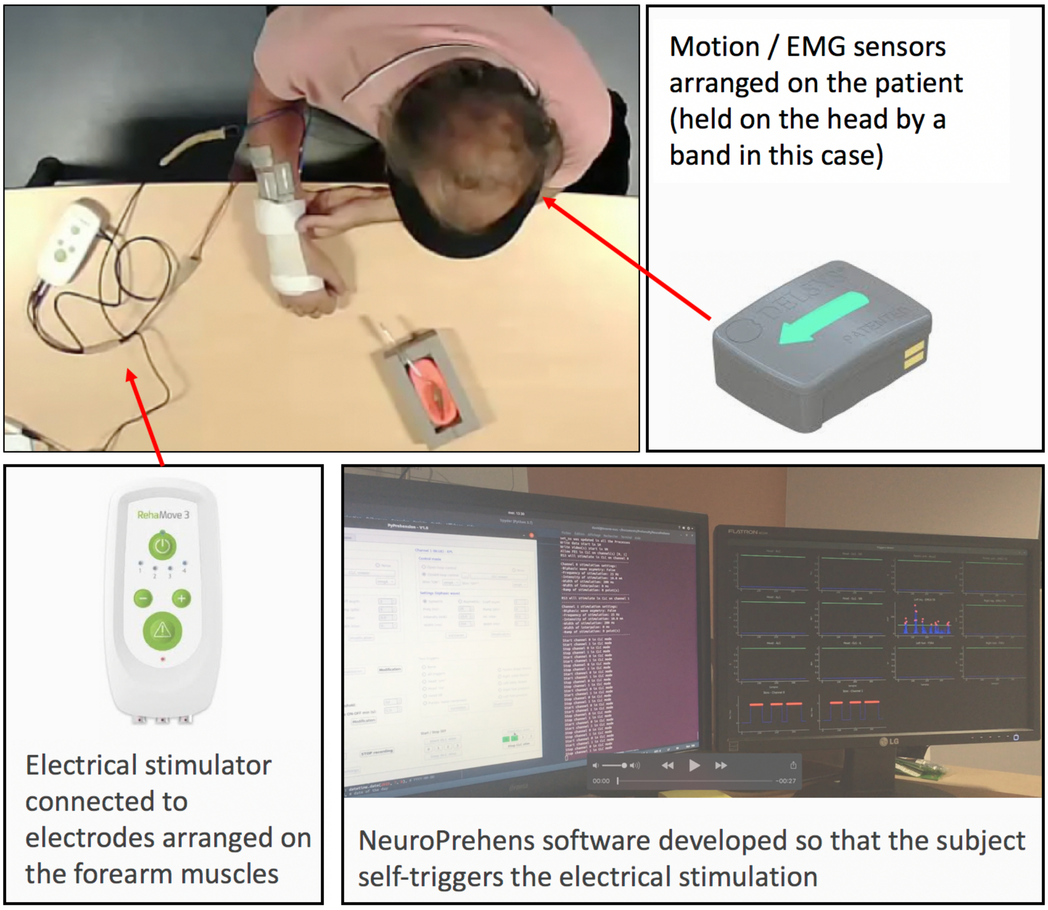

Figure 12. Experimental device constituting the self-triggered grasping neuroprosthesis.

6.6. Near-infrared spectroscopy time course under hypercapnia

Participants: Victor Vagné, David Guiraud, Vincent Costalat [CHU Montpellier], Emmanuelle Le-Bars, Stephane Perrey.

Partial arterial pressure of carbon dioxide (CO2) modulates cerebral blood flow through vasoreactivity mechanism. Near infrared spectroscopy (NIRS) can be used to record these changes in cerebral hemodynamics. However, no laterality comparison of the NIRS signal has been performed despite being a prerequisite for the use of such method in a vasoreactivity monitoring context. We propose to investigate laterality of NIRS signal in response to a CO2-inhalation-based hypercapnia paradigm in healthy volunteers.

Methods: Eleven healthy volunteers (6 women, 5 men, mean age: 31 ± 11) underwent a 3-block-design inhalation paradigm: normoxia (5min, “baseline”) – hypercapnia (2min, “stimulation”) – normoxia (5min, “post-stimulation”). NIRS signal was measured using a two-channel oximeter (INVOS 5100C, Medtronic, USA) with sensors placed symmetrically on both the left and right sides on each subject’s forehead. Additional heart rate (HR) monitoring was performed simultaneously. Based on the NIRS mean signal pattern, an a priori model of parametric identification was applied for each channel to quantify parameters of interest (amplitude, time delay, excitation and relaxation time) for each inhalation block.

Results: HR increased significantly during the stimulation block. The quality of the model was satisfactory: mean absolute error between modeled and experimental signals were lower than the resolution of the device. No significant lateralization were found between left and right values of most of the parameters.

Conclusion: Due to the lack of lateralization, this parametric identification of NIRS responses to hypercapnia could bring light to a potential asymmetry and be used as a biomarker in patients with cerebrovascular diseases.

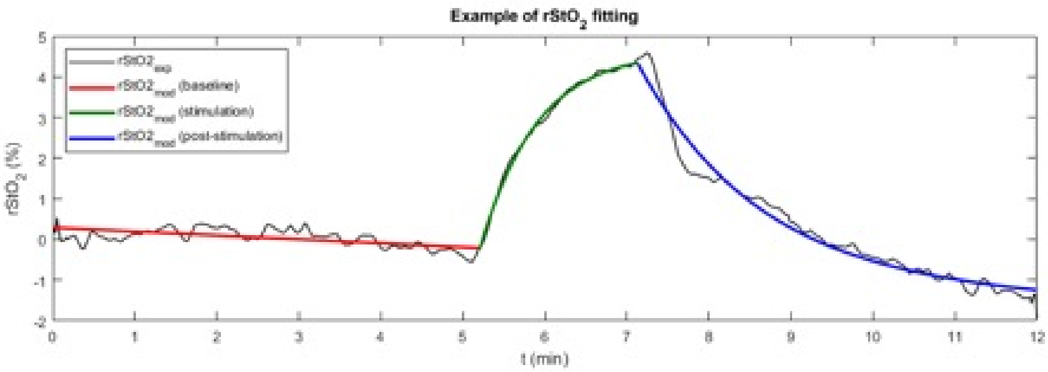

Figure 13. Example of curve fitting on NIRS signal with a compartmental first order model in response to a 2-min hypercapnic stimulus.

6.7. EPIONE

Participants: David Andreu, David Guiraud, Arthur Hiairrassary.

The project was completed in 2017 but major publications were issued in 2018 and 2019 reporting the most important results of both stimulation of the upper and lower limbs in amputees to restore sensations using 4 TIME electrodes. We developed original algorithms that convert signals acquired from sensors of the artificial lower limb, namely the prosthetic limb, into stimulus to the afferent branches of the sciatic nerve. This pioneering work shows that not only the gait performances were greatly enhanced but also the phantom pain relief was effective with a long lasting after stopping the therapy [22] [21]. These results follows the previous ones pbtained on the upper limb with similar results [23].

6.8. FES-assisted cycling

Participants: Benoît Sijobert, Ronan Le Guillou, Charles Fattal, Christine Azevedo, Martin Schmoll, Emerson Fachin-Martins [UnB, Brazil], Henrique Resende [UFMG, Brazil], David Lobato [UnB, Brazil].

Our team is working for several years on FES-assisted cycling for individuals with spinal cord injury. We intend to improve cycling accessibility to a larger population in order to propose exercising and leisure activity to improve quality of life and self esteem. On this context we have been working on three aspects this year: 1) improving training to be able to propose patients in rehabilitation centers a simplified and acceptable protocol to prepare muscles to cycling, 2) improving usability in a rehabilitation context to ease and simplify the access to FES-cycling, 3) better understanding fatigue phenomena to improve cycling performances.
A funding (EDF Foundation) has been obtained by our clinical partner "CRF La Châtaigneraie" to perform a clinical protocol to follow up the physical preparation of individuals with spinal cord injury to manage overground active pedaling after 4 months of 3 sessions per week training at home. The protocol has been approved by an ethical committee (§3.3). One of the participants will be involved in Cybathlon 2020 event. The inclusions began in September 2019. A longitudinal follow-up will allow to precisely assess the performances progress along the training period. After the 4-months at home training the participants will be using the overground cycling platform that has been developed by our team (§5.2.2).

Figure 14. Muscular preparation for overground cycling training. Left: Participant executing strengthening program with conventional multichannel stimulator (CEFAR); Right: Participant performing endurance training on FES-ergocycle.

It has been shown that FES-cycling of subjects with Spinal Cord Injuries (SCI) results in physiological and psychological positive effects such as cardiovascular training, decrease in pressure sores occurrence and self-esteem improvements. However, the use of this technology has often remained restricted to indoor and stationary ergometers in clinical contexts, partly due to the small amount (10–25 W) of power produced and the requirement of experimented users to finely tuned the stimulation patterns needed to stimulate lower limb muscles with an adequate modality. Our latest study on this subject introduces a novel approach of a Functional Electrical Stimulation (FES) controller intended for FES-induced cycling based on inertial measurement units (IMUs). This study aimed at simplifying the design of electrical stimulation timing patterns while providing a method adapted to different users and devices. In most of the different studies and commercial devices, the crank angle is used as an input to trigger stimulation onset. We propose to use instead thigh inclination as the reference information to build stimulation timing patterns. The tilting angles of both thighs are estimated from one inertial sensor located above each of the knees. An IF-THEN rules algorithm detects online and automatically the thigh peak angles in order to start and stop the stimulation of quadriceps muscles depending on these events. One participant with complete paraplegia was included and was able to propel a recumbent trike using the proposed approach after a very short setting time. This new modality opens the way to a simpler and user-friendly method to automatically design FES-induced cycling stimulation patterns, adapted to a clinical use, to multiple bike geometries and user morphologies. Using the online peak knee flexion algorithm developed in the study presented in last years section 6.2 to continuously detect this event, we validated a novel approach in order to trigger the quadriceps stimulation at the beginning of the pushing phase. These results can be seen in Figure 15. Enabling this method to take into account a possible sliding in seat position without requiring an accurate placement of the IMUs or a geometrical model of the individual [24].

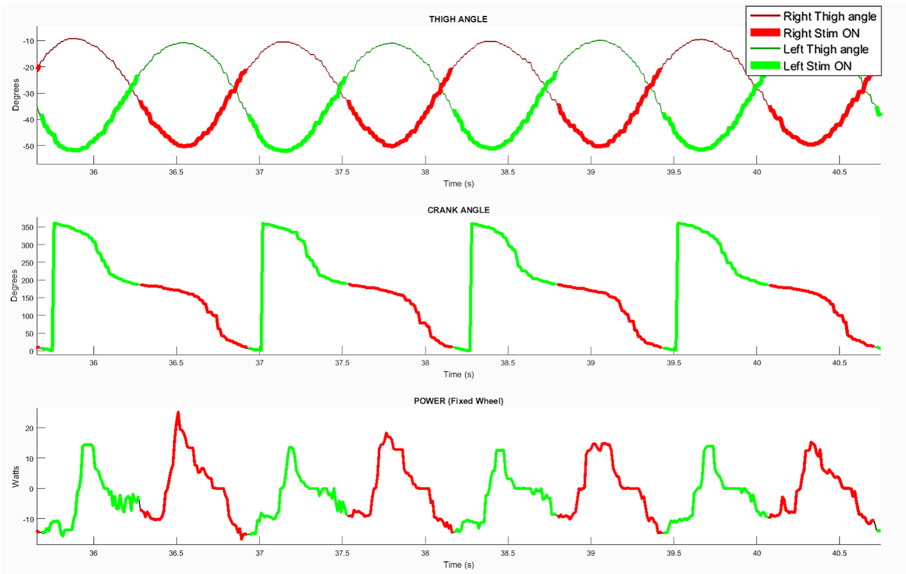

Figure 15. Data sample illustrating the results over four pedalling cycles in home trainer condition. TOP: Left (green) and right (red) thigh tilting angles - MIDDLE: crank angle - BOTTOM: developed power. The two stimulation channels activation are highlighted.

Another important aspect concerning FES-cycling is the pilots ability to resist fatigue for a prolonged time. Muscular activation as a result of electrical nerve stimulation is known to introduce a rather quick onset of fatigue. Therefore different approaches have been tested in literature to reduce the effective stimulation frequency received by individual motor-units. Several studies were able to show improvements using distributed multichannel stimulation against conventional single channel stimulation. A direct comparison between the different techniques is difficult as all studies use different methods of quantifying muscular fatigue. Further most studies fail to mention measured absolute values during a contraction at maximum strength. Therefore our team was designing a new testing protocol in collaboration with the University of Brasilia (CACAO Associate team) with the aim to assess muscular fatigue of currently published and new electrode positions against

Figure 16. Overground cycling. The participant was able to propel the recumbent trike over a 40 meter corridor.

conventional single channel stimulation (baseline) in a more practical setting. The fatigue testing protocol was tailored to mimic 10 min FES-cycling at 50 RPM using an isokinetic dynamometer (Biodex System 4). Assuming a torque-production of 40 percent of the maximal torque-production-capacity of a well-trained quadriceps muscle to be sufficient for FES-cycling. The active torque produced at this starting level was measured in a series of contractions, tracking the decline of torque. The study was conducted in Brasilia on 3 individuals expressing a complete spinal cord injury. All participants were enrolled in a FES-training program for about 14months. All participants were highly motivated and fulfilled the demanded inclusion criteria ensuring a safe execution of the protocol. For every subject both legs were measured individually leading to an overall sample size of n=6. Currently the data-analysis is still in progress. The results of this study should lead to optimized stimulation techniques to prolong the onset of fatigue during FES-cycling.

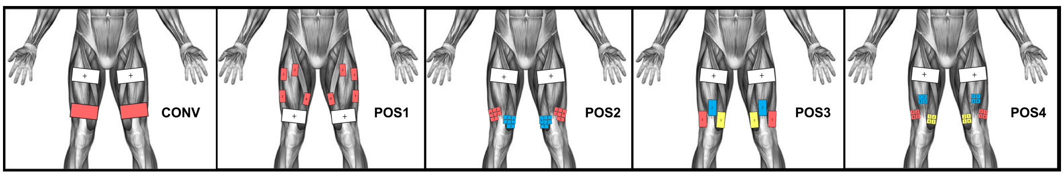

Figure 17. Electrode configurations examined. Electrodes marked with "+" were the Anodes (reference electrodes). CONV: Standard electrode configuration 40 Hz delivered to one pair of electrodes; POS1: One channel with 40 Hz distributed over 4 electrodes – common anode; POS2: Two channels with each 40 Hz distributed via 4 electrodes – common anode; POS3: Three channels of 40 Hz each delivered to one electrode – common anode: POS4: Three channels with each 40 Hz distributed via 4 electrodes – common anode

6.9. Breathing detection via tracheal sounds

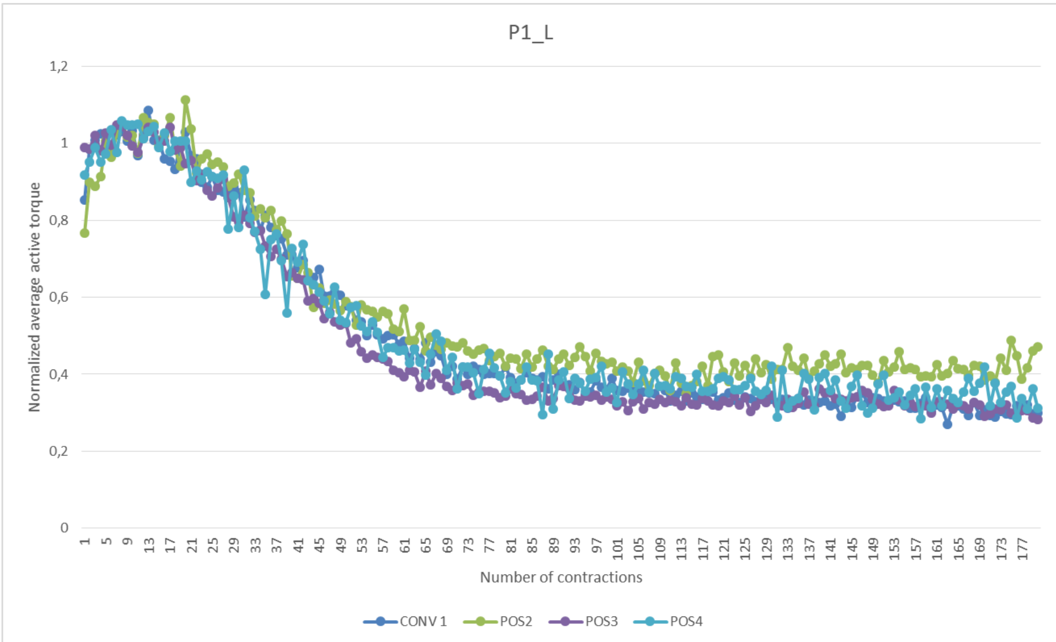

Figure 18. Preliminary data retrieved of the left leg of patient 1. The average active torque of the first 20 contractions was used to normalize fatigue curves. POS1 was excluded from the figure due to exaggerated fluctuations in torque.

Participants: Xinyue Lu, David Guiraud, Christine Azevedo, Serge Renaux [Neuroresp], Thomas Similowski [Hosp. LA Salpêtrière, Paris].

Individuals with a respiratory paralysis are essentially supplied by mechanical ventilation. However, severe drawbacks of mechanical ventilation were reported: low autonomy, high health costs, infection risk, etc. If patients' phrenic nerves and diaphragms are still functional, implanted diaphragm pacing can provide them a more natural respiration. Compared to classic mechanical ventilation, implanted diaphragm pacing can cancel some of the disadvantages mentioned above, and can also help to significantly improve speech and recover some olfactory sensation.

But existing implanted diaphragm pacing systems can not monitor patient's induced respiration and they stimulate at constant intensity and frequency - they work in open-loop. It means that stimulation intensity, pulse width and frequency are fixed at the installation of the implant, updated at each control visit, but do not adapt to patient's continuous situation evolution because of the absence of respiratory monitoring. To close the loop, an ambulatory respiratory monitoring solution needs to be developed. Adding adaptive abilities to existing systems would improve the efficiency of the delivered stimulation.

The gold standard for apnea/hypoventilation evaluation is the polygraph, which includes an pulse oximeter and at least one respiratory flow sensor. In a clinical use, flow sensors could be nasal cannula, pneumotachograph, thermistor or plethysmograph. But these sensors need to be placed over the face or are sensitive to patient's movements. They are therefore not compatible with an implanted diaphragm pacing system which is portable and for a daily living use. With this in mind, this study investigated an acoustic method. The proposed tracheal sounds recording requires only one tiny microphone fixed on the neck with a support, which is the only physical contact with the patient.

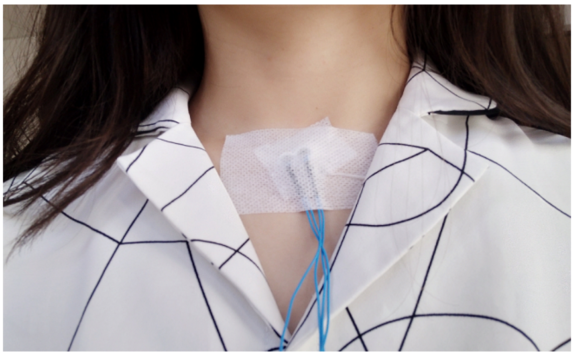

Figure 19. The position of microphone to record tracheal sounds.

Many previous studies have shown some positive results on respiration analysis from tracheal sounds in sleep apnea, especially for obstructive sleep apnea. But only few methods are developed for real-time applications (processing delay within seconds) with robustness requirements, indeed, all these studies have been carried out in quiet and controlled acoustic environments with stable sources of noises, and with limited movements of the subjects (during sleep).

In collaboration with NEURORESP company and La Salpêtrière Gospital (Paris) we are investigating the possibility to perform a real-time and continuous breathing detection (day and night), even during wakefulness in noisy environments. We proposed thea method with tracheal sounds recorded on the neck at suprasternal notch (Fig.19). This method is noninvasive and easy to apply. And the recorded tracheal sounds contain not only respiratory sounds, but also heart beats sounds (as phonocardiogram: PCG) so that some basic cardiac information, as cardiac rhythm, could be calculated. Furthermore, inspired by ECG-derived respiration, the similar method could also be applied on obtained PCG to get respiratory information.

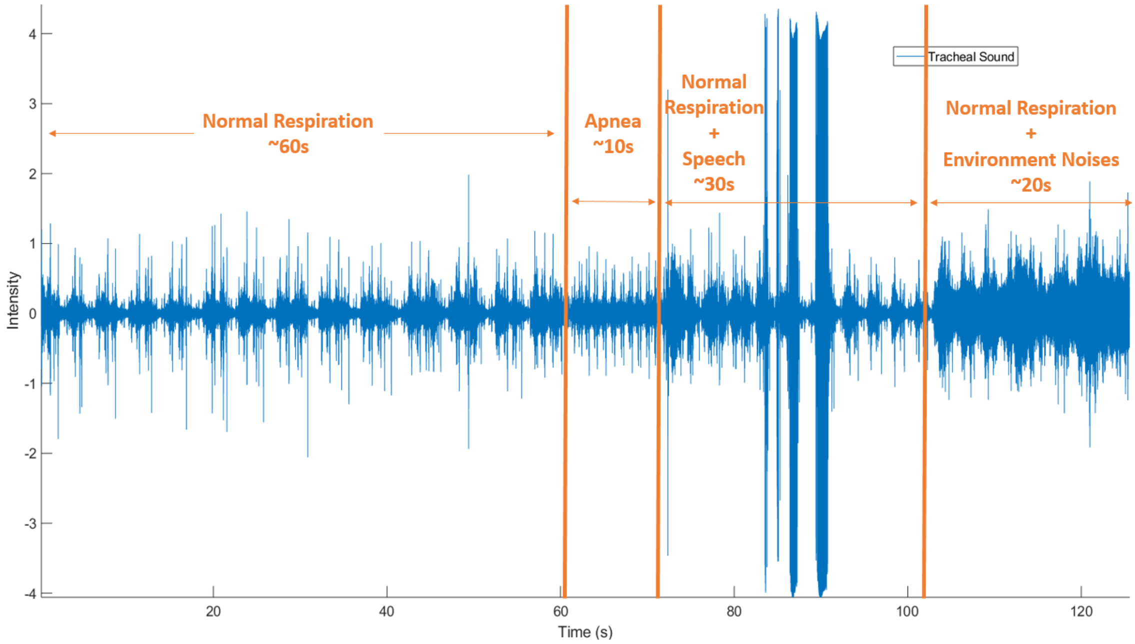

Figure 20. One example of a 2-min recording of tracheal sounds.

The proposed method has been tested on 30 recordings from 15 healthy subjects with different respiratory condition, one example is shown in Fig.20. We proposed a new algorithm to detect respiration phases, by combining the signal processing both in the temporal (envelope and PCG-derived respiration) and the frequency domains. We assessed the performances of the algorithm in emulated noisy environments. The accuracy, sensibility and specificity of system are all superior to 90%. The result is good enough to show a proof of such a conception. Furthermore, a tracheal sounds recording from a patient under implanted phrenic nerve stimulation has shown that the recording system has the possibility to capt an image of stimulation impulse from the wireless transmission. Getting the synchronization with respiratory sounds and stimulation signals can help to verify and even to adjust patient's stimulation parameters.

6.10. Attenuation and Delay of Remote Potentials Evoked by Direct Electrical Stimulation During Brain Surgery

Participants: Anthony Boyer, Hugues Duffau [CHU Montpellier], Emmanuel Mandonnet [CHU Lariboisière], Marion Vincent, Sofiane Ramdani [LIRMM], David Guiraud, François Bonnetblanc.

Direct electrical stimulation (DES) is used to perform functional brain mapping during awake surgery but its electrophysiological effects remain by far unknown. DES may be coupled with the measurement of evoked potentials (EPs) to study the conductive and integrative properties of activated neural ensembles and probe the spatiotemporal dynamics of short- and long-range networks. We recorded ECoG signals on two patients undergoing awake brain surgery and measured EPs on functional sites after cortical stimulations, using combinations of stimulation parameters. EPs were similar in shape but delayed in time and attenuated in amplitude when elicited from a different gyrus or remotely from the recording site. We were able to trigger remote EPs using low stimulation intensities. We propose different activation and electrophysiological propagation mechanisms following DES based on activated neural elements [15].

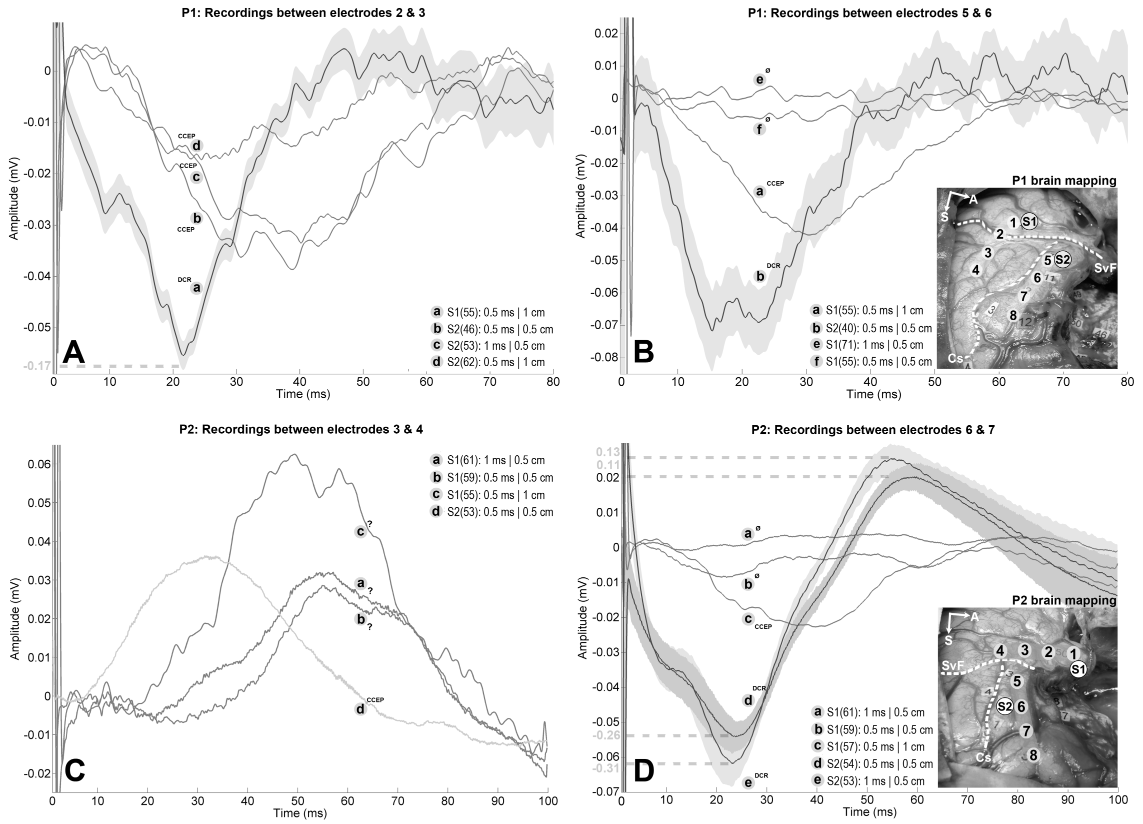

Figure 21. P1 and P2 brain mappings: Pictures illustrating the stimulation sites (S1, S2) and ECoG positioning with respect to the initial 60 Hz cortical brain mapping (numbered paper tags).

Electrodes of both ECoG strips are numbered from 1 to 4 and from 5 to 8. The Sylvian fissure and central sulcus are highlighted by a white dashed lines and annoted "SyF" and "Cs" respectively. For P1, experimental DES was applied on: (1) the Wernicke's area (S1), associated with complete anomia; (2) the ventral premotor cortex (S2), which led to movement and counting interruptions. Strip 1 spans over both temporal and parietal lobe with: electrode 1 over the most posterior part of the superior temporal gyrus; electrode 2 over the Sylvian fissure; electrodes 3 and 4 over the adjacent supramarginal gyrus. Strip 2 spans over the precentral gyrus with: electrodes 5 to 7 over the ventral premotor cortex; electrode 8 is bordering with the most posterior part of the partially resected dorsolateral prefrontal cortex. For P2, experimental DES was applied on: (1) the middle part of the superior temporal gyrus (S1) which led to complete anomia; (2) the precentral gyrus (S2), which induced articulatory disorders. Strip 1 spans over the superior temporal gyrus with: electrodes 1 and 2 over its middle third; electrodes 3 and 4 over its most posterior part. Strip 2 spans over the precentral and dorsolateral prefrontal gyri with: electrodes 5 and 6 over the ventral premotor cortex; electrodes 7 and 8 are respectively bordering and within the adjacent dorsolateral prefrontal cortex. Tumor was about 164 cm3 for P1 and 150 cm3 for P2. The number of averaged stimuli is reported within parentheses for each trace. 99% confidence interval estimated for DCRs are represented by grey surfaces to demonstrate that CCEPs do not belong to them. Additional traces corresponding to variations of stimulation parameters were added if available, regardless of the presence of EPs. A: Differential recordings between electrodes 2 and 3 for P1 while stimulating S1 (-170 μV, 21 ms delay) and S2 (amplitudes ranging from -40 μV to -17 μV, delays ranging from 25 ms to 38 ms). EPs following S2 stimulation are CCEPs because of the presence of the central fissure between the stimulation and recording sites. The EP measured after stimulating S1 is ambiguous because electrode 2 lies on the Sylvian fissure, but the short latency and enhanced amplitude with regard to the CCEPs suggest a DCR. Note the dashed line indicating a different amplitude scale for the DCR, which was reduced by a factor 3 for visualization purposes. B: Differential recordings between electrodes 5 and 6 for P1 while stimulating S2 (-75 μV, 20 ms delay) and S1 (-44 μV, 30 ms delay). EP following S1 stimulation is a CCEP because of the presence of the Sylvian fissure between the stimulation and recording sites. EP following S2 stimulation should be viewed as DCR as it was recorded on the same gyrus and it showed shorter latency and enhanced amplitude in comparison with the CCEP. C: Differential recordings between electrodes 3 and 4 for P2 while stimulating S1 (amplitudes ranging from +29 μV to +62 μV, delays ranging from 52 ms to 62 ms) and S2 (+36 μV, 32 ms delay). EP following S2 stimulation is a CCEP because of the presence of the Sylvian fissure between the stimulation and recording sites. EPs following S1 stimulations should be viewed as DCRs as they are recorded on the same gyrus but the latencies and amplitudes appeared unusual. EPs are positive because of differential measure. D: Differential recordings between electrodes 6 and 7 for P2 while stimulating S2 (amplitudes ranging from -260 μV to -310 μV, 20 ms delay) and S1 (-24 μV, 38 ms delay). EP following S1 stimulation is a CCEP because of the presence of the Sylvian fissure and the operative cavity between the stimulation and recording sites. EPs following S2 are likely DCRs as they are recorded on the same gyrus, which is corroborated by their short latencies and maximized amplitudes with regard to the CCEP. Note the dashed lines indicating different amplitude scales for the DCRs, which were reduced by a factor 5 for visualization purposes.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

NEURINNOV startup finances half of the PhD thesis salary of Lucie William.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- Occitanie Region finances half of the PhD thesis salary of Lucie William.
- Occitanie Region gave a grant to CAMIN for the PhD thesis of XinYue Lu (PILE-CIFRE) - 10.000 euros.

8.2. National Initiatives

- Inria ADT STIMBIO

  Participants : Christine Azevedo, Daniel Simon, Ronan Le Guillou, Benoît Sijobert.

  A 1-year engineer (R. LeGuillou) was funded by Inria ADT on the development of an architecture dedicated to FES-cycling platform.
- I-SITE MUSE COMPANIES AND CAMPUS grant - SPINSTIM project

  Collaboration with academic local partners (CHU, IES) and NEURINNOV company on the spinal stimulation for bladder and bowel functions restoration. This is linked to an ongoing collaboration with Oslo University (Norway).
- LABEX NUMEV - MEDITAPARK project Collaboration with Montpellier Hospital (Neurology service) and the Montpellier Mindfulness Center to analyze the impact of meditation on upper limb tremor.

- EDF Foundation - CYCLOSEF project

  Collaboration with La Châtaigneraie Hospital on FES-assisted cycling. Financial support for a study on FES-cycling training method and performance otimization on individuals with complete spinal cord injury.
- I-SITE MUSE - EXPLORE

  Support for the visit of Henrique Resende (UFMG, Brazil) and Emersion Fachin (UNB, Brazil) as guest researchers from December to February 2019. Completed with a LIRMM laboratory financial aid.
- I-SITE MUSE - EXPLORE

  Support for the visit of François Bonnetblanc at the Karolinska institute Hospital, Neurosurgery and Neurology Department
- ANR Grasp-It (2019-2023) - Leader LORIA, Nancy.

8.3. European Initiatives

8.3.1. Collaborations with Major European Organizations

CAMIN team is leader of a EIT Health project "AGILIS" on Grasping rehabilitation in individuals with quadriplegia (http://www.lirmm.fr/camin/agilis-project/).

8.4. International Initiatives

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

8.4.1.1. CACAO

Title: Lower limb electrical stimulation for function restoration

International Partner (Institution - Laboratory - Researcher):

UNB (Brazil) Physiology Faculty - FACHIN-MARTINS Emerson

Start year: 2019

See also: https://team.inria.fr/cacao/

The CACAO team has developed an expertise in the application of electrical stimulation for assisting seat-to-seat transfers and pedaling for people with paraplegia. The team shared a unique experience in 2016 by participating in the first Cybathlon techno-sports games with a Brazilian driver and a French driver in the assisted bicycle race. The team wishes to continue the work by optimizing the quality of pedaling to participate in the Cybathlon 2020 and extending the technique for the rehabilitation of patients with hemiplegia in a rehabilitation context.

8.4.1.2. Informal International Partners

We have an ongoing informal collaboration with Andrew Murray (DIMLAB, Dayton University) on the design of complex mechanisms in the context of cycling (trike design) and grasping (orthosis design).

8.5. International Research Visitors

Henrique Resende (UFMG, Brazil) and Emerson Fachin (UNB, Brazil) spent 3 months in CAMIN team from December 2018 to February 2019 to work on FES-cycling project (I-SITE MUSE Explore program and LIRMM support).

8.5.1. Internships

Camilo Silva is achieving a 6-months ERASMUS internship in the team on motion recognition using Deep Learning techniques.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

Christine Azevedo, Jessica Rose (Univ. Stanford, USA), Kelly Greves (Cincinnati Children's Hospital Medical Center, USA) organized an Instructional course during the EACD Conference (May, 23rd, 2019) in Paris : "Multichannel Neuromuscular Stimulation: NMES-assisted gait for children with cerebral palsy".

9.1.1.1. Member of the Conference Program Committees

- Daniel Simon is member of the ICINCO conference program committee

9.1.1.2. Reviewer

- Daniel Simon was reviewer for the RTNS, IEEE SYSTOL and IFAC ICINCO conferences
- Christine Azevedo was reviewer for IEEE EMBC, IROS, IFESS conferences

9.1.2. Journal

9.1.2.1. Member of the Editorial Boards

- David Guiraud is member of the Editorial Board of Journal of Neural Engineering (JNE) and Medical and Biological Engineering and Computing (MBEC).
- David Guiraud is Associate Editor of Theme 6 (Neurorahabilitation) at IEEE EMBC conference.
- Christine Azevedo is member of the Editorial Board of Neuroprosthetics as Review Editor for Frontiers in Neurology and Frontiers in Neuroscience
- Christine Azevedo is member if ERCIM News' Editorial Board as Inria representant.

9.1.2.2. Reviewer - Reviewing Activities

- Daniel Simon was reviewer for Simulation: Transactions of the Society for Modeling and Simulation International.

9.1.3. Invited Talks

- Daniel Simon gave a talk on "Feedback schedulers in practice A video decoder example" at the 40th International Summer School of Automatic Control Grenoble, France, September 9th, 2019.
- Daniel Simon gave a talk on "Dynamic simulation of a hand under electrical stimulation" at the "Modeling human through robotics, neuroscience, and ergonomics" AIST workshop, Montpellier, France, October 24th, 2019.
- François Bonnetblanc gave a talk on "Awake neurosurgery and electrophysiological spreading in the human brain: towards clinical applications through brain mapping? A new insight in brain connetivity" at the "Modeling human through robotics, neuroscience, and ergonomics" AIST workshop, Montpellier, France, October 24th, 2019.
- David Guiraud gave a talk on "Bidirectional control of hand prosthesis for amputees. A new breakthrough with sensory feedback to the brain" at the "Modeling human through robotics, neuroscience, and ergonomics" AIST workshop, Montpellier, France, October 24th, 2019.
- Christine Azevedo gave a talk on "FES-assisted grasping" at the "Modeling human through robotics, neuroscience, and ergonomics" AIST workshop, Montpellier, France, October 24th, 2019.
- Christine Azevedo gave a talk on " Interest of IMU sensors in various FES usages" at Lyon CyberBike event (https://lcb2019.sciencesconf.org/), September 9th, 2019.
- Christine Azevedo gave a talk on "Restoring a sport activity by stimulating paralyzed muscles" during Inria Scientific Days (June 2019).

9.1.4. Leadership within the Scientific Community

Christine Azevedo is member of the board of directors of International Functional Electrical Stimulation Society (IFESS).

9.1.5. Scientific Expertise

- Christine Azevedo is member of LIRMM CNU 61 commission
- Christine Azevedo was member of the selection committee for a Lecturer position at ISIR laboratory (Université Pierre et Marie Curie), (April 15th, 2019)
- Christine Azevedo was member of the selection committee of Researcher Competition at Inria Bordeaux (May 2019)

9.1.6. Research Administration

Christine Azevedo was member of Inria Evaluation Committee (CE). She participated in the competitive examinations for junior researcher recruitment in Inria Bordeaux Center (April 2019) and Inria Grenoble Center (May 2018).

Christine Azevedo is member of Inria Ethical Committee (COERLE).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master Neuroprothèses : Daniel Simon, "Control basics", 6.5h, M2, Université de Montpellier, France

Master Neuroprothèses : François Bonnetblanc, "Neurophysiologie", 8h, M2, Université de Montpellier, France

9.2.2. Supervision

PhD : Maxence Blond, "Optimisation de la propulsion d'un véhicule sous-marin à propulseurs azimutaux", University of Montpellier, April 17th 2019, Daniel Simon

PhD : Anthony Boyer, "Électrophysiologie cérébrale associée à la chirurgie éveillée des tumeurs lentes : Couplage de l'ECoG et de la SED pour les investigations peropératoires et analyse de l'EEG postopératoire", University of Montpellier, September 24th 2019, François Bonnetblanc.

PhD in progress : XinYue Lu, "Cardiorespiratory Monitoring by Microphone via Tracheal Sounds in the Context of Implanted Phrenic Nerve Stimulation", University of Montpellier - Inria - NeuroResp, April 2017-March 2020, Christine Azevedo, Thomas Similowski, Serge Renaux

PhD in progress : Lucie William, "Selective implanted neural stimulation to recover the prehension for quadriplegic", University of Montpellier-Inria-NEURINNOV, october 2019-september 2022, supervised by David Guiraud and Christine Azevedo

PhD in progress : Hélène Moron, MD, "Jitter of MUAP measured through needle EMG used as a biomearker of the Botulin toxin effect", University of Montpellier-Inria, october 2019-september 2022, supervised by David Guiraud and Arnaud Dupeyron.

9.2.3. Juries

Christine Azevedo was external examiner for the PhD thesis of Sean Doherty (UCL, London, France) "Investigation of transcutaneous neuromodulation techniques and development of a wearable device for control of the bladder following spinal cord injury." (April 30th 2019).

Christine Azevedo was examiner for the PhD thesis of Osama Mazhar (University of Montpellier, LIRMM, France) "Recognition of human gestures based on vision for the human-robot interaction." (October 24th 2019).

Christine Azevedo was examiner for the PhD thesis of Andrii Shachykov (University of Lorraine, LORIA, France) "Neural modeling of human motor coordination inspired by biological signals aiming for parkinsonian gaits." (December 17th 2019).

9.3. Popularization

- Christine Azevedo presented FREEWHEELS project at Sport Unlimitech event in Lyon https://sportunlimitech.com/ (September 2019)
- CAMIN team was present (demonstration and masterclass lecture) at FUTURES festival in Paris https://futures.paris/ (June 13th 2019)
- CAMIN team was present (demonstration and lecture) during the visit of the Secretary of State for Persons with Disabilities at Inria Paris Center (November 19th 2019)

9.3.1. Education

- Christine Azevedo was mentor (2018-2019) for one Savanturiers project with Saussan school (CM1/CM2 level) https://savanturiersdelahightech.wordpress.com/category/projets-2018-2019/ecole-elementaire-joseph-delteil/
- Christine Azevedo is mentor (2019-2020) for one Savanturiers project with Montbazin school (CE1/CE2 level) https://savanturiers-projects.cri-paris.org/projects/NhbsL7Uz/blogentries
- Christine Azevedo organized initiation sessions to informatics using Thymio robot at École Valfalis (Montbazin, France) in CP, CE1, CE2, CM1 and CM2 levels, 5 sessions of 1 hours per level (March-June 2019).
- Christine Azevedo participated to a 1-day of training future trainers in robotics at school (DANE) (March 2019).

9.3.2. Interventions

- CAMIN team welcomed 1 week internships of 3 schoolchildren this year (4e, 3e)

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