Activity Report 2017

Team CAMIN

Control of Artificial Movement & Intuitive Neuroprosthesis

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Neuroscience and Medicine

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Team CAMIN

Creation of the Team: 2016 January 01

Keywords:

Computer Science and Digital Science:

A1.2.6. - Sensor networks
A1.3. - Distributed Systems
A2.3. - Embedded and cyber-physical systems
A2.5.2. - Component-based Design
A4.4. - Security of equipment and software
A4.5. - Formal methods for security
A5.1.4. - Brain-computer interfaces, physiological computing
A6.1.1. - Continuous Modeling (PDE, ODE)
A6.3.2. - Data assimilation
A6.4.1. - Deterministic control

Other Research Topics and Application Domains:

B1.2.1. - Understanding and simulation of the brain and the nervous system
B2.2.1. - Cardiovascular and respiratory diseases
B2.2.2. - Nervous system and endocrinology
B2.2.6. - Neurodegenerative diseases
B2.5.1. - Sensorimotor disabilities
B2.5.3. - Assistance for elderly

1. Personnel

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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 (fig.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 will be 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.

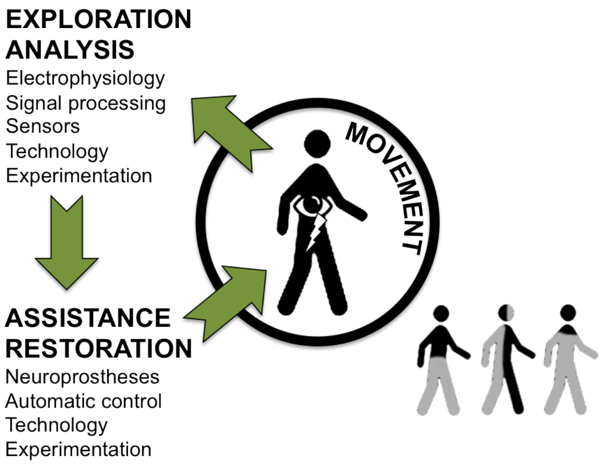


Figure 1. Overview of CAMIN *general scientific approach.*

The expertise and skills of our individual team members will be combined to design and develop solutions to restore movement functions.
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).

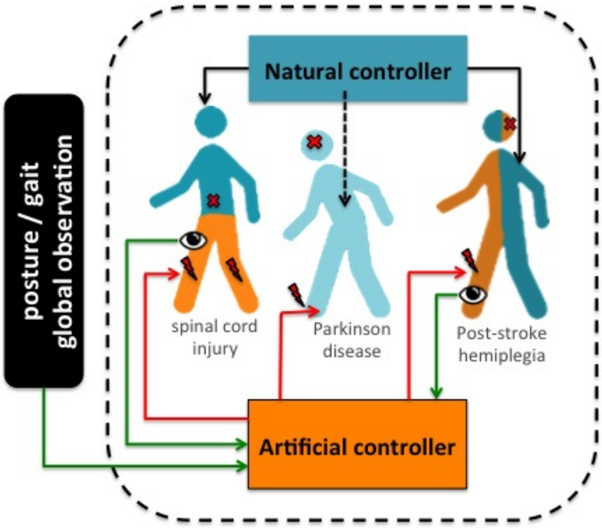


Figure 2. FES assistance should take into account the coexistence of artificial and natural controllers. Artificial controllers should integrate both global (posture/gait) and local (limb/joint) observations.

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.

4. Highlights of the Year

4.1. Highlights of the Year

4.1.1. Awards

A part of CAMIN team is in the process of creating a spin-off: Neurinnov which has been awarded with the i-Lab 2017 prize by the French Minister of Research and Innovation, that encourage the most innovative and promising startups in France.

5. New Software and Platforms

5.1. Softwares

5.1.1. HILECOP

Participants: Baptiste Colombani, David Andreu.

High Level hardware Component Programming

Functional Description: Our SENIS (Stimulation Electrique Neurale dIStribuee) based FES architecture relies on distributed stimulation units (DSU) which are interconnected by means of a 2-wire based network. A DSU is a complex digital system since its embeds among others a dedicated processor (micro-machine with a specific reduced instruction set), a monitoring module and a 3-layer protocol stack. To face the complexity of the units digital part and to ease its prototyping on programmable digital devices (e.g. FPGA), we developed an approach for high level hardware component programming (HILECOP). To support the modularity and the reusability of sub-parts of complex hardware systems, the HILECOP methodology is based on components. An HILECOP component has: an Interpreted Time Petri Net (ITPN) based behavior 3, a set of functions whose execution is controlled by the PN, and a set of variables and signals. Its interface contains places and transitions from which its PN model can be inter-connected as well as signals it exports or imports. The interconnection of those components, from a behavioral point out view, consists in the interconnection of places and/or transitions according to well-defined mechanisms: interconnection by means of oriented arcs or by means of the "merging" operator (existing for both places and transitions).

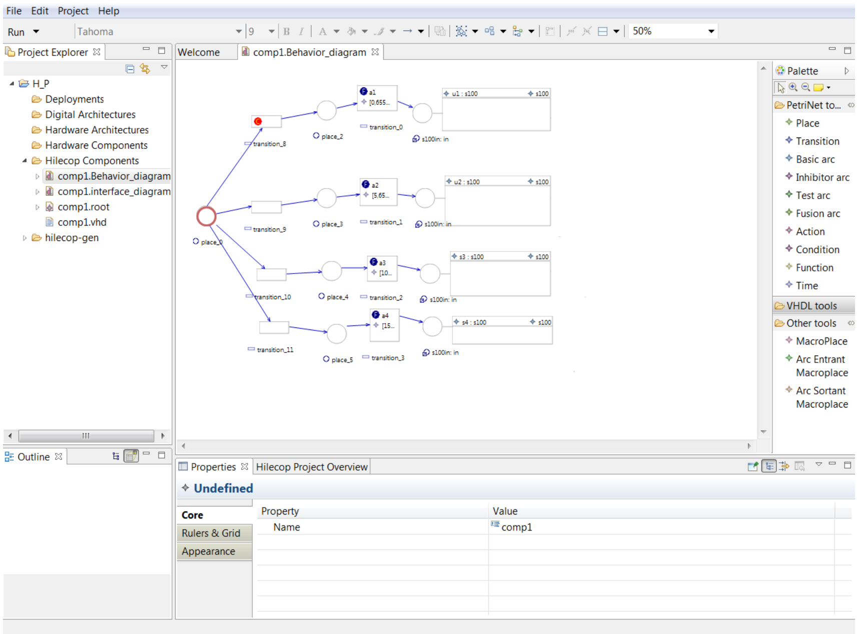


Figure 3. HILECOP screenshot

Several formalism evolutions have been integrated within the HILECOP software, like for instance behavior agregation as well as exception handling, both for analysis and implementation sides. Analysis has also been improved, a new approach for state space generation of synchronously executed ITPN has been designed, validated and then integrated within the software.

The Eclipse-based version of HILECOP (registered at the french Agence de Protection des Programmes (APP)) has been refactored: for instance, the application ECore model, a new Eclipse E4 architecture and a set of new features (new link types and new views to connect components) have been developed.

Specification of GALS systems (Globally Asynchronous Locally Synchronous) and their deployment on the hardware architecture are ongoing works; the aim is to take into account deployment properties like connecting different clocks to HILECOP components within a same FPGA, or on a set of interconnected FPGAs (and thus interconnecting them by means of asynchronous signals).

5.1.2. Sensbiotk

Participants: Christine Azevedo Coste, Roger Pissard-Gibollet, Benoît Sijobert.

Sensbiotk is a toolbox in Python for the calibration, the acquisition, the analysis and visualization of motion capture Inertial Measurement Units (IMU). Motion and Gait parameter reconstruction algorithms are also available. http://sensbio.github.io/sensbiotk/

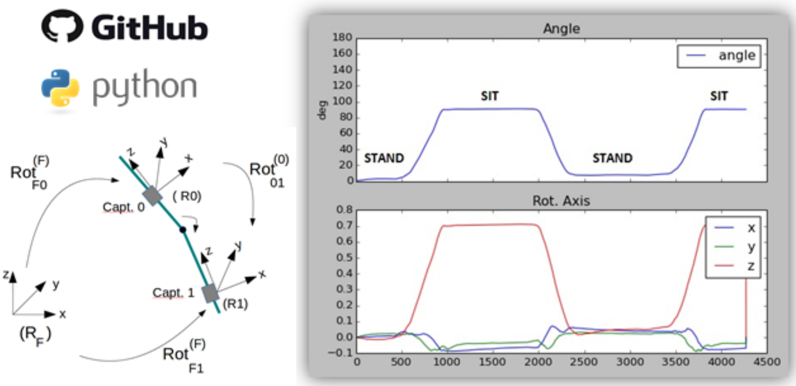


Figure 4. Sensbiotk toolbox for the calibration, the acquisition, the analysis and visualization of motion capture Inertial Measurement Units (IMU)

5.1.3. MOS2SENS

Participants: Mélissa Dali, Olivier Rossel, David Guiraud.

From Model Optimization and Simulation To Selective Electrical Neural Stimulation: it allows to manipulate 3D modeling of nerve and cuff electrodes taking into account anisotropy and the most advanced HH models of the myelinated axons. Based on optimized computing scheme, it allows to predict the acivation areas induced by a complex 3D spreading of the current over a multicontact electrodes. Moreover, the tool allows for performing optimization of the needed current to target a specific cross section of the nerve. Version 1.0 (IDDN.FR.001.490036.000.S.P.2014.000.31230) has been relaesed on december 2014 and v2.0 will be realeased January 2017. The last version includes full interface with OpenMEEG and COMSOL, and many other enhancements concerning both the model itself and the computation scheme.

6. New Results

6.1. Modeling and identification of the sensory-motor system

6.1.1. Inertial Sensor based Analysis of Gait for Post-stroke individuals

Participants: Christine Azevedo Coste, Benoît Sijobert, Jérôme Froger [CHU Nîmes], François Feuvrier [CHU Nîmes].

Walking impairment after stroke can be addressed through the use of drop foot stimulators (DFS). In these systems, electrical stimulation is applied to activate the common peroneal nerve and elicit ankle dorsiflexion during the swing phase of gait. DFS are generally piloted by a heel switch positioned in the shoe of the affected side with stimulation being triggered ON by heel rise of the affected foot and triggered OFF by heel strike.

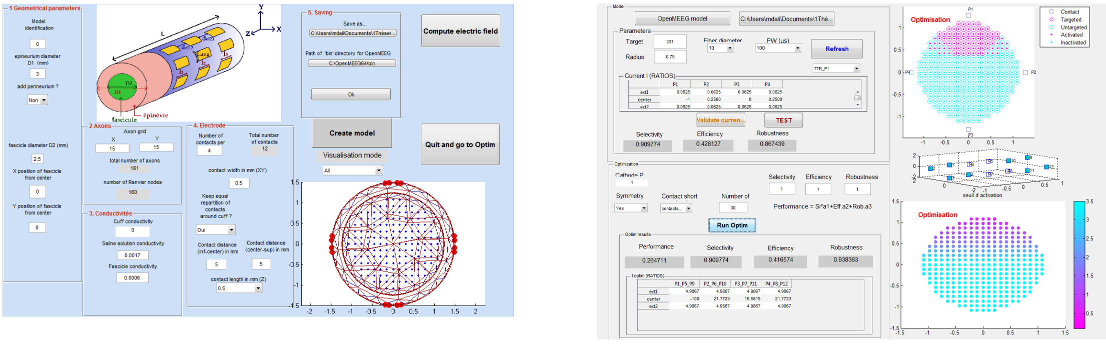


Figure 5. Graphical interface of software MOS2SENS, left: modeling multicontact CUFF electrode, right: optimization for spatial selectivity

Using inertial sensors for modulating FES intensity could provide a more optimized delivery of stimulation and could also enable to regulate dorsiflexion in the presence of disturbances, such as fatigue or stairs. It could also increase the number of potential users of the technology, allowing subjects walking without heel strikes to be stimulated at a correct timing. Meanwhile, pathological post-stroke gait requires the investigation of complex inertial sensors based algorithms for being able to compute different useful gait parameters for later triggering stimulation. Numerous constraints related to these clinical context, pathology and usability have to be taken into account for providing a reliable patient oriented solution. In this work, we aim to compare accuracy and feasibility of using a minimum amount of inertial sensors instead of the gold standard camera based motion capture, for assessing joint angles and gait events such as stride length or dorsiflexion speed at heel on. 29 subjects were included in this experimental protocol. Equipped with motion capture targets on which an inertial sensor is set, subjects had to perform an experimental path on a gait carpet. EMG recordings were also performed to monitor and evaluate fatigue. Algorithms were developped for computing 3D trajectory (6), dorsiflexion angles at mid-swing or before heel strike. Results shows an RMS error of 5.8° at heel on and 6.6° at mid-swing compared to motion capture data [20]. François Feuvrier has defended his medicine thesis on this topic on December 14th 2017.

6.2. Model based optimal multipolar stimulation without a priori knowledge of nerve structure: application to vagus nerve stimulation

Participants: Mélissa Dali, Olivier Rossel, David Guiraud.

Neural electrical stimulation, applied to the peripheral nervous system for motor functions restoration or neuromodulation, is a thriving technology, especially implanted stimulation using cuff electrodes positioned around a peripheral nerve. The main obstacle to the development of stimulation systems is the difficulty in obtaining the independent stimulation or inhibition of specific target functions (i.e. functional selectivity). The parameters involved in selectivity are not always intuitive and the number of degrees of freedom (choice of electrode, number of contacts, pulse shape etc.) is substantial. Thus, testing all these hypotheses in a clinical context is not conceivable. This choice of parameters can be guided using prior numerical simulations predicting the effect of electrical stimulation on the neural tissue. Numerous studies developed new strategies to achieve selectivity based on modeling results that have been validated a posteriori by experimental works. We presented a general method based on a spatiotemporal model to optimize and assess multipolar neural electrical stimulation without a priori knowledge of the nerve structure. The model consists of two independent components: a lead field matrix (LFM) and an activation model. It represents the transfer function from the applied current to the extracellular voltage present on the nodes of Ranvier along each axon. The determination

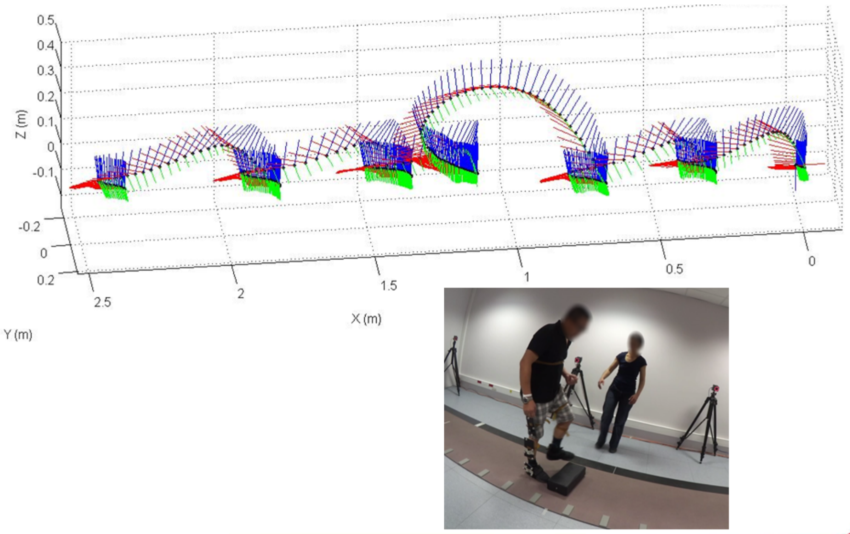


Figure 6. 3D trajectory reconstruction from inertial sensors

of fibers activation is used to optimize the spatial layout for the selective activation of specific fibers or nerve areas. Optimization is not only based on selectivity but also on robustness and efficiency of the stimulation settings.

The results show that state-of-the- art solutions are part of the optimized solutions but new ones can emerge depending on the trade-off between the criteria and the targeted area. We successfully assessed the solutions in-vivo to selectively induce a decrease in cardiac rhythm through vagus nerve stimulation. Experiments on animal model allowed us to evaluate the effectiveness and genericness of the method. These encouraging results suggest that this approach will have broader applications that would benefit from multicontact cuff electrodes to elicit very accurate and selective responses. This work was performed as part of a larger project on vagus nerve stimulation (INTENSE project) in which one of the applications focused on the treatment of cardiac disorders. The main objective was to selectively activate a specific population of nerve fibers to improve therapy and decrease side effects. Within the framework of the INTENSE project, the second application investigated vagus nerve stimulation as a therapy for morbid obesity. Activation of target axons related to gastric functions requires a significant amount of charge injection. Several studies suggest that non-rectangular waveforms can activate axons of the peripheral nervous system with a reduced amount of charge compared to the reference rectangular pulse shape. Our last contribution focuses on the experimental study and the modeling of these complex waveforms. The modeling approach, if performed properly and while bearing in mind its limits, provides a relevant and even indispensable analysis tool for the clinical adjustment of neuroprostheses.

6.3. Alterations of EEG rhythms and dynamics during motor preparation following wide-awake brain surgery

Participants: Anthony Boyer, Sofiane Ramdani [LIRMM], Hugues Duffau [CHU Montpellier], Bénédicte Poulin-Charronnat [Université de Bourgogne], David Guiraud, François Bonnetblanc.

Awake brain surgery of tumour is used to optimize the resection of tumoral tissue. Postoperatively, patients show mild and temporary neurological deficits despite massive cerebral resections. Reasons for these impairments along with the compensation mechanisms operating within the cortex and subcortical structures are

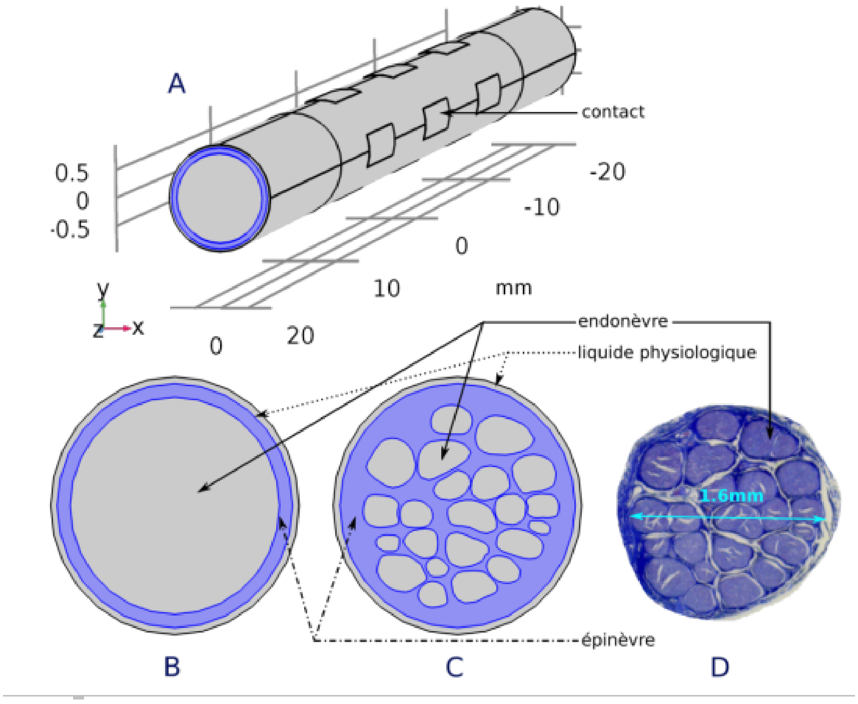


Figure 7. Generic nerve model (A,B) and realistic nerve model (C) based on histological data

barely understood. The objective of this project is to reveal the remote effects of the tumour and its resection, to determine their nature measuring changes induced in functional Magnetic Resonance Imagery (fMRI) and electroencephalographic signals using standard and nonlinear methods. Recently, we focused on postoperative brain dynamics of patients, who underwent wide-awake surgery for Low grade gliomas (LGG). We analysed EEG data of 5 patients, who perfomed an ecological visuomanual task, comparing them to a control group of 8 healthy subjects (fig. 8). We used the motor preparation period to extract power features and phase space features to better characterise changes in EEG signal following surgery and subsequent functional reorganisation. The preparation period was chosen for its stationarity allowing analyses, which were not applicable during the ERP period. Our results clearly identify changes in postoperative brain dynamics of patients, who underwent wide-awake surgery. Both spectral and recurrence quantification analyses suggested imbalances between the injured and healthy hemispheres for patients, whether in terms of spectral power density or temporal structure of EEG signal. These investigations performed on the motor preparation period also provided important information regarding longitudinal recovery of brain dynamics. Although all patients in our study had very different tumours, both in size and location, it is interesting to note that the 2 patients, who underwent the experimental protocol respectively 9 and 12 months after surgery, showed more moderate alterations of spectral content and signal complexity independently of the lesion size. This may be seen as an indicator for EEG signal standardization in time and presumably a resumption of brain dynamics. These findings have potential clinical rehabilitation implications.

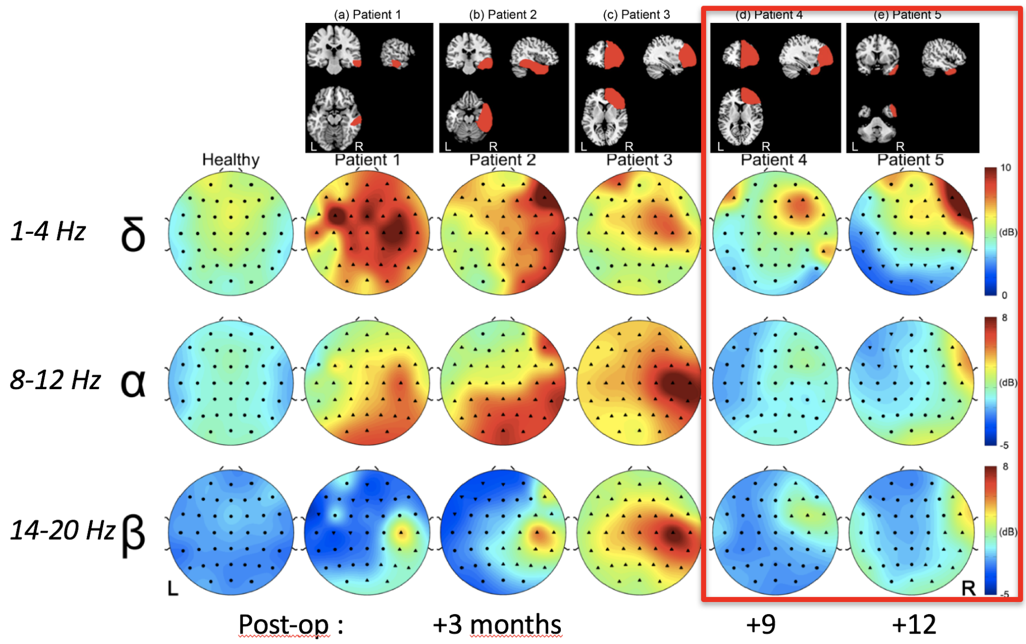


Figure 8. Topographical maps of spectral power: Maps illustrating the spatial distribution of the spectral power contained in a given frequency band over the scalp. We selected bands which showed significant peaks of spectral power for patients in comparison with control group (i.e. δ band: 1 - 4Hz, α/μ band: 9 - 12Hz and β band: 14 - 20Hz) and we then calculated the average power at each electrode for each band. Electrode locations are represented by a set of symbols: ● symbol is used when the corresponding spectral power falls within the 95% confidence interval estimated from healthy subjects. ▲ and ▼ symbols are respectively used when the power is either greater or smaller than the 95% confidence interval. α/μ band

6.4. Electrophysiological brain mapping: measuring evoked potentials induced by electrical stimulation and its physiological spreading in the human brain.

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

Being able to change or inhibit the activity of a region or population of neurons in the brain is an essential approach in fundamental neuroscience, as it helps the researcher to determine the functional role of neurons. This approach is also important at a more applied level, for brain function mapping during neurosurgical procedures. It is well known that electrical stimulation (ES) affects neural activity by modifying the voltage gradient along the neuronal cell inducing depolarization or hyperpolarization of the membrane. When a current flows in tissues around neuronal cells, it can change their membrane potential and trigger an action potential. However, this general principle can be applied in vivo via several different settings and much is unknown about which neural elements are excited or inhibited locally and how this local perturbation spreads within the brain through physiological pathways [35]. We are now able to record different types of electrophysiological potentials that are evoked by ES in the human brain and we developed some basic methodological considerations required for their correct assessment [26] (fig.9). With our methodology, three different types of evoked potentials can now be measured during brain surgery in the operative room: – Cortical evoked-potential (also called direct cortical response, DCR), when recording the cortex at the stimulation site, – Cortico-axono-cortical evoked-potential, i.e. recording the cortex at a distant site from the stimulating site. These potentials are elicited by physiological propagation through white matter associative pathways from the locally stimulated area towards the distal area, – Axono-cortical evoked potentials, when the cortex is distally recorded from a stimulation site within the white matter. These evoked potentials are technically difficult to observe. Their recording imposes important methodological considerations about the way they can be triggered and measured. In particular, proposed some factors potentially determining the generation of true cortico-axono-cortical evoked potentials, spreading from one stimulated cortical area to another distant one and passing through the white matter pathways. Correctly measuring evoked potentials in the human brain induced by electrical stimulation is important in the clinical domain especially in the neurosurgical context. It remains challenging because of many pitfalls that can occur at the methodological level and few teams in the world are currently able to efficiently record these evoked potentials. Nevertheless, they can give strong real-time in vivo insights into the functional state and connectivity of a patient's brain. In the next years measuring intraoperatively the evoked potentials with ES in the brain will be a new method for mapping the brain in vivo and in real time and taking into account the specificity of each patient's brain.

6.5. Diagnosis evaluation of acute ischemic stroke using new technics

Participants: Victor Vagné, Olivier Rossel, Emmanuelle Le Bars, Stéphane Perrey, Vincent Costalat, David Guiraud.

Cerebral infarctions can now be treated with new techniques using intravenous thrombolysis and thrombectomy. Their proven efficacy is directly correlated to the time lapse between the start of symptoms and the initiation of treatment. Currently, a definitive diagnosis can only be made once the patient has performed a radiological imaging (CT scan or MRI) on a medical center equipped with these expensive devices, thus enabling the medical team to initiate the appropriate treatment. Transit times during the pre-hospitalization phase before diagnosis are therefore often longer and have the greatest negative impact on the patient's prognosis. In collaboration with the interventional neuroradiology department of Gui de Chauliac Hospital, I2FH and Euromov, the EleVANT project is aiming to prospectively evaluate new techniques to assess a diagnosis of acute cerebral ischaemia. This low cost technology could be used in a mobile way for the very early diagnosis of cerebral infarction and thus reduce treatment delays, opening the way to a new generation of diagnostic tools. The concept consist on evaluating the cerebral near-infrared spectroscopy (NIRS) response to different stimulus, and to evaluate its lateralization. Recently, we tested our device on healthy volunteers. Method: Left

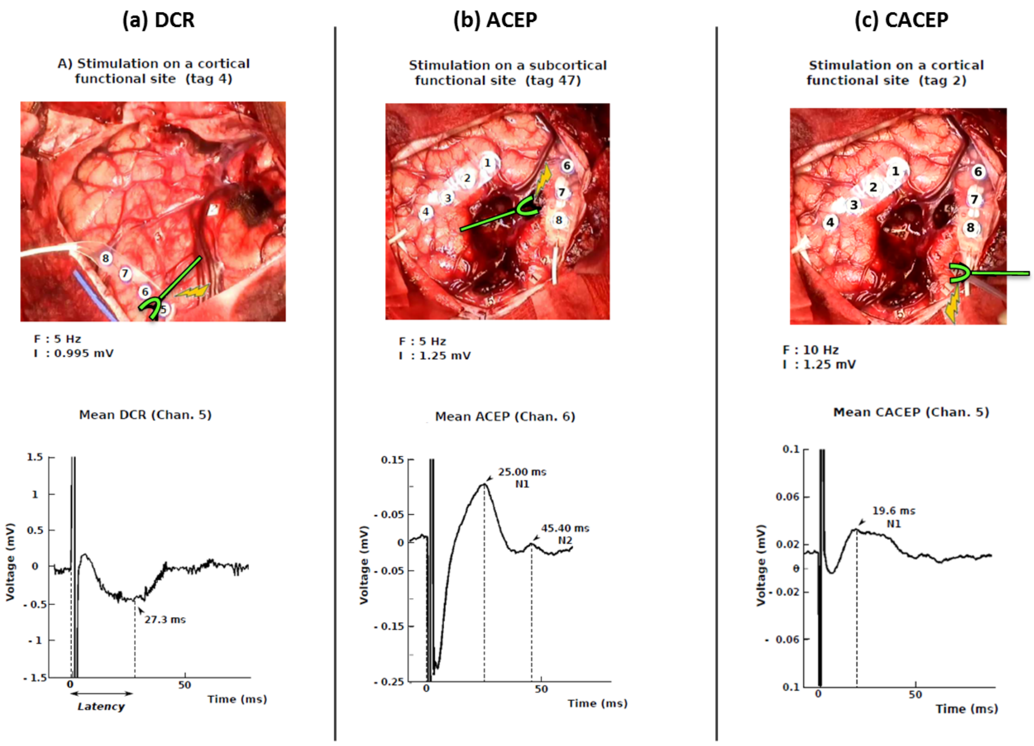


Figure 9. Example of mean evoked potentials induced by DES. (a) Direct cortical responses (DCR) present one primary peak around 27 ms after the stimulation onset. They were measured on 4 patients on cortical sites distant of less than 2 cm from the cortical stimulation site. (b) Axono-cortical evoked potentials (ACEP) presented a primary peak around 25 ms after DES, followed by a second peak 20 ms later. DES is applied subcortically, around 1.7 cm away from the recording site. ACEP were osberved on 2 patients. (c) Cortico-axono-cortical evoked potentials (CACEP) were oberved in 1 patient. Cortical DES induced a one-peak waveform 14 to 35 ms after the artefact onset. CACEP were recorded on cortical site more than 2 cm away from the stimulation site.

and right hemisphere reactivity index are recorded by NIRS and normalized (Figure 10). Result: The experiment present a suitable feasibility and repeatability. In healthy subjects, a good response to the stimulus is recorded, and no significant differences between hemispheres are observed. The confidence level is acceptable since the amplitude response in above the standard deviation level.

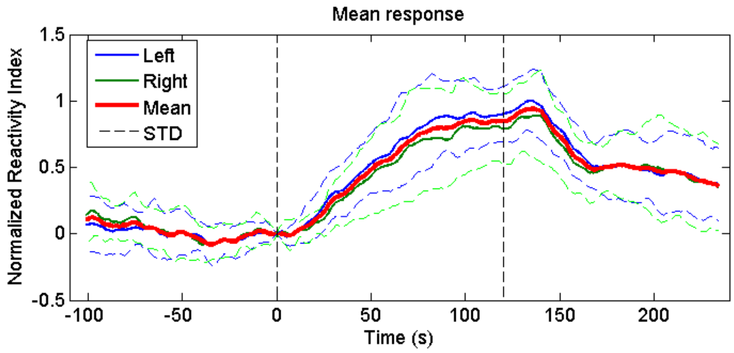


Figure 10. NIRS reactivity Index in response to a stimulus (bounded by the dashed lines)

Discussion: The approach reveal interesting results on healthy subject group. We expect a discriminant difference between hemispheric signals in acute cerebral ischemia.

6.6. A study on Natural user feedback in BCI with peripheral sensory stimulation toward efficient motor learning

Participants: Saugat Bhattacharyya, Maureen Clerc, Mitsuhiro Hayashibe.

Brain-computer Interfacing (BCI) measures the neural activity of the brain to create a direct communication channel to peripheral devices in form of robots, prosthesis, wheelchair or a computer controlled by the user, independent of the peripheral nerves and muscles. To improve the performance of the BCI operation and provide a feedback to the user as an indication of his/her achievement in terms of voluntary brain modulation, a feedback in form of visual, auditory or (vibro-)tactile medium can be provided to the user during training.

One can employ Functional Electrical Stimulation (FES) targeting specific muscle group as a feedback modality in BCI research. Functional Electrical Stimulation (FES) is often applied during rehabilitation to directly engage muscles of the affected side of the body. FES is capable of reconstructing certain daily life skills for physically challenged patients by directly stimulating the targeted muscles group. Thus, it is quite natural to combine FES rehabilitation with BCI systems, where the FES can activate the sensory channel to provide a maximal inflow in the brain and the BCI would provide an efferent outflow of motor commands to close the motor loop. Thus, we aim at studying the effect of electrical stimulation (ES) on the motor imagery EEG and to implement the usage of ES as a natural feedback to BCI. The purpose was to extract all relevant information from the current EEG dataset acquired during BCI experiment with FES based neuro-feedback and to compare the results to the classical visual neuro-feedback paradigm.

The EEG data in this study were recorded from 14 right-handed participants (11 male and 3 female) with a mean age of 28 years and standard deviation of 9 years. The experiments took place at Inria Montpellier and Inria Sophia Antipolis centers. In this experiment, we abide by the norms of the local Inria ethical committee. The participants sat in front of a display placed at eye level and performed the following cued motor imagery tasks: left hand movement, right hand movement, left foot movement and right foot movement. The participants were randomly divided into two groups: one group was provided with only visual feedback (VIS) and the other group was relayed with only FES as feedback during the motor imagery tasks. This step was taken in the experimentation so that the groups were not influenced by both feebacks and were trained on only one feedback. The VIS feedback group received the feedback in form of a uni-directional bar whereas the FES feedback group received the feedback in form of electrical stimulation on their respective limbs. The group with FES feedback performed two different sets of experiment, which are: 1) the participant performed the motor imagery tasks while receiving electrical stimulation as feedback, which we term as *FES-Active (ACT)* sessions, and 2) the participant performed no motor imagery tasks (relaxation condition) and received the electrical stimulation as a stimuli, which we term as *FES-Passive (PAS)* sessions.

The raw EEG data was first filtered using a notch filter to remove the 50Hz noise from the signal. Then, a 4th order Butterworth filter was applied to the signal. Then, the mean of the signal was removed followed by a spatial filtering using common average referencing technique. Finally, the continuous EEG data were segmented into smaller samples (Epochs) from -1s to 4s, where 0 indicates the onset of the motor imagery task (left hand, right hand, right foot). After filtering and epoching the EEG data, the EEG epochs are spatially filtered using common spatial patterns (CSP) algorithm. Then, the log-variance of 4 discriminating CSP filters (2 for either classes) were selected as features. These features are then used as inputs to a linear discriminating analysis (LDA) classifier to derive the output of the current motor task imagined by the participant. We provide the average classification result across all subjects for three (ACT and VIS) and two sessions (PAS) in Fig.11. As noted from the figure, the performance of the decoder improves after every session for the VIS and ACT sessions. This can be attributed to the increase in learning occurring to the participant during the progression of the experiment. As the subject was performing no mental tasks during the PAS session, thus, no such improvement on the classification performance is noticed. On the contrary, a decrease in the performance is noted after the second session.

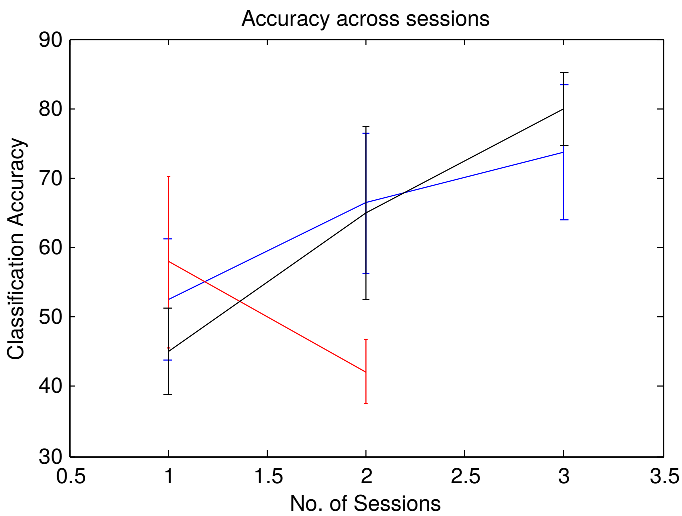


Figure 11. Classification result across all subjects for subsequent sessions.

To further investigate the learning occurring across trials, we have calculated the band power of the epochs at the mu-band (8-12Hz) and the central-beta band (16-25 Hz) at Cz electrode (Fig.12). To calculate the power we have employed Welchs' periodogram at an overlap of 75% and a window size of 250ms. Finally, the average is calculated over all windows of the given trial to determine its power. As seen from the example in Fig.12, ACT and VIS conditions show a monotonic increase of power which can be quantified as an indication of learning occurring in the participant across the trial.

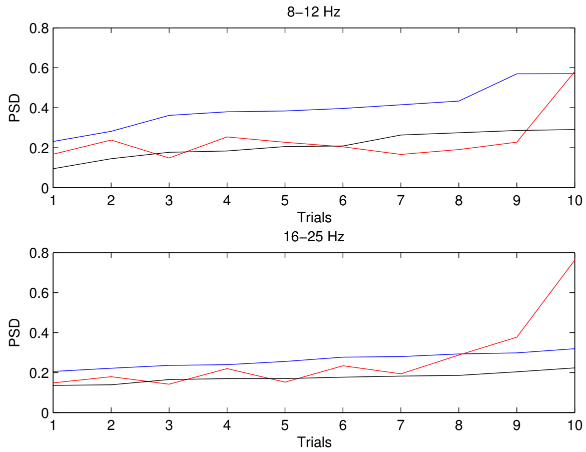


Figure 12. The distribution of power from the first to the tenth correctly classified trial during left hand imagery. Blue is for ACT condition, Red is for PAS and Black is for VIS condition.

6.7. Formal validation for critical digital embedded systems

Participants: Ibrahim Merzoug, Karen Godary-Dejean, David Andreu.

The works addressed here fall under the domain of formal modelling, semantics and verification methods (model checking). We focus on the analysis part of the HILECOP methodology, integrating the specific execution constraints (non-functional properties) into the validation process to guarantee the validation results. Indeed, the state space that is analyzed is that of the model of the system (based on Interpreted Time Petri Nets). It is clear that, if we want to obtain confident validation results, this analyzed state space must include all the possible behaviors of the real system (i.e., considering the execution of the model on the target).

One solution has been studied in the PhD thesis of H. Leroux [34], which lays the foundations of translation rules from the designed model to the analyzed model integrating part of implementation and execution characteristics. These transformations rules allow analyzing the resulting model with classical Petri nets analysis tools (as the Tina toolbox), and to guarantee the inclusion of the real states and traces into the analyzed state space.

However, if the formal model, the Interpreted Time Petri Net in this case (ITPN), is inherently asynchronous, it is nevertheless executed synchronously on the target. In fact, the usual analysis approaches are not adapted in the sense that they construct state graphs that do not conform to the real state evolution within the target. In order to gain confidence in the validity of the results of the formal analysis, we carried on, through the PhD thesis of I. Merzoug, capturing the so-called non-functional characteristics to reify them on the model and finally to consider their impact through a dedicated analysis approach. In other words, we improved the expressiveness of the model and the relevance of the analysis, considering aspects such as clock synchronization, effective parallelism, the risk of blocking induced by the expression of an event (condition) and a time window of occurrence, without omitting the management of exceptions.

To deal with all these aspects, we have proposed a new method of analysis for Synchronously executed ITPN (SITPN), transforming them into an equivalent formalism that could be analyzed ([29]). This formalism is associated with a new formal semantics integrating all the particular aspects of the execution. We also propose and implement a dedicated state space construction algorithm: the Synchronous Behavior Graph (an example being given on Fig. 13 and Fig. 14). Our work has been applied to an industrial case, more precisely to the validation of the behavior of the digital part of our neuro-stimulator.

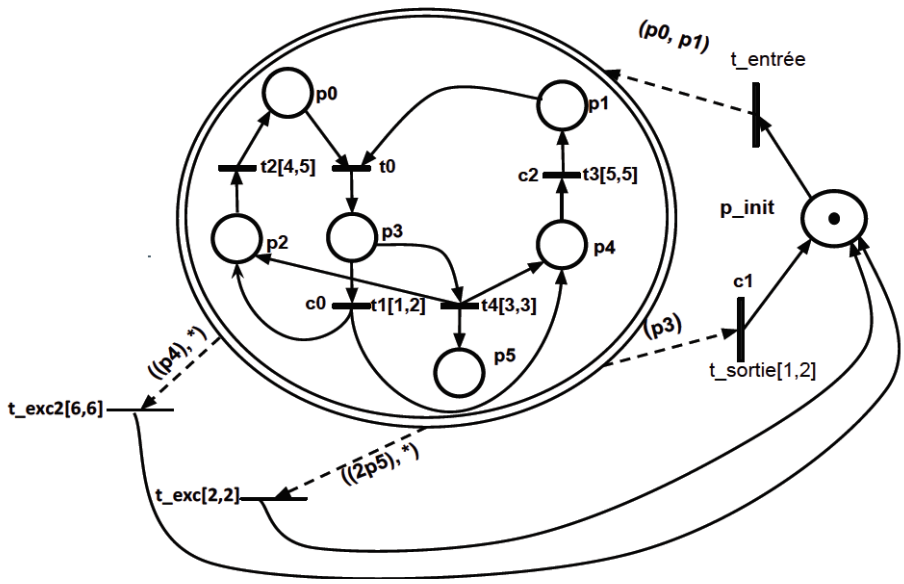


Figure 13. Example of SITPN model with state aggregation and exception handling

6.8. Respiratory detection and monitoring

Participants: Xinyue Lu, Christine Azevedo Coste, David Guiraud, David Andreu, Serge Renaux [Neuroresp], Thomas Similowski [Groupe Hospitalier Pitié-Salpêtrière].

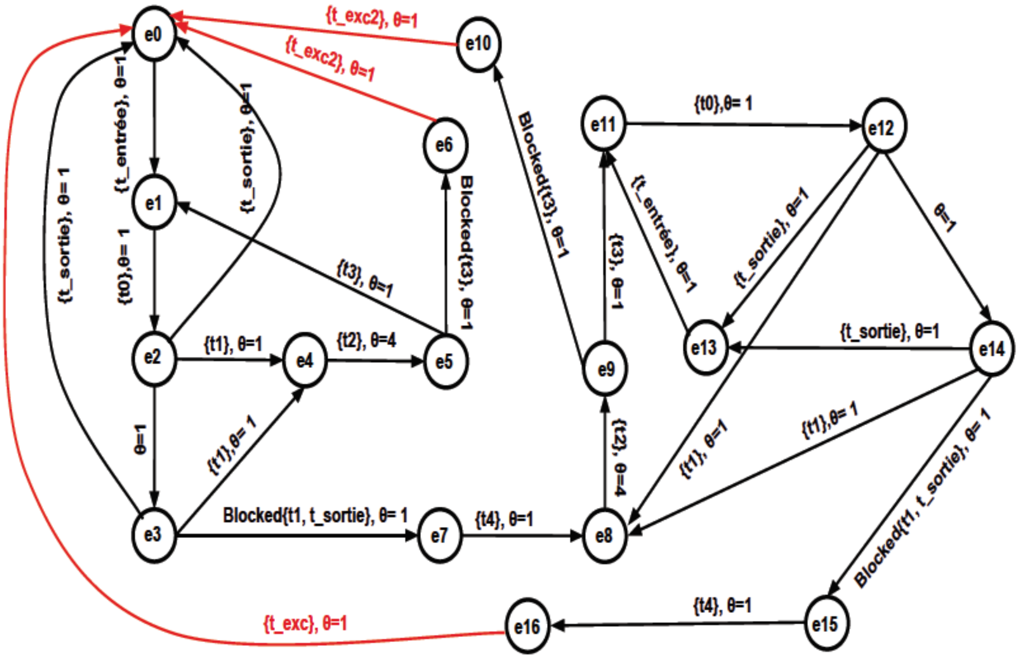
This work is conducted within a CIFRE PhD thesis. The general subject is the respiration induced by implanted stimulation for the tetraplegic and syndrome of Ondine. In France, every year, there is approximately 90 new spinal cord injuries who have a ventilatory dependence due to a high cervical involvement. The prevalence of syndrome of Ondine (central sleep apnea) would be 25.5 per million inhabitants. Because of many disadvantages of mechanical ventilation, the technique of implanted electrical stimulation to restore the respiratory function of the patients can be proposed. But existing systems are based on open-loop controllers, i.e. the phrenic nerve is stimulated with the same intensity, at the same frequency for the whole time, even when the patients can breathe spontaneously. The principle aim of the work is to develop a respiratory detection/monitoring module in this context.

We have developped a first solution bases on a microphone. The signal is processed in order to determine the spectral power between 400Hz and 600Hz (the band of respiratory sounds) and a threshold detection applied to detect respiration.

Preliminary recordings on healthy individuals have been perfomed. Advance signal processing techniques are now under study.

6.9. Evoked EMG correlation with muscle torque

Participants: Adriana Mendes, Mitsuhiro Hayashibe, David Guiraud.



e0: p_init, **B**{}, {t_entrée[1,1]}	**e3:** p3, **B**{}, {t1[1,1], t4[2,2], t_sortie[1,1]}	**e6:** p0,p4, **B**{t3}, {t_exc2[1,1]}	**e9:** p0,p4,p5, **B**{}, {t3[1,1], t_exc2[2,2]}	**e12:** p3,p5,**B**{}, {t1[1,2], t4[3,3], t_sortie[1,2]}	**p15:** p3, p5 **B**{t1, t_sortie}, {t4[1,1]}
e1: p0,p1,**B**{}, {t0[1,1]}	**e4:** p2,p4, **B**{}, {t2[4,4], t3[5,5], t_exc2[6,6]}	**p7:** p3, **B**{t1,t_sortie}, {t4[1,1]}	**e10:** p0,p4, p5 **B**{t3}, {t_exc2[1,1]}	**e13:** p_init,p5 **B**{}, {t_entrée[1,1]}	**p16:** p3, p4, p5(2) **B**{}, {t_exc[1,1]}
e2: p3, **B**{}, {t1[1,2], t4[3,3], t_sortie[1,2]}	**e5:** p0,p4, **B**{}, {t3[1,1], t_exc2[2,2]}	**e8:** p2,p4,p5 **B**{}, {t2[4,4], t3[5,5], t_exc2[6,6]}	**e11:**p0,p1,p5, **B**{}, {t0[1,1]}	**e14:** p3,p5, **B**{}, {t1[1,1], t4[2,2], t_sortie[1,1]}	

Figure 14. Synchronous Behavior Graph of the model given Figure 13

During the internship, we developed software, based on algorithms available in literature, that allow to recover M-Wave induced by surface FES. The algorithm detects the onset of the artifact, the Otsu method is used to determine the length of the contaminated data and finally, the M-wave is interpolated through Cubic Hermite extensions. The results can be seen on Figure 15 where the M-wave, fully reconstructed can then be quantified. We thus verified that the classical torque-EMG relationship can be recovered using MAV, RMS or P2P and the results show a very good correlation. Finally we successfully developed a realtime version of the processing and tested it through a closed loop control of the FES through EMG measurements. The technology used was completely wireless (Delsys for the EMG and Vivaltis for the stimulation). One journal paper is under writing in collaboration with the Technological University of Compiègne.

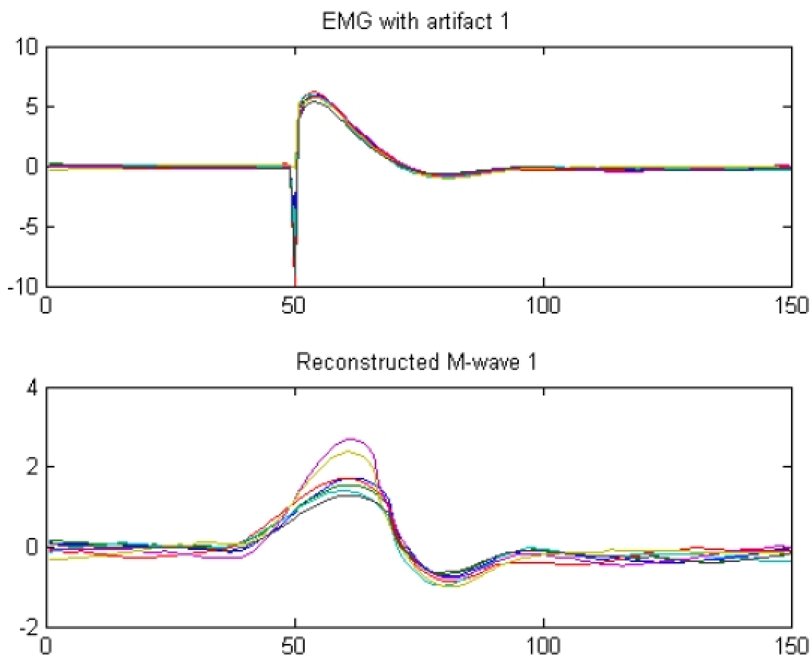


Figure 15. Reconstructed M-Wave

6.10. Pivot transfer assistance in SCI subjects

Participants: Lucas Fonseca [Univ. Brasilia], Antonio Padilha Lanari Bo [Univ. Brasilia], Ana Claudia Lopes [SARA hosp], Christine Azevedo Coste, Emerson Fachin Martins [Univ. Brasilia], Claudia Ochoa-Diaz [Univ. Brasilia].

Spinal cord injured (SCI) patients that have no lower limb motor function perform several transfers during a day. Those transfers are from and to a wheelchair, a car, a hygienic chair, among other situations. These repetitive motions can cause overload on their upper limbs over time. Functional Electrical Stimulation may be used to induce contraction on knee extensors, providing additional support at the joint level during transfer [33]. However, the design of the interface with which to control the onset of stimulation is challenging. The use of some automated system is beneficial, particularly since the user is using both hands to perform the transfer. Therefore, the precise moment of activation is important because, if erroneous, it can cause the user's loss of balance. In the context of CACAO associate team with Brasilia University, a system with which the users themselves were activating the stimulation with triggers in gloves was used to collect kinematic data from SCI patients during Sitting Pivot Transfers (16). The results show that the trunk angle can be used along a threshold for a reliable assistance device [28].

Figure 16. Experimental set-up. The gloves embed pressure sensors. It is possible to see the markers over the subject body, which are captured by the motion capture system.

6.11. Real-time control and scheduling for stimulation systems

Participants: Daniel Simon, David Andreu, Ronan Le Guillou, Benoît Sijobert.

Functional Electrical Stimulation (FES) is used in therapy for rehabilitation or substitution for disabled people. They are control systems using electrodes to interface a digital control system with livings. Hence the whole system gathers continuous-time (muscles and nerves) and discrete-time (controllers and communication links) components. During the design process, realistic simulation remains a precious tool ahead of real experiments to check without danger that the implementation matches the functional and safety requirements [15].

To this aim a real-time open hybrid simulation software has been developed. It is dedicated to the analysis of FES systems deployed over distributed execution resources and wireless links. The simulation tool is especially devoted to the joint design and analysis of control loops and real-time features. Such simulator can be used for the design, testing and preliminary validation of new technologies and implementation. The initial design, working with a simple model of a knee, is currently extended with the dynamic model of a human hand (Figure 17).

A portable controller has been prototyped to run control loops using stimulation and sensing probes. ([32]). It is architectured around a Raspberry Pi3B single board computer, and provides USB ports towards sensing probes from HiKoB and stimulation units from Vivaltis. It uses a dedicated RT_PREEMPT linux kernel to make the system real-time control compliant (Figure 18).

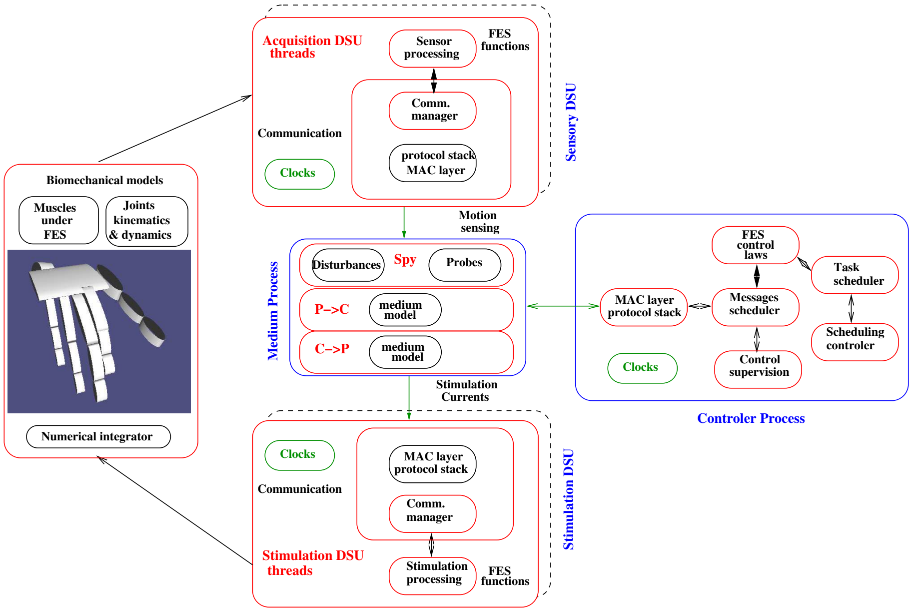


Figure 17. Hybrid simulation of a hand under FES

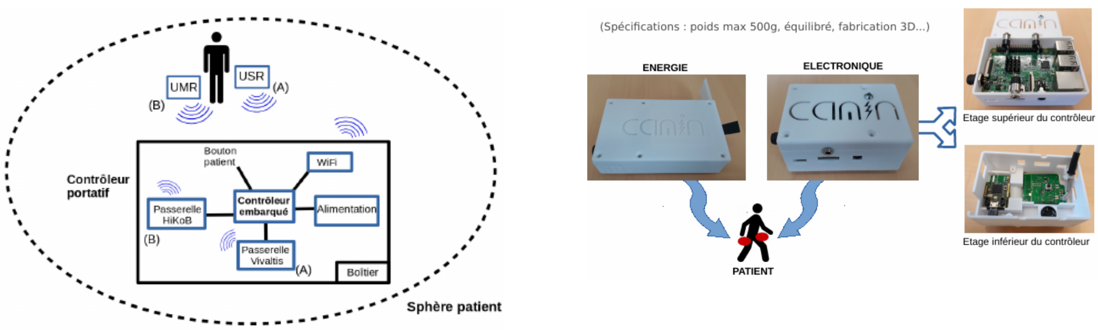


Figure 18. Portable stimulation controller architecture and components

Beyond software-in-the-loop simulation, the controller has been firstly tested connected with the previously developed simulation models to perform a hardware-in-the-loop simulation system and further experiment control/computing co-design algorithms ([25]). Gateways has been developed to connect the Vivaltis and HiKoB probes, together with a small graphical end-user interface. The whole embedded system has been succesfully validated for future applications through a pertinent real-time metrology.

6.12. Sensory feedback for phantom limb pain modulation

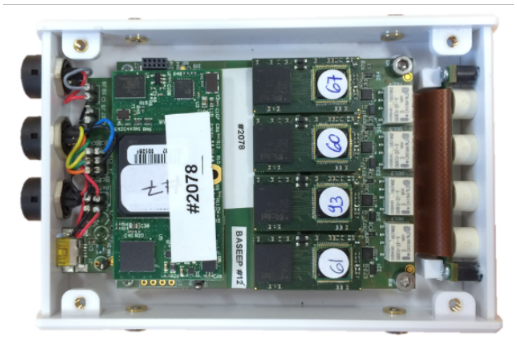
Participants: Arthur Hiairrassary, David Andreu, Christine Azevedo Coste, Thomas Guiho, David Guiraud.

In the EPIONE european project, the partners UM and MXM-OBELIA are responsible for the design and manufacturing of the STIMEP stimulator (see figure 1) and in charge of all the software and the experimental follow-up.

During the first round, we were able to quantify the state of each contact of each electrode to prevent misinterpretation of feedback sensation. Indeed, if the patient does not feel anything while stimulating, impedance check may show that it is due to a contact failure and not to a lack of nerve response.

This estimation was done during the "Contacts Check" functionality embedded in the STIMEP. At the same time, a more detailed measure was stored in the STIMEP (but only reachable off-line for further investigation).

For instance, the following figure shows the number of valid contacts during the clinical phase of the 4 TIME-4H electrodes computed by the "Contacts Check" functionality. The electrodes stand almost OK up to February-March on this example (2-3 months) then failures begin to occur.



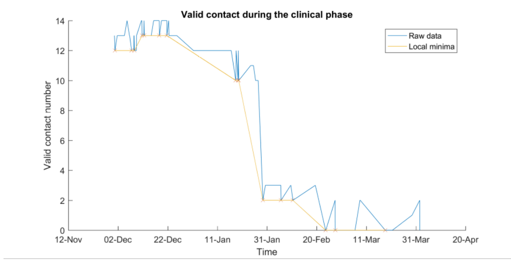


Figure 19. a) the STIMEP b) Ulnar nerve – Proximal electrode

However, these data were not detailed enough so we decided to develop an easy to use software able to control automatically in the same time the STIMEP and the acquisition card (NI-6218). It performed voltage and current measurements to follow and to assess the complex impedance evolution of the TIME-4H in vivo. This software, named "Synergy Acquire" (Figure 3), was used by the clinic of Roma with the second patient.

Synergy Acquire performs safe, really quick stimulation and measurement on an electrode (around 1 minute, less than 5 minutes for the 4 TIME-4H, figure 4), which allow a very regular follow-up (2-3 times by week) by the practitioners. Data were logged, sent to us, processed and then sent back to UCSC for checking. This work is related to clinical trials follow-up. In conclusion, within this project that ended in August, we developed software (following 62304 class B regulation), test in animals, used in humans and we processed all the data

6.13. Spin-off Neurinnov

Participants: David Andreu, David Guiraud, Olivier Climent, Milan Demarcq, Guillaume Souquet.

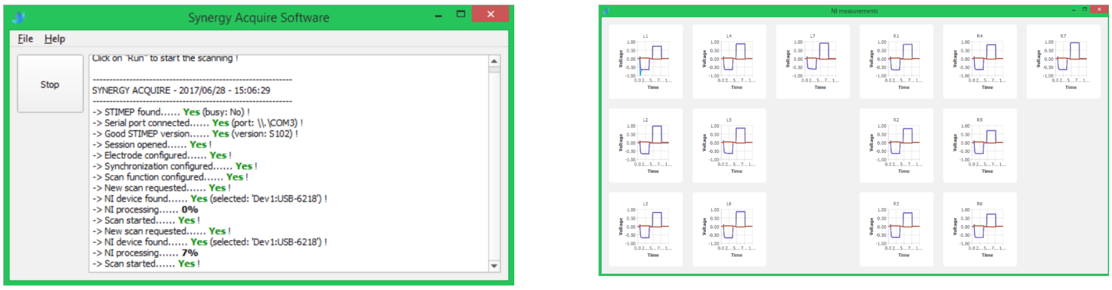


Figure 20. a) Synergy Acquire b) Results of the voltage and current measurements

Thanks to the support of the Inria-DGDT, the spin-off Neurinnov has started the industrialization of the innovative technology developed in CAMIN, a new generation of active implantable medical device (AIMD). Neurinnov has been awarded with the i-Lab 2017 prize by the French Minister of Research and Innovation, that encourage the most innovative and promising startups in France. Moreover, Neurinnov is accredited by the Business Incubation Center of Montpellier and incubated by the Languedoc-Roussillon Incubation Center.

Industrialization means on the one hand the development of an industrial version of the technology with all the regulatory documents required by the Technical Documents part of the CE certification, and on the other hand the setting up of our own system of quality management in accordance with ISO 13485. Since the beginning the spin-off has to consider regulatory aspects, of which the quality management system (QMS). A QMS is a set of policies, processes and procedures designed to help an organization to consistently provide safe and effective medical devices, and to comply with customer and regulatory requirements. Thus the team worked on defining processes and associated procedures regarding for instance the design, the development and the verification of our stimulation device.

The design and verification of the two parts of our AIMD (stimulator), namely the digital part (FPGA) and the analogue part (ASIC), were carried out in accordance with the defined procedure and applicable standards.

The core of the stimulators developed in the CAMIN team are based on an Application Specific Integrated Circuit (ASIC). It includes both the analog part with the generation of 12 current sources that are able to drive a pulticontact electrode. The global ASIC architecture fully implements our patent and allows to spread the current from a unique current source over the 12 outputs through ratios programming. This unique feature is a consequence of researches about the multicontact selective stimulation through neural cuffs. In the new 0.18μ new design, the analog part was entirely revised to enhance power consumption and global analogue features. On the digital aprt the concept of virtual electrode was fully implemented within this ASIC (named CORAIL) to embed all the low level programming parts dedicated to the spreding of the current. It enhances the safety but also the efficacy of the code developed to control this ASIC as it virtualize the concept of ratios. Moreover CORAIL stores the Virtual Electrode so that the needed bandwidth but also the transfer time between CORAIL and the hiigh level control is much lowered compared to the previous version we developed. We tested and implemented this original digital part in collaboration with the micro-electronics department at LIRMM and SL3J company. A first version of the ASIC was made and is under investigation to prepare the next version.

The digital part of the device embeds a set of functionalities (described section 5.1.1) allowing the stimulator to be programmable, communicating and fully controllable remotely. The formal design and verification of this digital part is based on the HILECOP software developed within CAMIN (see sections 5.1.1 and 6.7). All constituent components have been developed, verified and documented in accordance with the defined procedure.

In addition, Neurinnov has focused on setting up the necessary industrial collaborations on the one hand to complement its device (e.g., electrodes, connectors) and on the other hand to manufacture it.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- FUI MMCD (Multifunctions Modular Cockpit Display) [2014-2018] Labels : Pegase, ASTech

  The MMCD project (Multi Functions Modular Cockpit Display) aims at designing a mechatronic architecture that is modular, certifiable and evolutive in terms of embedded GPU. This project will contribue to Avionics 2020 by developping a mock-up of new cockpit display system, allowing easy to manage GPU evolution.

  Our contribution concerns formal design and prototyping of embedded supervisory functions, using the HILECOP methodology and tool.
- collaboration contract with FEETME [1] company.
- collaboration contract with Innopsys [2] company.
- collaboration contract with NEURORESP [3] company (CIFRE PhD thesis).

8. Partnerships and Cooperations

8.1. National Initiatives

- BCI-LIFT: an Inria Project-Lab Participants : Mitsuhiro Hayashibe, Saugat Bhattacharyya.

  BCI-LIFT is a large-scale 4-year research initiative (2015-2018) which aim is to reach a next generation of non-invasive Brain-Computer Interfaces (BCI), more specifically BCI that are easier to appropriate, more efficient, and suit a larger number of people. We work on BCI-FES study for promoting motor learning.
- ADT PersoBalance2

  Participants : Mitsuhiro Hayashibe, Philippe Fraisse.

  A half-year engineer was funded by Inria ADT on "Personalized Balance Assessment in Home Rehabilitation, version2 (PersoBalance2)".

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

Program: FP7

Project acronym: EPIONE

Project title: Natural sensory feedback for phantom limb pain modulation and therapy

Duration: 2013-2017

Coordinator: AAU (Aalborg, Denmark)

[1] http://www.feetme.fr
[2] https://www.innopsys.com/en
[3] http://neuroresp.com/

Other partners: Ecole polytechnique fédérale de Lausanne (EPFL), IUPUI (Indianapolis, USA), Lund University (LUNDS UNIVERSITET), MXM (Vallauris, France), Novosense AB (NS), IMTEK (Freiburg, Germany), UAB (Barcelona, Spain), Aalborg Hospital, Universita Cattolica del Sacro Cuore (UCSC), Centre hospitalier Universitaire Vaudois (CHUV)

Abstract: http://project-epione.eu/. The aim of the project is to treat phantom limb pain. CAMIN is only involved in the invasive approach using intrafascicular electrodes. We developed certified software with EPFL and AAU, co-supervised animal tests and data processing with UAB, provide support to clinical trials with IMTEK and UCSC and developped a new stimulator with MXM.

8.3. International Initiatives

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

8.3.1.1. CACAO

Lower limb electrical stimulation for function restoration University of Brasilia, UNB (Brazil)
Núcleo de Tecnologia Assistiva, Acessibilidade e Inovação (NTAAI)
https://team.inria.fr/cacao/
Start year: 2016
Electrical stimulation (ES) can activate paralyzed muscles to support rehabilitation. ES applied to fully or partially paralyzed muscles artificially induces muscle contraction substituting or completing the normal volitional control. In CACAO team we will join our efforts and specific expertise to develop approaches of lower limb function restoration in spinal cord injured individuals. Two main applications will be addressed: 1) Functional Electrical Stimulation (FES) to assist SCI individuals to perform pivot transfers and 2) FES-assisted cycling. We aim at proposing solutions that can have an effect on patients' quality of life, thus our choices intend to be realistic form a practical point of view. We will take care in evaluating both functional and psychological effects of our solutions and to constrain technical choices to be acceptable by final user. CACAO project will be a good opportunity to combine "bioengineer" (DEMAR) and "physiology/rehabilitation" (NTAAI) visions and knowledges towards solutions for clinical applications.

8.3.2. Participation in Other International Programs

Programme Ciensia Sem Fronteiras CAPES, avec l'Univeristé Brasilia (chercheur invité).

8.4. International Research Visitors

8.4.1. Visits of International Scientists

Antonio Lanari Padilha Bo spent one month in CAMIN in July 2017 as invited reseracher (LIRMM funding).
Adriana Mendes, M2 Univ Lisboa spent 9 months (funded by Erasmus) from october 2016 to june 2017
Lucas Fonseca, PhD student in Brasilia University, spent 9 months in CAMIN.

8.4.2. Visits to International Teams

Thomas Guiho, Aurora program with Norway, short stays to initiate collaborations

8.4.2.1. Research Stays Abroad

Christine Azevedo spent 1 month in Brasilia University between october and december in the context of CACAO associate team with a grant from CAPES for invited researchers.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. Member of the Organizing Committees

David Guiraud was member of the organizing committee of IEEE NER 2017 Shangai

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

Christine Azevedo was member of the JNRR (french journeys of research in robotics) program committee.

David Andreu was member of the European Congress on Embedded Real Time Software and Systems (ERTS2) program committee

Daniel Simon was member of the ICINCO (Int. Conf. on Informatics in Control, Automation and Robotics) program committee

David Guiraud was Associate editor of Theme 6 at IEEE EMBC

9.1.2.2. Reviewer

David Andreu was reviewer for ERTS2 2018.

Daniel Simon was reviewer for the ICINCO, IFAC and ECC conferences.

Christine Azevedo was reviewer for several journals and conferences this year.

David Guiraud was reviewer for IEEE EMBC and IEEE NER

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

Christine Azevedo was guest editor for EJTM journal and Artificial Organs (2 special issues).

David Guiraud is associate editor for MBEC and JNE

9.1.3.2. Reviewer - Reviewing Activities

Daniel Simon was reviewer for Real-Time Systems.

David Guiraus was reviewer for JNE J. of Neuroscience Methods, MBEC and EJTM

9.1.4. Invited Talks

Christine Azevedo was invited to give a lecture in January 5th at Institut de la Moelle in Paris in the context of a meeting of the consortium ANR ECOTECH dedicated to Parkinson Posture.

Christine Azevedo and David Guiraud were invited to give 2 lectures in March on hand function rehabilitation during the symposium organized at CHUV hospital in Lausanne "Rehabilitation de la main : de l’amputation à la lésion centrale. Peut-on rêver à de nouvelles solutions technologiques ?".

Christine Azevedo was invited to give a lecture on FES during the workshop organized by BIONESS company at the SOFMER congress.

David Guiraud was invited for a plenary talk in Nagoya, Japan for the International Funciotnal Reconstruction of the Hand Symposium (28-29 of April)

9.1.5. Leadership within the Scientific Community

David Guiraud was member of « Gourpe de Travail Neurostimulation alliance Aviesan »

9.1.6. Scientific Expertise

David Guiraud was expert for the ERC Advanced Grant
David Guiraud was expert for ANR

9.1.7. Research Administration

Christine Azevedo was in charge of one working group to write a scientific challenge on handicap for Inria Strategic Plan.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence : François Bonnetblanc, Movement Physiology and Electrophysiology, 6h ETD, Movement Physiology and Electrophysiology, 6h ETD, L3 DU Functional Electrical Stimulation, University of Montpellier, France

Master : D. Andreu, Software engineering, real time OS, discrete event systems, control architectures, networks, neuro-prosthesis, 200 h, master and engineers degrees, Polytech Montpellier, France;

Master : D. Simon, Basics in feedback control, 6.5 h, M2 STIC, University of Montpellier, France;

Master : François Bonnetblanc, Motor Control applied to Neuroprosthesis, 6h ETD, M2 STAPS, University of Montpellier, France

Master : François Bonnetblanc, Neurophysiology of movement et Neuroprosthesis, 6h ETD, M2 Mechanics and Interactions, Polytech, University of Montpellier, France

Master : K. Godary-Dejean, real time OS, embedded and industrial networks, formal validation, dependability, 200h, master and engineers degrees, Polytech Montpellier, France;

Master : D. Guiraud, muscle modeling and FES basics, , SMH master2,

9.2.2. Supervision

PhD defended on november 7, 2017:Marion Vincent, Measuring the electrophysiological effect of direct electrical stimulation during awake brain surgery, 01/12/2013, François Bonnetblanc, David Guiraud and Hugues Duffau

PhD defended on november 17, 2017: Mélissa Dali, Modèles de génération et de propagation de potentiel d'action neuronale en condition de stimulation sélective multipolaire, since october 2014, David Guiraud and Olivier Rossel.

PhD in progress : Antony Boyer, Neuroplasticity and recovery in remote (sub)cortical structures following wide-awake surgery of infiltrative low-grade gliomas: investigation of fMRI and EEG signals, 01/09/2016, François Bonnetblanc and Sofiane Ramdani.

PhD in progress : Maxence Blond, Commande et modélisation d'un véhicule sous-marin, 18/01/2016, Daniel Simon, Vincent Creuze (LIRMM) and Ahmed Chemori (LIRMM).

PhD in progress : Ibrahim Merzoug, Validation formelle pour les systèmes embarqués critiques, Since Oct. 2014, K. Godary-Dejean and D. Andreu.

PhD in progress : Benoît Sijobert, Stimulation électro-fonctionnelle pour l'assistance aux mouvements des membres inférieurs dans les situations de déficiences sensori-motrices, Since Dec. 2015, Christine Azevedo Coste and D. Andreu.

PhD in progress: Victor Vagne, "Couplage de la Spectroscopie en proche infrarouge et de la stimulation Transcrânienne (NIRS-tDCS) à courant continu dans l'Evaluation diagnostique de l'ischémie cérébrale lors d'un AVC", Oct. 2016, M. Hayashibe, D. Guiraud, Vincent Costalat (CHU Montpellier) and Emmanuelle Le Bars (CHU Montpellier)

PhD in progress: XinYue Lu, Respiratory detection and monitoring Since March 2017, C. Azevedo Coste, T Similowski (Groupe Hospitalier Pitié-Salpêtrière), S Renaux (NEURORESP)

9.2.3. Juries

Christine Azevedo participated in M Merad (UPMC, Paris) PhD thesis defense, December 1, 2017, as Reporter. The PhD was entitled "Investigations on upper limb prosthesis control with an active elbow."

Christine Azevedo participated in A Kubicki (Université de Bourgogne / UFR Staps, Dijon), HDR thesis defense, July 7th, 2017, as Reporter. The HDR was entitled "Comprendre la fragilisation du contrôle moteur prédictif pour optimiser la rééducation gériatrique."

Karen Godary-Dejean participated in M. Senoussi (IRIT, Université de Toulouse) PhD thesis defense, July 12, 2017, as examiner. The PhD was entitled "Etude et prototypage d'une nouvelle méthode d'accès aléatoire multi-canal multi-saut pour les réseaux locaux sans fils".

Karen Godary-Dejean participated in P. Delarboulas (ETIS, Université de Cergy Pontoise) PhD thesis defense, December 20, 2017, as examiner. The PhD was entitled "Navigation bio-inspirée pour un robot mobile autonome dans de grands environnements intérieurs".

Christine Azevedo participated in F Feuvrier Université de Montpellier, Faculté de Médecine Montpellier-Nîmes) Medicine thesis defense, December 20, 2017. The thesis was entitled " Evaluation des qualités métrologiques d 'une centrale inertielle par rapport à un système optique de capture du mouvement chez des patients avec foot-drop post AVC ."

David Guiraud was president of the PhD defense of Melissa Sourioux, Université de Bordeaux, 15/12/2017 « Etudes des mécanismes de coordination des activités rythmiques locomotrices et sympathiques au sein d'un réseau spinal activé par l'acethylcholine chez le rat nouveau-né »

David Guiraud was reviewer of the HDR of Nicolas Lonjon, 18/12/2017 " La pathologie vertébro-médullaire : Innovation en chirurgie rachidienne pour améliorer la qualité de vie des patients Mécanismes physiopathologiques des lésions médullaires et stratégie de réparation "

David Guiraud was examiner of the PhD defense Vincent Carriou 4/10/2017 "Multiscale, multi-physic modeling of the skeletal muscle during isometric contraction »

David Guiraud was examiner of the PhD defense Kai Dang 13/06/2017 "Electrical conduction models for cochlear implant stimulation"

David Andreu participated in V. Monthé PhD thesis defense (Lab-STIC, Brest University), December 1, 2017, as Reporter. The PhD was entitled « Développement des systèmes logiciels par transformation de modèles : Application aux systèmes robotiques ».

9.3. Popularization

CAMIN participed into Fête de la Science at LIRMM with 2 demos (cycling, EMG robotics hand control).

David Andreu presented the job of researcher in secondary school Collège Vincent Badie (Montarnaud)

Christine Azevedo organized Initiation sessions to informatics using Thymio robot at Collège Léon Cordas (Montpellier) in 3 classes (one 5e and two 6e). 3 sessions of 1h30 per class were organized followed by a half day visit at LIRMM robotics hall. One day session was also organized with École primaire Valfalis (Montbazin) in CE2 level.

10. Bibliography

Major publications by the team in recent years

[1] C. AZEVEDO COSTE, J. JOVIC, R. PISSARD-GIBOLLET, J. FROGER. *Continuous gait cycle index estimation for electrical stimulation assisted foot drop correction*, in "Journal of NeuroEngineering and Rehabilitation", 2014, vol. 11, n^o 1, 118 p. [*DOI :* 10.1186/1743-0003-11-118], https://hal.inria.fr/hal-01060086

[2] A. BOYER, J. DEVERDUN, H. DUFFAU, E. LE BARS, F. MOLINO, N. MENJOT DE CHAMPFLEUR, F. BONNETBLANC. *Longitudinal Changes in Cerebellar and Thalamic Spontaneous Neuronal Activity After Wide-Awake Surgery of Brain Tumors: a Resting-State fMRI Study*, in "Cerebellum", August 2016, vol. 15, n^{o} 4, pp. 451-465 [*DOI :* 10.1007/S12311-015-0709-1], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01348011

[3] J. JOVIC, V. BONNET, C. FATTAL, P. FRAISSE, C. AZEVEDO COSTE. *A new 3D center of mass control approach for FES-assisted standing: First experimental evaluation with a humanoid robot*, in "Medical Engineering and Physics", September 2016, In press [*DOI :* 10.1016/J.MEDENGPHY.2016.09.002], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01373662

[4] Z. LI, M. HAYASHIBE, C. FATTAL, D. GUIRAUD. *Muscle Fatigue Tracking with Evoked EMG via Recurrent Neural Network: Toward Personalized Neuroprosthetics*, in "IEEE Computational Intelligence Magazine", April 2014, vol. 9, n^{o} 2, pp. 38-46 [*DOI :* 10.1109/MCI.2014.2307224], https://hal-lirmm.ccsd.cnrs.fr/lirmm-00980641

[5] O. ROSSEL, F. SOULIER, S. BERNARD, D. GUIRAUD, G. CATHÉBRAS. *A phantom axon setup for validating models of action potential recordings*, in "Medical and Biological Engineering and Computing", 2016, vol. 10, n^{o} 4, pp. 671-678 [*DOI :* 10.1007/S11517-016-1463-3], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01347422

[6] D. SIMON, D. ANDREU. *Real-time Simulation of Distributed Control Systems: The example of Functional Electrical Stimulation*, in "13th International Conference on Informatics in Control, Automation and Robotics (ICINCO)", Lisboa, Portugal, July 2016, pp. 455 - 462 [*DOI :* 10.5220/0005967804550462], https://hal.inria.fr/hal-01379164

[7] W. TIGRA, B. NAVARRO, A. CHERUBINI, X. GORRON, A. GÉLIS, C. FATTAL, D. GUIRAUD, C. AZEVEDO COSTE. *A novel EMG interface for individuals with tetraplegia to pilot robot hand grasping*, in "IEEE Transactions on Neural Systems and Rehabilitation Engineering", September 2016, In press [*DOI :* 10.1109/TNSRE.2016.2609478], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01373668

[8] H. M. R. UGALDE, D. OJEDA, V. LE ROLLE, D. ANDREU, D. GUIRAUD, J.-L. BONNET, C. HENRY, N. KARAM, A. HAGEGE, P. MABO, G. CARRAULT, A. I. HERNANDEZ. *Model-Based Design and Experimental Validation of Control Modules for Neuromodulation Devices*, in "IEEE Transactions on Biomedical Engineering", June 2016, vol. 63, n^{o} 7, pp. 1551-1558, https://hal.archives-ouvertes.fr/hal-01337430

[9] M. VINCENT, O. ROSSEL, B. POULIN-CHARRONNAT, G. HERBET, M. HAYASHIBE, H. DUFFAU, D. GUIRAUD, F. BONNETBLANC. *Case report: remote neuromodulation with direct electrical stimulation of the brain, as evidenced by intra-operative EEG recordings during wide-awake neurosurgery*, in "Clinical Neurophysiology", November 2015, pp. 1752-1754, Letter to the editor [*DOI :* 10.1016/J.CLINPH.2015.11.005], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01237964

[10] Q. ZHANG, M. HAYASHIBE, C. AZEVEDO COSTE. *Evoked Electromyography-Based Closed-Loop Torque Control in Functional Electrical Stimulation*, in "IEEE Transactions on Biomedical Engineering", March 2013, vol. 60, n^{o} 8, pp. 2299-2307 [*DOI :* 10.1109/TBME.2013.2253777], https://hal-lirmm.ccsd.cnrs.fr/lirmm-00806283

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] M. DALI. *Modélisation de l'interface entre une électrode multipolaire et un nerf périphérique : Optimisation des courants pour la stimulation neurale sélective*, Université de Montpellier, November 2017, http://www.theses.fr/s174726

[12] M. VINCENT. *Electrophysiological brain mapping: basics of recording evoked potentials induced by electrical stimulation and its physiological spreading in the human brain*, University of Montpellier, nov 2017, CORDI grant from Inria and supported by a "bourse fin de these" grant from the ARC Fundation.

Articles in International Peer-Reviewed Journals

[13] C. AZEVEDO COSTE, V. BERGERON, R. BERKELMANS, E. F. MARTINS, C. FORNUSEK, A. JETSADA, K. J. HUNT, R. TONG, R. TRIOLO, P. WOLF. *Comparison of strategies and performance of functional electrical stimulation cycling in spinal cord injury pilots for competition in the first ever CYBATHLON*, in "European Journal of Translational Myology", 2017, vol. 27, n^{o} 4, pp. 251-254 [*DOI :* 10.4081/EJTM.2017.7219], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01656814

[14] C. AZEVEDO COSTE, M. R. POPOVIC, W. MAYR. *Functional Electrical Stimulation*, in "Artificial Organs", November 2017, vol. 41, n^{o} 11, pp. 977-978, Guest Editorial [*DOI :* 10.1111/AOR.13052], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01636985

[15] A. BEN KHALED-EL FEKI, L. DUVAL, C. FAURE, D. SIMON, M. BEN GAÏD. *CHOPtrey: contextual online polynomial extrapolation for enhanced multi-core co-simulation of complex systems*, in "SIMULATION", January 2017, vol. 93, n^{o} 3, pp. 185–200, accepté pour publication [*DOI :* 10.1177/0037549716684026], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01326188

[16] V. BONNET, C. AZEVEDO COSTE, T. ROBERT, P. FRAISSE, G. VENTURE. *Optimal External Wrench Distribution During a Multi-Contact Sit-to-Stand Task*, in "IEEE Transactions on Neural Systems and Rehabilitation Engineering", March 2017 [*DOI :* 10.1109/TNSRE.2017.2676465], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01515473

[17] S. CHANDRA, M. HAYASHIBE, A. THONDIYATH. *Empirical Mode Decomposition-based filtering for fatigue induced hand tremor in laparoscopic manipulation*, in "Biomedical Signal Processing and Control", 2017, vol. 31, pp. 339-349 [*DOI :* 10.1016/J.BSPC.2016.08.025], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01402103

[18] A. DAUBIGNEY, C. AZEVEDO COSTE, B. SIJOBERT, J. PARENT, C. FATTAL. *Stimulation électrique fonctionnelle et vélo couché : un apport rééducatif et récréatif dans la prise en charge du blessé médullaire*, in "Kinésithérapie, la revue", April 2017, vol. 17, n^{o} 184, 88 p. [*DOI :* 10.1016/J.KINE.2017.02.099], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01598324

[19] C. FATTAL, B. SIJOBERT, A. DAUBIGNEY, B. LUCAS, C. AZEVEDO COSTE. *The feasibility of training with FES-assisted cycling: Psychological, physical and physiological consideration*, in "Annals of Physical and Rehabilitation Medicine", September 2017, vol. 60, pp. 9 - 15 [*DOI :* 10.1016/J.REHAB.2017.07.201], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01609311

[20] F. FEUVRIER, B. SIJOBERT, C. AZEVEDO COSTE, A. DUPEYRON, I. LAFFONT, J. FROGER. *Assessment of the metrological qualities of inertials sensors compared to the reference system for adaptive trigger functional electrical stimulation to correct dropfoot in poststroke hemiplegic patients*, in "Annals of Physical and Rehabilitation Medicine", September 2017, vol. 60 [*DOI :* 10.1016/J.REHAB.2017.07.182], https://hal.inria.fr/hal-01626065

[21] T. GUIHO, C. DELLECI, C. AZEVEDO COSTE, C. FATTAL, D. GUIRAUD, J.-R. VIGNES, L. BAUCHET. *Impact of direct epispinal stimulation on bladder and bowel functions in pigs: A feasibility study*, in "Neurourology and Urodynamics", June 2017 [*DOI :* 10.1002/NAU.23325], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01539038

[22] C.-H. MALBERT, E. BOBILLIER, C. PICQ, J.-L. DIVOUX, D. GUIRAUD, C. HENRY. *Effects of chronic abdominal vagal stimulation of small-diameter neurons on brain metabolism and food intake*, in "Brain Stimulation", August 2017 [*DOI :* 10.1016/J.BRS.2017.04.126], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01551445

[23] B. SIJOBERT, C. AZEVEDO COSTE, D. ANDREU, C. VERNA, C. GENY. *Effects of Sensitive Electrical Stimulation-Based Somatosensory Cueing in Parkinson's Disease Gait and Freezing of Gait Assessment*, in "Artificial Organs", November 2017, vol. 41, n^{o} 11, pp. E222-E232 [*DOI :* 10.1111/AOR.13059], https://hal.inria.fr/hal-01638837

[24] B. SIJOBERT, C. FATTAL, A. DAUBIGNEY, C. AZEVEDO-COSTE. *Participation to the first Cybathlon: an overview of the FREEWHEELS team FES-cycling solution*, in "European Journal of Translational Myology", December 2017, vol. 27, n^{o} 4, pp. 265-271 [*DOI :* 10.4081/EJTM.2017.7120], https://hal.inria.fr/hal-01656602

[25] D. SIMON, A. SEURET, O. SENAME. *Real-time control systems: feedback, scheduling and robustness*, in "International Journal of Systems Science", 2017, vol. 48, n^{o} 11, pp. 2368-2378 [*DOI :* 10.1080/00207721.2017.1316879], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01515226

[26] M. VINCENT, D. GUIRAUD, H. DUFFAU, E. MANDONNET, F. BONNETBLANC. *Electrophysiological brain mapping: Basics of recording evoked potentials induced by electrical stimulation and its physiological spreading in the human brain*, in "Clinical Neurophysiology", October 2017, vol. 128, n^{o} 10, pp. 1886 - 1890 [*DOI :* 10.1016/J.CLINPH.2017.07.402], https://hal-lirmm.ccsd.cnrs.fr/hal-01613032

Invited Conferences

[27] C. AZEVEDO COSTE. *SEF et applications, limitations et pistes de recherche*, in "SOFMER", Nancy, France, Symposium BIONESS, October 2017, https://hal-lirmm.ccsd.cnrs.fr/lirmm-01585511

International Conferences with Proceedings

[28] L. FONSECA, A. C. LOPES, C. OCHOA-DIAZ, C. AZEVEDO COSTE, E. FACHIN-MARTINS, A. PADILHA LANARI BO. *Towards Transfers in Paraplegia Assisted by Electrical Stimulation and Inertial System*, in "LSC 2017 - first IEEE Life Sciences Conference", Sydney, Australia, December 2017, pp. 1-4, https://hal-lirmm.ccsd.cnrs.fr/lirmm-01630001

National Conferences with Proceedings

[29] I. MERZOUG, K. GODARY-DEJEAN, D. ANDREU. *Analyse de Réseau de Petri Temporels Exécutés de Façon Synchrone*, in "MSR 2017 - 11ème Colloque sur la Modélisation des Systèmes Réactifs", Marseille, France, November 2017, 15 p. , https://hal-lirmm.ccsd.cnrs.fr/lirmm-01591153

Conferences without Proceedings

[30] B. SIJOBERT, A. DAUBIGNEY, E. FACHIN-MARTINS, C. AZEVEDO COSTE, C. FATTAL. *Longitudinal feasibility study of a SCI subject one-year training based on sublesional muscles FES assisted cycling*, in

"IFESS 2017", Londres, United Kingdom, International Functional Electrical Stimulation Society, July 2017, https://hal-lirmm.ccsd.cnrs.fr/lirmm-01547869

Scientific Books (or Scientific Book chapters)

[31] M. HAYASHIBE, A. GONZÁLEZ, P. FRAISSE. *Personalized Modeling for Home-Based Postural Balance Rehabilitation*, in "Human Modelling for Bio-Inspired Robotics", Elsevier, 2017, pp. 111-137 [*DOI :* 10.1016/B978-0-12-803137-7.00005-7], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01402234

Other Publications

[32] R. LE GUILLOU. *Contrôleur de stimulation temps réel embarqué en boucle fermée*, École Nationale d'Ingénieurs de Brest, September 2017, https://hal.inria.fr/hal-01646653

References in notes

[33] J. JOVIC, C. AZEVEDO COSTE, P. FRAISSE, S. HENKOUS, C. FATTAL. *Coordinating Upper and Lower Body During FES-Assisted Transfers in Persons With Spinal Cord Injury in Order to Reduce Arm Support*, in "Neuromodulation", May 2015, vol. 18, n° 8, pp. 736-742 [*DOI :* 10.1111/NER.12286], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01146757

[34] H. LEROUX. *A methodology for the design of complex digital architectures: from formalism to implementation, taking into account formal analysis. Application to neuroprosthetics*, Université Montpellier 2, October 2014, http://hal-lirmm.ccsd.cnrs.fr/tel-01111881

[35] M. VINCENT, O. ROSSEL, M. HAYASHIBE, G. HERBET, H. DUFFAU, D. GUIRAUD, F. BONNETBLANC. *The difference between electrical microstimulation and direct electrical stimulation – towards new opportunities for innovative functional brain mapping?*, in "Reviews in the Neurosciences", April 2016, vol. 27, n° 3, pp. 231-258 [*DOI :* 10.1515/REVNEURO-2015-0029], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01237972