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Activity Report 2015

Project-Team DEMAR

Artificial movement and gait restoration

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

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Neuroscience and Medecine

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Project-Team DEMAR

Creation of the Project-Team: 2003 October 01, end of the Project-Team: 2015 December 31

Keywords:

Computer Science and Digital Science:

1.1.2. - Hardware accelerators (GPGPU, FPGA, etc.)
1.2.6. - Sensor networks
1.3. - Distributed Systems
2.3.1. - Embedded systems
2.3.3. - Real-time systems
2.4.1. - Analysis
2.4.2. - Verification
5.1.4. - Brain-computer interfaces, physiological computing
5.1.5. - Body-based interfaces
5.9.1. - Sampling, acquisition
5.9.2. - Estimation, modeling
6.1.1. - Continuous Modeling (PDE, ODE)
6.1.4. - Multiscale modeling
6.1.5. - Multiphysics modeling
6.2.6. - Optimization
6.3.2. - Data assimilation
6.3.3. - Data processing
6.4.3. - Observability and Controlability
6.4.4. - Stability and Stabilization

Other Research Topics and Application Domains:

1.1.11. - Systems biology
1.3.1. - Understanding and simulation of the brain and the nervous system
2.2.1. - Cardiovascular and respiratory diseases
2.2.2. - Nervous system and endocrinology
2.2.6. - Neurodegenerative diseases
2.4. - Therapies
2.5.1. - Sensorimotor disabilities
2.5.3. - Assistance for elderly
2.7. - Medical devices

1. Members

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2. Overall Objectives

2.1. Overall Objectives

Functional Electrical Stimulation (FES) has been used for about 30 years in order to restore deficient physiological functions. At the beginning, only surface stimulation was possible and thus only used in a clinical context due to the low reliability of electrode placements. In the early eighties, implanted FES appeared through well-known applications: pacemaker, Brindley bladder control, cochlear implant, and more recently deep brain stimulation (DBS).

Currently, FES is the only way to restore motor function even though biological solutions are studied, but not yet successfully tested on humans. Few teams carry out researches on implanted FES and the functional results remain poor. Nevertheless, the technique has proved to be useable and needs enhancements that we address in DEMAR. Regarding technology, complex electrode geometries associated with complex stimulus waveforms provide a way to perform fibre type selectivity and spatial localisation of the stimuli in the nerves. These features are not yet implemented and demand new hardware and software architectures. Several teams in Denmark (SMI U. Aalborg), Germany (IBMT Franhaufer Institute), England (U. College of London), Belgium (U. Catholique de Louvain), United States (Cleveland FES centre), and Canada (Ecole Polytechnique de Montréal), work on multi-polar neural stimulation but mainly on electrode aspect, except Polystim Lab of Montréal.

Such a complex system needs advanced control theory tools coupled with a deep understanding of the underlying neurophysiological processes. This major area of research will be also an important part of the DEMAR objectives.

Besides, experiments are necessary to: improve neurophysiology knowledge, identify and validate models, evaluate control strategies or test neuroprostheses. Our experiments are carried on valid and non-valid individuals in clinical environment, but also on animals. Nevertheless, it is really worth the effort in order to bring theory to useable systems.

Finally, industrial transfer is mandatory since we aim at proposing effective solutions to patients. Thus we try to prototype all our findings in order to validate and transfer efficiently our concepts. To be useable in clinical or private environments by the patients themselves, systems need to be certified as an industrial Medical Device.

DEMAR research is organized as follows:

1. Modelling and identification of the human sensory-motor system
2. Synthesis and control of functions
3. Interfacing artificial and natural parts through neuroprosthetic devices including stimulation and recording

The main applied research fields are then:

- Quantitative characterization of the human sensory-motor system firstly for motor disorders diagnosis and objective quantification, and secondly in order to help the design and the control of neuroprosthetic devices.
- Restoring motor and sensitive functions through implanted FES and neural signal sensing such as lower limb movement synthesis and control for spinal cord injured patients, synergetic control of the deficient limb for hemiplegic patients, bladder control, pain relief...
- Improving surface stimulation for therapy such as active verticalization of paraplegic patients, reduction of tremor, reeducation of hemiplegic post-stroke patients...

3. Research Program

3.1. Modelling and identification of the sensory-motor system

Participants: Mitsuhiro Hayashibe, Christine Azevedo Coste, David Guiraud.

The literature on muscle modelling is vast, but most of research works focus separately on the microscopic and on the macroscopic muscle's functional behaviours. The most widely used microscopic model of muscle contraction was proposed by Huxley in 1957. The Hill-Maxwell macroscopic model was derived from the original model introduced by A.V. Hill in 1938. We may mention the most recent developments including Zahalak's work introducing the distribution moment model that represents a formal mathematical approximation at the sarcomere level of the Huxley cross-bridges model and the works by Bestel and Sorine (2001) who proposed an explanation of the beating of the cardiac muscle by a chemical control input connected to the calcium dynamics in the muscle cells, that stimulates the contractile elements of the model. With respect to this literature, our contributions are mostly linked with the model of the contractile element, through the introduction of the recruitment at the fibre scale formalizing the link between FES parameters, recruitment and Calcium signal path. The resulting controlled model is able to reproduce both short term (twitch) and long term (tetanus) responses. It also matches some of the main properties of the dynamic behaviour of muscles, such as the Hill force-velocity relationship or the instantaneous stiffness of the Mirsky-Parmley model. About integrated functions modelling such as spinal cord reflex loops or central pattern generator, much less groups work on this topic compared to the ones working on brain functions. Mainly neurophysiologists work on this subject and our originality is to combine physiology studies with mathematical modelling and experimental validation using our own neuroprostheses. The same analysis could be drawn with sensory feedback modelling. In this domain, our work is based on the recording and analysis of nerve activity through electro-neurography (ENG). We are interested in interpreting ENG in terms of muscle state in order to feedback useful information for FES controllers and to evaluate the stimulation effect. We believe that this knowledge should help to improve the design and programming of neuroprostheses. We investigate risky but promising fields such as intrafascicular recordings, area on which only few teams in North America (Canada and USA), and Denmark really work on. Very few teams in France, and none at Inria work on the peripheral nervous system modelling, together with experimental protocols that need neuroprostheses. Most of our Inria collaborators work on the central nervous system, except the spinal cord, (ODYSSEE for instance), or other biological functions (SISYPHE for instance). Our contributions concern the following aspects:

- Muscle modelling,
- Sensory organ modelling,
- Electrode nerve interface,
- High level motor function modelling,
- Model parameters identification.

We contribute both to the design of reliable and accurate experiments with a well-controlled environment, to the fitting and implementation of efficient computational methods derived for instance from Sigma Point Kalman Filtering.

3.2. Synthesis and Control of Human Functions

Participants: Christine Azevedo Coste, Philippe Fraisse, Mitsuhiro Hayashibe, David Andreu.

We aim at developping realistic solutions for real clinical problems expressed by patients and medical staff. Different approaches and specifications are developped to answer those issues in short, mid or long terms. This research axis is therefore obviously strongly related to clinical application objectives. Even though applications can appear very different, the problematic and constraints are usually similar in the context of electrical stimulation: classical desired trajectory tracking is not possible, robustness to disturbances is critical, possible observations of system are limited. Furthermore there is an interaction between body segments under voluntary control of the patient and body segments under artificial control. Finally, this axis relies on modelling and identification results obtained in the first axis and on the technological solutions and approaches developped in the third axis (Neuroprostheses). The robotics framework involved in DEMAR work is close to the tools used and developped by BIPOP team in the context of bipedal robotics. There is no national team working on those aspects. Within international community, several colleagues carry out researches on the synthesis and control of human functions, most of them belong to the International Functional Electrical Stimulation

Society (IFESS) community. In the following we present two sub-objectives. Concerning spinal cord injuries (SCI) context not so many team are now involved in such researches around the world. Our force is to have technological solutions adapted to our theoretical developments. Concerning post-stroke context, several teams in Europe and North America are involved in drop-foot correction using FES. Our team specificity is to have access to the different expertises needed to develop new theoretical and technical solutions: medical expertise, experimental facilities, automatic control expertise, technological developments, industrial partner. These expertises are available in the team and through strong external collaborations.

3.3. Neuroprostheses

Participants: David Andreu, David Guiraud, Daniel Simon, Guy Cathébras, Fabien Soulier.

The main drawbacks of existing implanted FES systems are well known and include insufficient reliability, the complexity of the surgery, limited stimulation selectivity and efficiency, the non-physiological recruitment of motor units and muscle control. In order to develop viable implanted neuroprostheses as palliative solutions for motor control disabilities, the third axis "Neuroprostheses" of our project-team aims at tackling four main challenges: (i) a more physiologically based approach to muscle activation and control, (ii) a fibres' type and localization selective technique and associated technology (iii) a neural prosthesis allowing to make use of automatic control theory and consequently real-time control of stimulation parameters, and (iv) small, reliable, safe and easy-to-implant devices.

Accurate neural stimulation supposes the ability to discriminate fibres' type and localization in nerve and propagation pathway; we thus jointly considered multipolar electrode geometry, complex stimulation profile generation and neuroprosthesis architecture. To face stimulation selectivity issues, the analog output stage of our stimulus generator responds to the following specifications: i) temporal controllability in order to generate current shapes allowing fibres' type and propagation pathway selectivity, ii) spatial controllability of the current applied through multipolar cuff electrodes for fibres' recruitment purposes. We have therefore proposed and patented an original architecture of output current splitter between active poles of a multipolar electrode. The output stage also includes a monotonic DAC (Digital to Analog Converter) by design. However, multipolar electrodes lead to an increasing number of wires between the stimulus generator and the electrode contacts (poles); several research laboratories have proposed complex and selective stimulation strategies involving multipolar electrodes, but they cannot be implanted if we consider multisite stimulation (i.e. stimulating on several nerves to perform a human function as a standing for instance). In contrast, all the solutions tested on humans have been based on centralized implants from which the wires output to only monopolar or bipolar electrodes, since multipolar ones induce to many wires. The only solution is to consider a distributed FES architecture based on communicating controllable implants. Two projects can be cited: Bion technology (main competitor to date), where bipolar stimulation is provided by injectable autonomous units, and the LARSI project, which aimed at multipolar stimulation localized to the sacral roots. In both cases, there was no application breakthrough for reliable standing or walking for paraplegics. The power source, square stimulation shape and bipolar electrode limited the Bion technology, whereas the insufficient selection accuracy of the LARSI implant disqualified it from reliable use.

Keeping the electronics close to the electrode appears to be a good, if not the unique, solution for a complex FES system; this is the concept according to which we direct our neuroprosthesis design and development, in close relationship with other objectives of our project-team (control for instance) but also in close collaboration with medical and industrial partners.
Our efforts are mainly directed to implanted FES systems but we also work on surface FES architecture and stimulator; most of our concepts and advancements in implantable neuroprostheses are applicable somehow to external devices.

4. New Software and Platforms

4.1. Synergy Neurostimulation Software

Participants: Arthur Hiairrassary, David Andreu, David Guiraud.

We have developed a specific software environment called Synergy Neurostimulation Software (fig.1), allowing to remotely manage a stimulation architecture based on one controller piloting a set of distributed stimulation units, connected by means of a dedicated network. The controller embeds the set of FES functions according to which it controls stimulation units, in real-time.

This FES distributed architecture is based on our last version of stimulation units that embed stimulation sequencing and a more efficient modulation mechanism.

Synergy Neurostimulation Software has been registered at the french Agence de Protection des Programmes (APP).

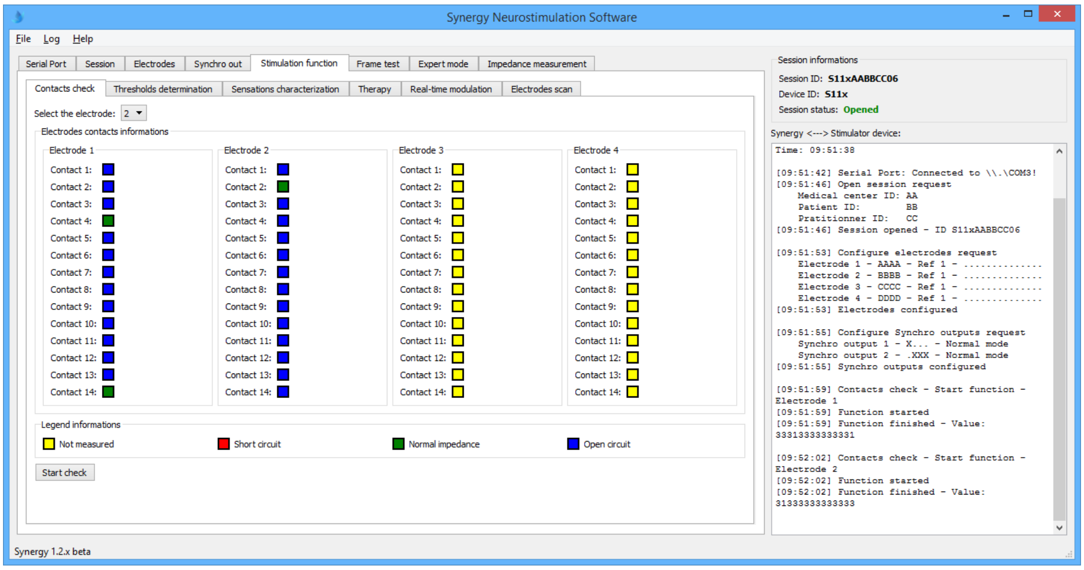


Figure 1. Synergy Neuromodulation Software

4.2. HILECOP

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: a Petri Net (PN) based behavior (fig.2), 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).

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.

Undergoing work concerns the integration, in the HILECOP tool, of the formalism evolutions that allow behavior agregation as well as exception handling, both for analysis and implementation sides.

Specification of GALS systems (Globally Asynchronous Locally Synchronous) is also an ongoing work, the aim being 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).

- Participants: Baptiste Colombani, David Andreu, Thierry Gil, Robin Passama
- Contact: David Andreu

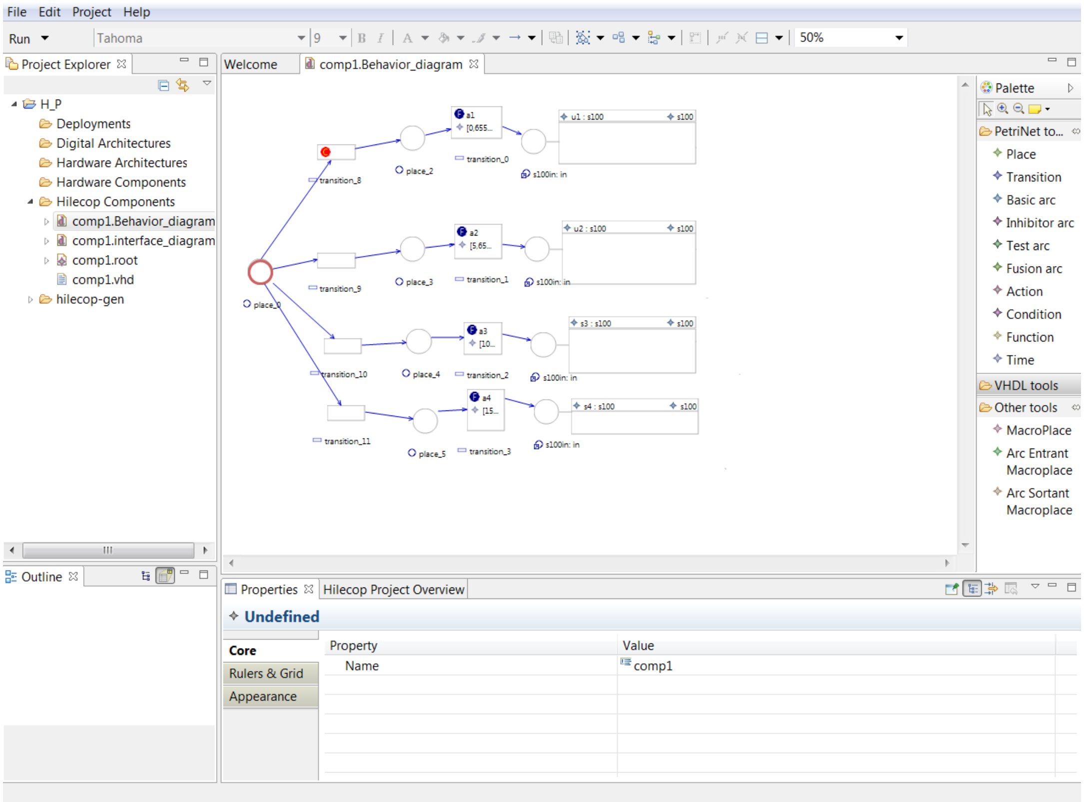


Figure 2. HILECOP screenshot

4.3. MOS2SENS

Model Optimization and Simulation To Selective Electrical Neural Stimulation

KEYWORDS: Neurosciences - Health - Physiology

FUNCTIONAL DESCRIPTION

This model can predict nerve fiber activation through multipolar electrode stimulation. Furthermore the models provide an optimal current configuration to activate accurately the targeted muscle or organ (indeed a targeted group of fiber).

The new software MOS2SENS is an adjustment support tool for neuroprosthetics devices. It models and optimizes the current injected by multipolar CUFF electrodes inside the nerve in order to activate selective fiber targets in terms of spatial criterion.

- Participants: Melissa Dali, Olivier Rossel and David Guiraud
- Contact: David Guiraud

4.4. PALGate

KEYWORDS: Health - Home care - Handicap

- Contact: David Daney

4.5. PersoBalance

PersoBalance: A Personalized Balance Assessment in Home Rehabilitation
KEYWORDS: Health - Home care - Handicap

4.5.1. PersoBalance: A Personalized Balance Assessment in Home Rehabilitation

Participants: Mitsuhiro Hayashibe, Alejandro Gonzalez [Euromov], Philippe Fraisse.

The objective of this software is to realize a personalized evaluation of the postural balance to be used in home-based rehabilitation, by using portable sensors such as Kinect and wii board. After the one time of identification, the system provide us the personalized estimation of the center of mass (CoM) for the whole body only with Kinect information, through Statically Equivalent Serial Chain method.

The first function is the adaptive identification interface for the CoM parameters based on Kalman filter which allows a subject to provide different postures interactively with minimized time length. The second function is the balance measure visualization (stable or instable) based on the identified model for each subject considering subject-specific body differences on the segment mass distribution.

Recently, this software was demonstrated at the event of Rencontre Inria-Industrie 13/10/2015 at Bordeaux. https://www.inria.fr/centre/bordeaux/innovation/rii-sante/demonstrations2 It is also filed at Software Catalogue of Inria. https://www.inria.fr/centre/bordeaux/innovation/rii-sante/catalogue-logiciels

PersoBalance is registered with the Agency for the Protection of Programs (APP) and deposited at the BNF (Bibliotheque Nationale de France). Its registration number is Antepedia Deposit 20150710154654.

4.6. SENISManager

Stimulation Electrique Neurale dIStribuee
FUNCTIONAL DESCRIPTION

SENISManager is a specific software environment allowing to remotely manage and control a network of DSUs, i.e. the distributed FES architecture. SENISManager performs self-detection of the architecture being deployed. This environment allows the manipulation of micro-programs from their edition to their remote control. It also allows the programming of control sequences executed by an external controller in charge of automatically piloting a stimulator.

- Participants: David Andreu and Robin Passama
- Contact: David Andreu

4.7. sensbiotk

KEYWORDS: Motion analysis - Sensors

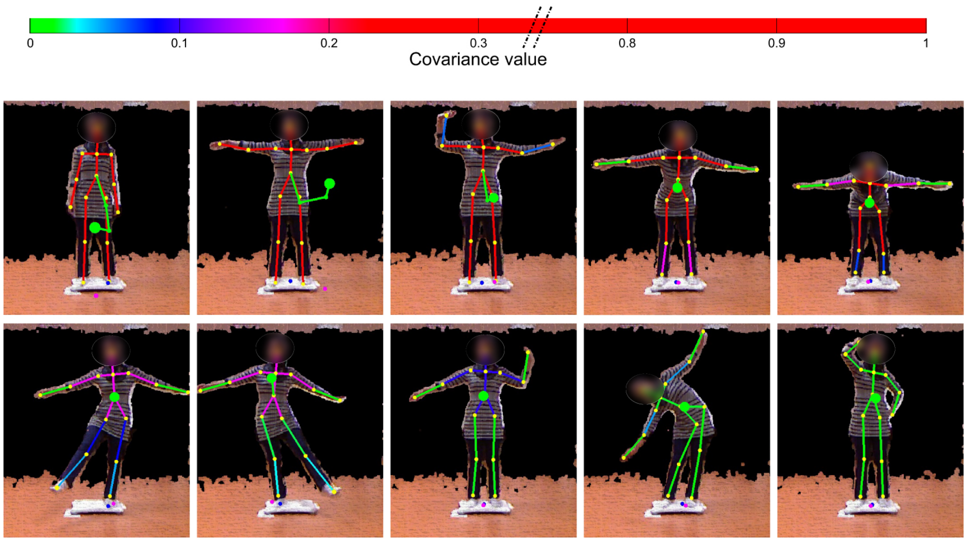


Figure 3. PersoBalance: A Personalized Balance Assessment in Home Rehabilitation: This scene shows the process how the CoM is being identified through different postures information with portable sensors.

SCIENTIFIC DESCRIPTION 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.

FUNCTIONAL DESCRIPTION

sensbiotk toolbox for Python. for the calibration, acquisition, analysis and visualization of motion capture using IMU

- Participants: Christine Azevedo Coste, Roger Pissard-Gibollet and Benoît Sijobert
- Contact: Roger Pissard Gibollet
- URL: http://sensbio.github.io/sensbiotk/

5. New Results

5.1. Modelling and identification of the sensory-motor system

5.1.1. Implementation and Validation of a Stride Length Estimation Algorithm, Using a Single Basic Inertial Sensor on Healthy Subjects and Patients Suffering from Parkinson's Disease

Participants: Christine Azevedo Coste, Benoît Sijobert, Mourad Benoussaad [ENIT, Tarbes, France], Christian Geny [CHU Montpellier, Neurology, France], Jennifer Denys [stagiaire M2 STIC SANTE - DEMAR].

Providing a clinical oriented solution, our study presented a gyrometer and accelerometer based algorithm for stride length estimation. Compared to most of the numerous existing works where only an averaged stride length is computed from several IMU, or where the use of the magnetometer is incompatible with everyday use, our challenge here has been to extract each individual stride length in an easy-to-use algorithm requiring only one inertial sensor attached to the subject shank. Our results were validated on healthy subjects and patients suffering from Parkinson's disease (PD). Estimated stride lengths were compared to GAITRite walkway system data: the mean error over all the strides was less than 6 percents for healthy group and 10.3 percents for PD group. This method provides a reliable portable solution for monitoring the instantaneous stride length and opens the way to promising applications ([27]).

5.1.2. Dynamic mapping of upper limb tremor by muscle ultrasonography

Participants: Olivier Tassaert [stagiaire M1 - DEMAR / ICAR], Benjamin Gilles, Olivier Strauss [LIRMM], Christian Geny [CHU Montpellier, Neurology, France], Christine Azevedo Coste.

Focal treatment of action tremor by botulinum toxin injections has been inadequately investigated and at best provides modest relief with significant muscle weakness. Complexity of multi-joint tremulous movements results in non-individualized dosing regimens. Tremor is complex, especially in the upper extremity, and its manifestation can change depending on posture, task, and bodypart. Proper characterization of the tremor based on visual inspection alone is a daunting task for the clinician. Identification of the main trembling muscles task disturbing is challenging because many upper limb muscles are bi-functional. The performance of electromyographic(EMG) pattern-recognition based method in classifying movements strongly depends on arm positions and needs multiple measurements. High density-surface EMG (HD-sEMG) is a non-invasive promising technique to measure electrical muscle activity but has not been used for tremor research because deep muscles could not be investigated Quantification of tremor dynamics by kinematics may be a feasible assessment and guidance tool which can be used to optimize injection conditions for focal tremor therapy. This approach is limited by the redundancy of the upper limb muscle organization Contribution of synergistic muscles toward specific movements over multi joint systems may change with varying position of distal or proximal joints. The choice of injected muscles remains highly subjective and variable. In the study of Rahami, ten different arm or forearm muscles have been injected and improvement was mild and delayed and associated with muscle weakness. In recent years, muscle ultrasonography has become a promising tool for diagnosing neuromuscular disorders . This technique is a non-invasive, low-cost, imaging modality that may be used to characterize normal and pathological muscle tissue but also subtle muscular activity (fasciculatios) in amyotrophic lateral sclerosis. The frequency of tremor remains stable during movement (3 to 8 Hz). We have initiated the investigation of the use of standard ultrasound as a technique to identify muscle groups responsible of upper limb tremor in patient with essential tremor or Parkinson's disease. The feasibility of the overall procedure has been validated: the acquisition procedure on patients, the possibility to track and segment the apparent motion in images using optical flow, and the ability to segment muscle groups by registering a 3D anatomical template.

5.1.3. Understanding electrophysiological effects of direct electrical stimulation of the brain during wide awake surgery

Participants: Marion Vincent, Olivier Rossel, Mitsuhiro Hayashibe, Hugues Duffau [CHU Montpellier], David Guiraud, François Bonnetblanc.

Direct electrical stimulation (DES) have been recently introduced in the neurosurgery of slow-growing and infiltrative brain tumors to guide the resection. By generating transient perturbations, this method allows the real-time identification of both cortical areas and subcortical networks that are essential for the function. Thus, as much as possible, non-functional tissue can be removed while minimizing the sequelae. However, there is much controversy as to whether the use of DES during wideawake surgery is the gold standard for studying the brain function. It is sometimes wrongly assumed that electrical microstimulation (EMS) and DES induce similar effects in the nervous tissues and have comparable behavioural consequences. Both of them are used to perform functional brain mapping: EMS for animal fundamental neuroscience experiments, and DES for neurosurgery patients. We tried to shed new light on electrical stimulation (ES) techniques in brain mapping by comparing EMS and DES [1]. In fact, their effects cannot be directly compared - especially in the electrophysiological domain. There is a gap between theory and practice for ES of the brain. We do not know exactly how ES and especially DES influence the electrophysiological state of networks in the brain; a strong biophysical rationale is lacking. In contrast, the gap between EMS and DES highlights the potential for new experimental paradigms in electrical stimulation for functional brain mapping. In view of this gap and recent technical developments in stimulator design, it may now be time to move towards alternative, innovative protocols. Moreover, the understanding of the electrophysiological effects of DES remains an open and key question. Intra-operative EEG (iEEG) recordings were studied to analyze if and how stimulation currents spread at distant sites. Data were collected during an awake brain surgery for one patient. We observed significant changes in the frequency content at different iEEG sites during DES [2]. Subcortical DES led to neuromodulation at more sites than cortical DES (Figure 4). This may be due to (i) a better conduction and propagation following the direct stimulation of large, myelinated axons and (ii) the greater current intensity in subcortical DES. Further research will have to characterize these aspects more carefully and apply cortical and subcortical DES with identical current intensities [30], [31].

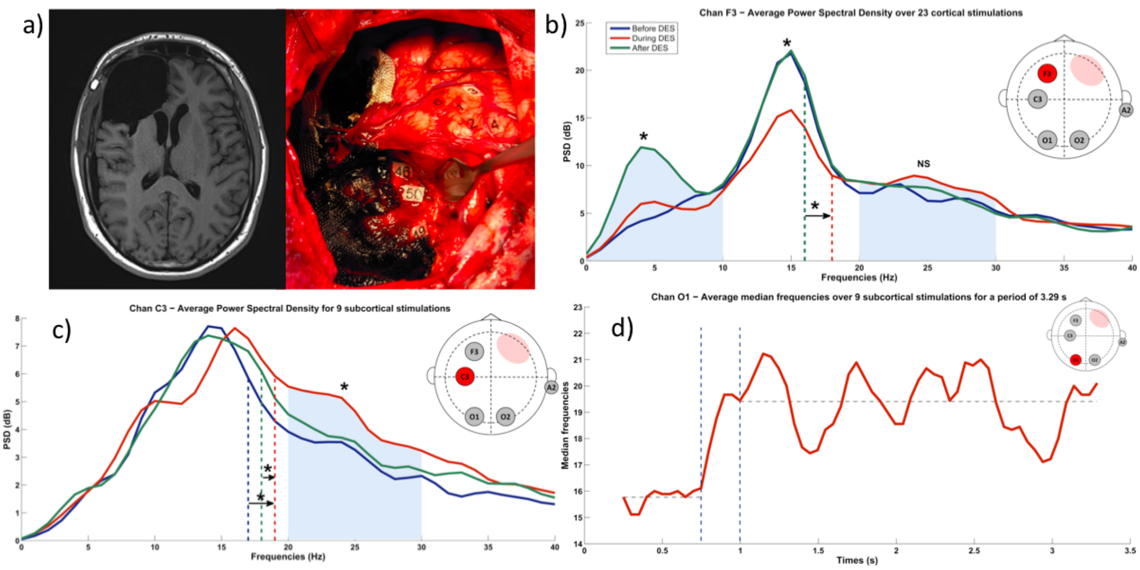


Figure 4. (a) Post-operative MRI of the patientâs brain, showing the right frontal cavity and an intraoperative view of the brain with the main anatomical landmarks. (b) The mean PSD of the iEEG signal, on F3, before, during and after each period of cortical DES. (c) The mean PSD of the iEEG signal, on C3, before during and after each period of subcortical DES. (d) The moving window median frequency averaged over nine subcortical DESs periods for PSD measured at O1.

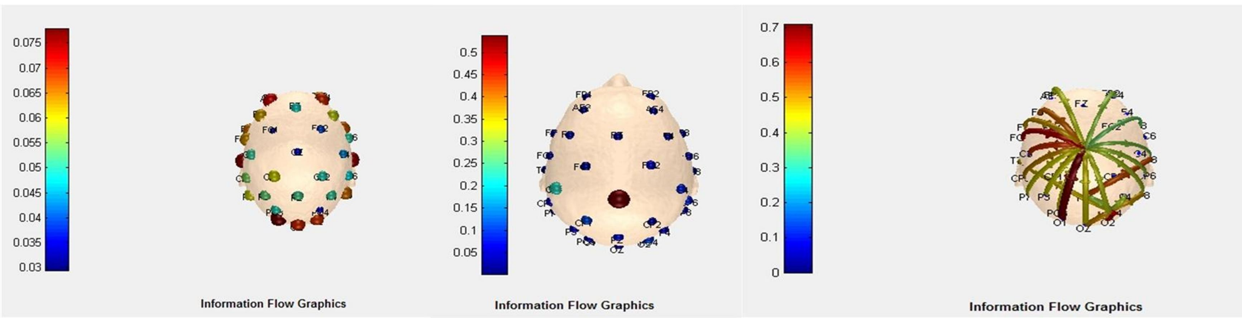
5.1.4. Functional Connectivity Analysis of Motor Imagery EEG signal for Brain-computer Interfacing Application: A preliminary study

Participants: Saugat Bhattacharyya, Poulami Ghosh [Jadavpur University, India], Ankita Mazumder [Jadavpur University, India], D.n. Tibarewala [Jadavpur University, India], Mitsuhiro Hayashibe.

The human brain can be considered as a graphical network having different regions with specific functionality and it can be said that a virtual functional connectivity are present between these regions. These regions are regarded as nodes and the functional links are regarded as the edges between them. The intensity of these functional links depend on the activation of the lobes while performing a specific task(e.g. motor imagery tasks, cognitive tasks and likewise). The analysis of these networks are performed by using a very useful mathematical tool called graph theory. Graph theory basically represents the entire functional network with a number of nodes and edges between them and the amount of connectivity existing between two nodes is depicted by assigning weights to the edges between them. In this study we have tried to utilize functional connectivity between different parts of the human brain for classifying a motor imagery task.

Brain connectivity patterns can be determined by using two types of measures, namely, Bivariate and Multivariate. Here we have considered a multivariate measure known as multivariate autoregressive (MVAR) model. One of the most widely investigated connectivity measure is the Directed Transfer Function (DTF). This function basically computes the directional influences between any two given nodes. There are a number of theoretical indices for defining a graph. In this preliminary work, two indices, namely node strength and network density are measured from the DTF values. In the current study, the BCI competition Dataset III is used for computing different multivariate measures.

The inflow-outflow graph of subject 1 while imagining right hand movement in the first training set are given in Fig.5. Fig. 5(a) describes the amount of inflow of functional connectivity going out of all the 32 electrodes and these are color coded to indicate the intensity of these inflows. From Fig. 5(a) it is quite evident that the inflows are maximum in the frontal, temporal and occipital lobes. Figure 5(b) depicts the functional outflow from the nodes and in contrast to Fig.5(a) it shows that the outflows are maximum from the Central lobe(Cz). In Fig 5(c), the direction of the flow between different nodes are shown and it can be seen clearly that majority of the paths are going from Cz to different nodes of the frontal, parietal and temporal lobes.



(a) (b) (c)

Figure 5. (a) Inflow graph, (b) Outflow graph and (c) Out to inflow graph of the functional connectivity network of the brain while imagining right hand movement.

5.1.5. A Generic Transferable EEG Decoder for Online Detection of Error Potential in Target Selection

Participants: Saugat Bhattacharyya, Amit Konar [Jadavpur University, India], D.n. Tibarewala [Jadavpur University, India], Mitsuhiro Hayashibe.

Detection of error from electroencephalography (EEG) signals as feedback while performing a discrete target selection task is beneficial for general Brain-computer Interfacing (BCI) systems including rehabilitative application. Error Related Potentials (ErrP) are EEG signals which occur when the participant observes an erroneous feedback from the system.

In this study, we have designed a novel scheme for detection of error feedback directly from the EEG signal. For this purpose, we have used a P300-speller dataset from the 'BCI Challenge @ NER 2015' competition hosted at Kaggle. The task involves the subject to select a letter of a word which is followed by a feedback period. The feedback period displays the letter selected and if the selection is wrong, the subject perceives it by the generation of ErrP signal. Our proposed system is designed to detect whether the feedback is erroneous or not. The decoder designed for this task is an ensemble of linear discriminant analysis, quadratic discriminant analysis and logistic regression classifier. The decoder is also transferable in nature as it is should work with single-trial on new subject without any prior subject-specific training.

The block diagram of the BCI system adopted for online ErrP detection from input EEG signals is shown in Fig.6. The system implements three main processes: i) Pre-processing of the signal, i.e., temporal filtering in the bandwidth [0.1, 10]Hz, ii) Extraction of relevant features corresponding to the mental state from the signal using savitzsky-golay filter and meta-data of the features, and iii) Classification of the features, using our proposed decoder, to detect the intention of the participant from two given states: *Error* and *No-Error*. A switch is incorporated in the design to detect the beginning of feedback period in the trials, which is marked in the datasets. We have tested the online functionality of the BCI system on the test dataset provided in the website. To simulate a real-time condition, the EEG is continuously streamed until an onset of the feedback period is detected. On detection of the feedback period, the system extracts a pre-defined length of signal for further processing and the rest are rejected.

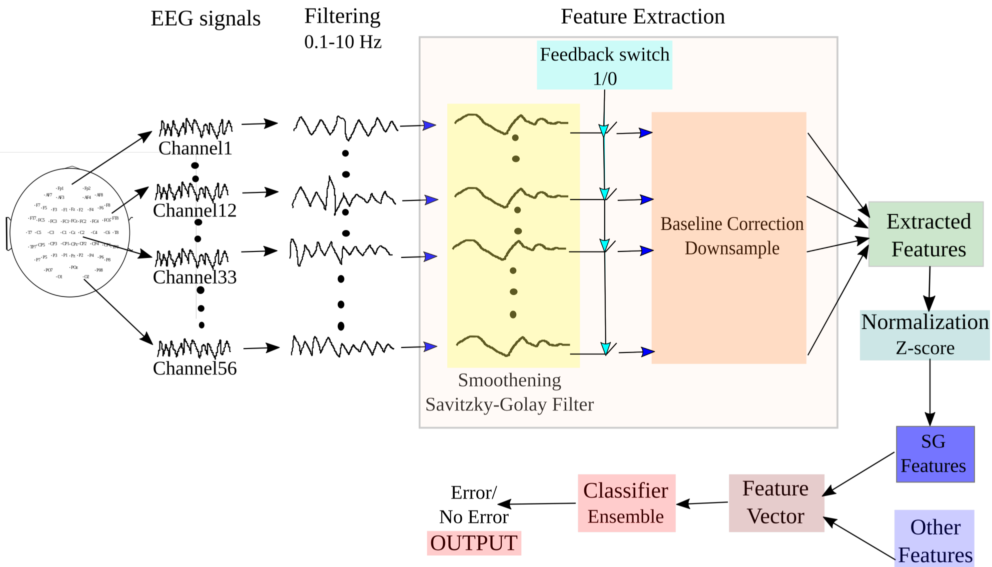


Figure 6. Block diagram of the BCI system adopted for online detection of Error Related Potentials from the input EEG

5.2. Synthesis and Control of Human Functions

5.2.1. FES-cycling and participation to Cybathlon competition

Participants: Christine Azevedo Coste, Benoît Sijobert, Charles Fattal [CRF DIVIO, Dijon, France], Antonio Padilha [UNB, Brasilia, Brazil], Emerson Fachin Martins [UNB, Brasilia, Brazil], David Andreu.

DEMAR and University of Brasilia will jointly participate with two SCI pilots to Cybathlon - FES-Bike competition. Cybathlon intends to promote assistive technologies during a competition. Two trikes will be adapted, an original control strategy will be proposed and two paraplegic individuals (one from Brazil and one from France) will be trained during the upcoming year. The protocol will be submitted to CPP ethical committee for agreement in the coming weeks (http://freewheels.inria.fr/).

5.2.2. PersoStim: A Personalized Closed-loop FES Control of Muscle Activation with Evoked EMG Feedback

Participants: Mitsuhiro Hayashibe, Zhan Li [University of Electronic Science and Technology of China], David Andreu, David Guiraud.

Functional electrical stimulation (FES) is a useful technique for restoring motor functions for spinal cord injured (SCI) patients. Muscle contractions can be artificially driven through delivery of electrical pulses to impaired muscles, and the electrical activity of contracted muscles under stimulus recorded by electromyography (EMG) is called M-wave. The FES-induced muscle activation which is represented by evoked EMG recordings can indicate the muscle state. Accurate control of muscle activation level by FES is the first step toward achieving more complicated FES control tasks.

A new FES closed-loop control strategy, EMG-feedback predictive control (EFPC), was developped to adaptively control stimulation pattern compensating to time-varying muscle state changes such as muscle fatigue and stimulation electrode detachment, along with the consideration of the personalized muscle responses to the electrical stimulation. This software manages a real-time FES system for control of muscle activation by online modulating pulse width of stimulus. The excitation muscle dynamics is modelled by Hammerstain system with stimulus pulse width and eEMG as input and output respectively. The model predictive control strategy is adopted to systematically produce the pulse width command of the stimulator. It is implemented together with Vivaltis portable stimulator. Four reference muscle activation patterns are provided to test and validate the real-time closed-loop FES control system. Real-time control results show promising control performances.

Recently, this software was demonstrated at the event of Rencontre Inria-Industrie 13/10/2015 at Bordeaux. https://www.inria.fr/centre/bordeaux/innovation/rii-sante/demonstrations2

5.2.3. Direct spinal stimulation for rehabilitation of bladder, bowel and sexual functions in spinal cord injury

Participants: Christine Azevedo Coste, Luc Bauchet [CHU Montpellier], Claire Delleci [CHU Bordeaux], Charles Fattal [CRF DIVIO, Dijon, France], Thomas Guiho, David Guiraud, Jean-Rodolphe Vignes [CHU Bordeaux].

Complete spinal cord injury results in loss of movement and sensory sensations but also in function of organs. For example, nearly all spinal cord injured subjects lose their bladder control and are prone to kidney failure if they do not apply intermittent (self-) catheterization. Electrical stimulation of the sacral spinal roots with an implantable neuroprosthesis is one option besides self-catheterization to become continent and control micturition. However, many persons do not ask for this neuroprosthesis since deafferentation and loss of sensory functions and reflexes are serious side effects. Spinal cord stimulation (SCS) is a general term which includes both epidural and intradural stimulation. Originally associated with the treatment of chronic neurogical pain (in the 1970ies), SCS led also to immediate and profound improvements of sensory and motor functions in recent studies both on SCI patients (only on very few case studies) and rodents. Despite these promising results some limitations have still to be overcome. Among them, the use of small animal models, the empirical aspect of the stimulation procedure and the impact of these protocols on intestinal and urinary functions are critical. To counteract these limits, we want to explore intradural and epidural stimulations in an intermediate model- the house pig- and assess their impact on bladder, guts and genitals. In order to evaluate our approach, we will record EMG signals of lower limbs and sphincters (both urethral and anal), and simultaneously, we will monitor bladder and rectal pressure.

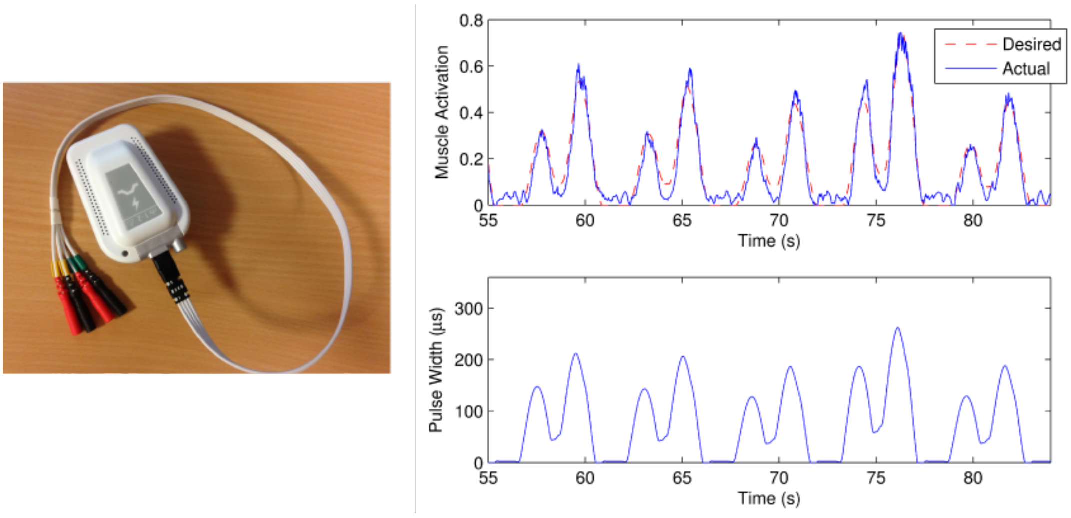


Figure 7. Left: Vivaltis portable stimulator, Right: Real-time control performance of muscle activation with desired dual sinusoidal shaped muscle activation pattern (red dash line is desired muscle activation trajectory and blue solid line is the measured muscle activation under the muscle activation control by FES). The lower plot is the corresponding computed stimulation pulse width.

Already preliminary experimental explorations were performed with direct spinal cord stimulation in June (on 2 animals). Experiments were conducted under neurosurgeons involved in the project and urodynamics was recorded together with rectum pressure and sphincters EMG during each stimulation session.

5.3. Neuroprostheses and technology

5.3.1. Selectivity of nerve stimulation using a 12 pole multipolar cuff

Participants: Wafa Tigra, Olivier Rossel, Thomas Guiho, David Guiraud, Christine Azevedo Coste, Hubert Taillades [UM].

Experimentations were performed on 5 rabbits (New Zealand white). A multipolar cuff electrode (12 poles, diameter 3 mm, length 20 mm, 12 oblong contacts of 5mm length) was placed around the sciatic nerve of the rabbit 3 cm above the tibiofibular bifurcation. The nerve was stimulated with increasing intensity. The protocol consisted of the activation of one or more channels of the electrode, the input is a biphasic asymmetric stimulation and the pulse width is modulated in intensity (up to 2.4 mA) and fixed in length (250 μsec, 100 μsec interstim). A stimulus (4 Hz) is used for 2 seconds. 48 configurations of stimulation were tested. Needle electrodes were inserted on the lateral and medial gastrocnemius, soleus, tibialis and extensor digitorum muscles to record EMG signals and were used to evaluate the selectivity capacities of given cuff electrode configuration. The rabbit foot was also attached to a force platform. Inter-fascicular selectivity was observed for the 5 animals. Intra fascicular selectivity was also observed in 3 animals. Placed at a single location, our cuff electrode is capable to activate, selectively, some muscles. Experiments were performed under ethical comittee agreement at the "Plateau Technique Chirurgie Exprimentale" (Montpellier).

5.3.2. A novel EMG interface for individuals with quadriplegia to pilot robot hand grasping

Participants: Wafa Tigra, Benjamin Navarro [LIRMM], Andrea Cherubini [LIRMM], Xavier Gorron [???], Anthony Gelis [PROPARA], Charles Fattal [CRF DIVIO, Dijon, France], David Guiraud, Christine Azevedo Coste.

We have developed and validated a new human-machine interface dedicated to individuals with quadriplegia. We investigated the feasibility of online processing sus-lesional muscle responses, to pilot an assistive device. The ability to voluntary contract a set of selected muscles was assessed in five spinal cord injured subjects through electromyography analysis. Two subjects have also been asked to use the EMG interface to control palmar and lateral grasping of a robot hand (fig.8). These preliminary results sound very promising and open the way to new interface solutions for high level spinal cord injured patients(fig.8).

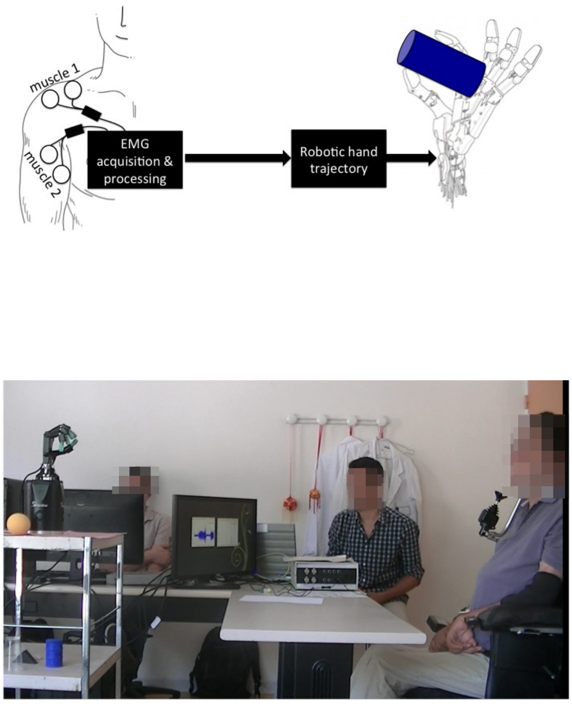


Figure 8. Principle of robot hand control through EMG signals; Setup description and upper arm positioning during EMG recordings.

5.3.3. Wearable 56-pole stimulator

Participants: Arthur Hiairrassary, David Andreu, David Guiraud, Olivier Rossel, Thomas Guiho.

In the context of the EPIONE European project, we have designed and developed, with Axonic, a wearable multichannel stimulator (fig.9), to face phantom limb pain (PLP). This 56-pole neural stimulator is based on four 16-pole stimulation units (each one being connected to a 16-pole TLIFE intra-fascicular electrode) connected to a real-time controller by means of an embedded deterministic network. This controller, in charge of executing FES functions (threshold determination, sensation characterization, etc.), pilots the stimulation units and allows for real-time modulation of the multisite stimulation. The controller can be remotely configured and exploited by the practitioner, by means of a dedicated software (Synergy Neuromodulation Software). But it has been also connected to the controller of the EPFL's artificial hand, in order to link hand touch sensors with neural stimulation to induce natural, meaningful sensations to the amputee.

This stimulator has been deeply validated through animal experiments (rats and pigs, respectively with UAB Barcelone and SMI Alboorg) and is currently used on human at UCBM Rome (http://project-epione.eu/).

Figure 9. 56-pole neural stimulator

5.3.4. CORAIL: Neural Stimulation Integrated Circuit

Participants: Jérémie Salles, Guy Cathébras, Milan Demarcq, David Guiraud, Guillaume Souquet, David Andreu.

DEMAR is currently finishing the development of CORAIL (Current Output Reconfigurable Asic Interface Low power), a new ASIC dedicated to electric neural stimulation.

Its main analog characteristics are:

- 12 independent current output channels;
- a full-scale current of 5 mA with a quantum of 1.3 μA;
- a symmetrical power supply ($\pm$ VHT with ground middlepoint).

This front-end integrated circuit is designed to perform multipolar electrical stimulation of the nerve with highly configurable waveforms in order to achieve selective activation of organs or muscles. In comparison with previously developed current output ASICs, the CORAIL IC embeds new features such as the storage of multiple electrode configurations or the possibility to internally combine poles. These specific aspects of CORAIL and the fact that its elaboration benefited from clinical experience in the team will allow enhanced integration within the whole electrical stimulation environment.

The resulting stimulation ASIC aims to be part of an implanted distributed stimulation system, composed of multiple stimulation units spread across the body, in which CORAIL will be the front-end entity in charge of delivering the current to the electrode. Thus, special care has been paid to its integration in such a network with an emphasis on low power consumption for which different mechanisms have been implemented.

The ASIC is currently undergoing the last phases of its development and a first version is due for fabrication in February 2016.

5.3.5. Tele-Rehabilitation Platform for Gait Training

Participants: Mitsuhiro Hayashibe, Antonio P.l. Bo [Universidade de Brasilia, Brasil], Leslie Casas [Pontificia Universidad Catolica del Peru, Peru], Gonzalo Cucho [Pontificia Universidad Catolica del Peru, Peru], Dante Elias [Pontificia Universidad Catolica del Peru, Peru].

Throughout the world there is an increasing need for better technologies for rehabilitation and assistance. These new solutions must present improved performance in terms of therapy effectiveness, while at the same time minimizing the corresponding costs. In this scenario, computer-aided methods represent a promising alternative for the challenges currently faced by the rehabilitation domain. A tele-rehabilitation platform for gait training in intercontinental circumstances is developed under STIC-AmSud program. This project was joint program 2012-2013 among Inria France, UnB (University of Brasilia) and PCUP (Pontifical Catholic University of Peru) for tele-rehabilitation framework. This system has two mode: Self-modulation control in which the subject can control the speed of the motion therapy with his comfortable training speed and Guidance control mode in which the motion transfer is performed from one therapist to one patient. Guidance control can be performed both with local data transmission and intercontinental data transmission. Fig. 10 shows the case where the motion transfer regarding foot placement was performed with local data transmission. The test with intercontinental data transmission was also realized between France and Peru.

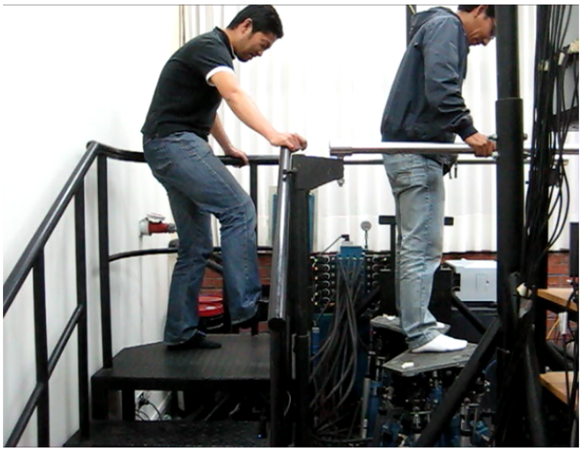


Figure 10. Tele-rehabilitation platform for gait training: Guidance control mode.

5.3.6. Control and scheduling co-design for stimulation systems

Participants: Daniel Simon, David Andreu.

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. To this aim we are developing a real-time open software simulation system, 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.

Realistic simulations are effective tools to design and tune complex systems whose analysis cannot be provided only by theory. Several simulation steps can be explored, from simple functional analysis to HIL, to design, test, tune and validate both the single components of the system and their interactions in a distributed architecture. Simulations are precious, as they allow for non-destructive trials, which must be considered in any domain but this is of particular interest for bio-engineering [42].

It is expected that this particular simulator may provide inputs in two main directions. Firstly it allows for preliminary testing and tuning new FES protocols without needing for real experiments with patients, and

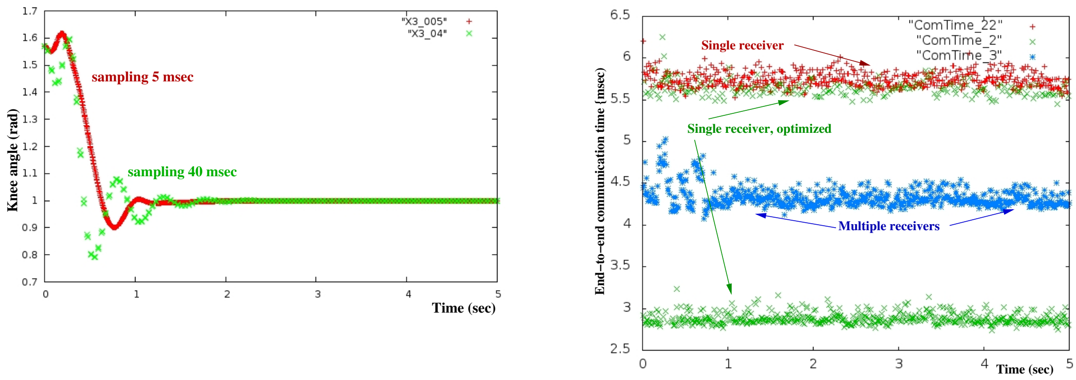


Figure 11. Simulation traces : knee position w.r.t. sampling and communication delays

may help for writing the ethical protocols needed for any experiments involving livings. Secondly it can be used to preliminary evaluation of new technologies or implementations, without costly reworking of existing electronic chips or certified components.

The simulation software is open, so that enhancements w.r.t. to the original release can be added upon request of various designers and to fulfill various objectives.

5.3.7. Control loops design principles for autonomic computing

Participants: Daniel Simon, Eric Rutten [Inria Grenoble Rhône-Alpes], Nicolas Marchand [GIPSA-lab].

Computing systems are becoming more and more dynamically reconfigurable or adaptive, to be flexible w.r.t. their environment and to automate their administration. Autonomic computing proposes a general structure of feedback loop to take this into account. We are particularly interested in approaches where this feedback loop is considered as a case of control loop where techniques stemming from Control Theory can be used to design efficient safe, and predictable controllers. This approach is emerging, with separate and dispersed effort, in different areas of the field of reconfigurable or adaptive computing, at software or architecture level.

We aim at conveying to Computer Scientists the interest and advantages of adopting a Control Theory perspective for the efficient and predictable design of autonomic systems. Compared with open-loop, closed-loop control provides adaptability and robustness, allowing for the design of fault-tolerant systems against varying and uncertain operating conditions. However, there still is a deep need for research in the problems of mapping from high-level objectives in terms of Quality of Service (QoS) or Service Level Objectives (SLO) and abstract models towards lower-levels effective actions on the managed systems [46].

5.4. Others

5.4.1. Do doors opening affect the air contamination in clean surgery? A Prospective, Cross-sectional Study (the ARIBO Project)

Participants: Gabriel Birgand [APHP], Christine Azevedo Coste, Stephane Rukly [INSERM], Roger Pissard-Gibollet [Inria Grenoble Rhône-Alpes], Jean-Christophe Lucet [APHP].

Inappropriate staff behaviours can lead to environmental contamination in the operating room (OR) and subsequent surgical site infection (SSI). This study focused on the continued assessment of OR staff behaviours using doors sensors and their impact on the SSI risk during surgical procedures. This multicentre observational study included 13 ORs in 10 hospitals, 5 University hospitals and 5 private hospitals. Two specialties of clean surgery with cutaneous approach were included: cardiac surgery with procedures requiring a full median sternotomy (CABG or valve replacement surgery); and planned orthopaedic surgery for total hip (THR) or knee replacement (TKR). For each surgical specialty involved, the observed ORs were randomly selected. Doors opening were observed by means of wireless inertial sensors fixed on the doors. For each surgical procedure, 3 microbiological air counts, continuous particles counts of 0.3, 0.5 and 5μm particles, and one bacteriological sample of the wound before skin closure were performed. We collected informations on the OR staff, surgical procedures and surgical environment characteristics. Statistics were performed using univariate and multivariate analysis to adjust on aerolic and architectural characteristics of the OR. We included 34 orthopaedic and 26 cardiac procedures. The mean duration of intervention, from patient entry to exit in the OR, was 5.3 (SD 1.1) h. in cardiac and 2.6 (0.7) h. in orthopaedic surgery. The median number of doors opening was 146 (IQR: 121-183; Min-Max: 86-319) per intervention and 29 (IQR: 23-36; Min-Max: 17, 54) per h. in cardiac surgery and 71.5 (IQR: 58-92; Min-Max: 54-136) per intervention and 29 (IQR: 25-34; Min-Max: 16-65) per h. in orthopaedic procedures. Doors stayed open in average 43 minutes (Min-Max: 19-115) in cardiac and 36 (8-199) in orthopaedic, representing respectively 13.5 percents and 23 percents of the duration of intervention. The highest frequency of doors opening was observed between wound closure and patient exit, median 20.1 openings/h (12.5-32.3) and from patient entry to the incision 13.2 openings/h (8-19). The number and duration of doors opening was significantly different between centres (higher in university hospital, p<0.01)). High frequency of openings was observed for doors that should stay closed during procedures (materials store, decontamination room). The number of doors opening from skin incision to wound closure affected significantly the 0.5 and 5μm particles count (p<0.01 and 0.02 respectively). This study based on automatic observation suggests a large heterogeneity of doors openings between types of interventions, ORs and hospitals. Data give a standard of doors opening for CABG, THR and TKR. Door openings affected air contamination, potentially jeopardizing operating room sterility. The causes and influences of behaviours in the OR must be evaluated to identify ways to reduce the associated risks.

6. Partnerships and Cooperations

6.1. Regional Initiatives

AOI PARKDEMAR Participants: Christine Azevedo Coste, Benoît Sijobert. Appel d'offre Interne (AOI) CGS Merri (CHU Montpellier). Development and evaluation of Freezing detection system in parkinson disease.
Program Région Languedoc-Roussillon "Manifestations scientifiques 2016" - 11000 euros for the organization of IFESS conference in 2016. http://ifess2016.inria.fr/
LABEX NUMEV Participants: Christine Azevedo Coste, Christian Geny, Benjamin Gilles. A M2 internship will be funded by the NUMEV Labex on the dynamic cartography of tremor using muscular echography.

6.2. National Initiatives

6.2.1. ADT SENSAS - SENSBIO

Participants: Christine Azevedo Coste, David Andreu, Benoît Sijobert.

SENSAS is an Inria ADT (Actions de Développement Technologique), implying several Inria project teams on the "SENSor network ApplicationS" theme. SENSAS aims to propose applications based on wireless sensor and actuator network nodes provided from the work done around senslab and senstools preliminary projects. SENSAS is organized around the following work packages :

- SensRob : Robotics applications
- SensBio : Bio-Logging applications
- SensMGT : Wireless sensor/actuator network management/configuration applications
- SensBox : Wireless sensor/actuator network simulation applications and tools

Our team is mainly implied in the SensBio work package, in particular for the following applications: Spinal Cord Injured Patients FES-Assisted Sit to Stand, Post-Stroke Hemiplegic Patient FES-correction of drop foot, Gait analysis of parkinson freezing and Motion analysis of longterm race data.

6.2.2. INTENSE project

Participants: David Guiraud, Olivier Rossel, Melissa Dali, Christine Azevedo Coste, David Andreu, Jérémie Salles, Guy Cathébras, Fabien Soulier, Baptiste Colombani, Guillaume Souquet, Milan Demarcq.

INTENSE (Initiative Nationale Technologique d'Envergure pour une NeuroStimulation Evoluée) is a PIA-PSPC Project (Programme Investissement d'Avenir, Projets RD Structurants des Pôles de Compétitivité) [2012-2018]. The aim of this project is to develop new implantable devices, based on neurostimulation, for heart failure.

Partners of this project are: DEMAR, SORIN CRM, MXM-Obélia, 3D plus, CEA-Leti, INRA Rennes, INSERM Rennes, HEGP, CHU Rennes.

6.2.3. 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.

6.3. European Initiatives

6.3.1. 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)

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/

6.4. International Initiatives

6.4.1. Inria Associate Teams not involved in an Inria International Labs

6.4.1.1. NEUROPHYS4NEUROREHAB

Title: Development of neurophysiological test setup for customizing and monitoring patient-specific non-invasive electrical stimulation-facilitated neurorehabilitation.

International Partners (Institution - Laboratory - Researcher):

IITH (India) - Centre for VLSI and Embedded Systems Technology - Shubhajit Roy Chowdhury

IIT Gandhinagar (India) - ___Centre for Cognitive Science ___ - Uttama Lahiri

Start year: 2014

See also: https://team.inria.fr/nphys4nrehab/

Stroke presents with heterogeneous patient-specific impairments in motor, sensory, tone, visual, perceptual, cognition, aphasia, apraxia, coordination, and equilibrium where the functional limitations following stroke are varied, including gait dysfunction, fall risk, limited activities of daily living, difficulties in swallowing, reduced upper extremity function, altered communication, besides others. These heterogeneous patient-specific impairments make planning of the neurorehabilitation therapy challenging. Here, it may be important to stratify the stroke survivors for restorative neurorehabilitation based on the prognosis and the ability of the stroke survivor to undergo therapy depending on their cardiovascular and neuromuscular capacity besides psychological factors such as motivation where the therapy needs to be tailored to individual health condition. The WHO International Classification of Functioning (ICF) model recommends intervention at multiple levels (e.g., impairment, activity, participation) where environment and personal factors can play an important role in resource-limited India. In fact, deconditioned chronic stroke survivor will need to recondition their cardiovascular endurance, metabolic fitness, and muscle conditions with a gradual increase in the intensity (number of hours per day) and frequency (number of days per week) of therapy, providing a higher level as they improve their function. Towards that overarching goal in a low-resource setting, we propose development of neurophysiological screening and monitoring tools using low-cost sensors.

6.4.2. Inria International Partners

6.4.2.1. Declared Inria International Partners

Technology artificial and natural control assisted by electrical stimulation in functional transfers for subjects with disabilities after spinal cord injury Inria principal investigator: Christine Azevedo Coste International partner: Faculty of Ceilandia/ University of Brasilia - Emerson Fachin Martins, leader of the NTAAI-team. Nucleus of Assistive Technology, Accessibility and Innovation. CAPES, Scholarship: BEX 3160/13-0 (Montpellier/France - December 2013 - February 2015) CAPES, Appel: 88881.068134/2014-01 (2015 - 2017) Around 90 million people acquired disabilities from Spinal Cord Injury (SCI) worldwide. The options available to stand up individuals with SCI without orthotics devices do not provide a functional upright position. The wheelchairs and seats to verticalize do not ensure an active participation based in a technology-human interaction. Moreover, the Verticalization devices are rarely used outside. The present international collaboration initiates a series of collaborations between the DEMAR- team and the NTAAI-team based on academic mobility of students and researchers. The general aim of this project is investigated technologies based in the functional electrical stimulation to promote functional transfers of the individuals with disabilities after SCI.

6.4.3. Participation In other International Programs

France-Stanford GRANT :

DEMAR and the Department of Orthopaedic Surgery of Stanford University awarded with a collaborative research grant from the France-Stanford Center for Interdisciplinary Studies. on the topic of "Inertial Sensors Based Analysis of Gait on Children with Spastic Cerebral Palsy". https://project.inria.fr/siliconvalley/2015/11/23/interview-chrisitine-azevedo-coste/

6.5. International Research Visitors

6.5.1. Visits of International Scientists

6.5.1.1. Internships

Mitsuhiro Hayashibe supervised Saugat Bhattacharyya on "Study on Probabilistic nature of Motor Imagery Electroencephalography signals for control", PhD internship, Svaagata.eu: experience Europe as an Indian Erasmus Mundus, Jadavpur University, Kolkata, India, from Oct. 2014 to Jun. 2015.

Mitsuhiro Hayashibe supervised Roberto Baptista on "Framework for Automatic Assessment of Human Motion for Rehabilitation", PhD internship, bourse d'etudes du Gouvernement Bresilien, Fondation Capes, Universidade de Brasilia (UnB), Brasil, from May 2014 to Apr. 2015.

6.5.2. Visits to International Teams

Mitsuhiro Hayashibe visited Dr. Uttama Lahiri - Centre for Cognitive Science, IIT Gandhinagar, India and Dr. Abhijit Das, MD, Director of Neurorehabilitation, AMRI Institute of Neurosciences, Kolkata, India together with Dr. Anirban Dutta under Inria-DST project. (15-24 Jan. 2015).

Mitsuhiro Hayashibe was Visiting Researcher at RIKEN BSI-TOYOYA research institute and worked on "Tacit Synergetic Motor Learning for rehabilitation" (Jul.-Aug. 2015).

6.5.2.1. Research stays abroad

Christine Azevedo Coste is spending 2,5 months (November 2015-February 2016) at Brasilia University as an invited researcher. She is working in collaboration within Emerson FACHIN-MARTINS responsible of the NTAAI (Nucléo de Tecnologia Assistiva, Acessibilidade e Inovacão) initiative. Brazilian program: Science without borders (Ciencías sem fronteiras) CAPES.

7. Dissemination

7.1. Promoting Scientific Activities

7.1.1. Scientific events organisation

7.1.1.1. General chair, scientific chair

D. Guiraud is the conference chair of IEEE EMBS Neural Engineering Conference to be held in Montpellier in April 2015.

M. Hayashibe is Co-Chair of IEEE Technical Committee on Human Movement Understanding at Robotics and Automation Society with E. Demircan (Univ. of Tokyo), D. Kulic (Univ. of Waterloo) and D. Oetomo (Univ. of Melbourne). https://sites.google.com/site/ieeehmu/

7.1.1.2. Member of the organizing committees

D. Andreu is organizer of the working group on Control Architectures of Robots of the french GdR Robotique.

D. Andreu is co-organizer of the "action transversale inter-GdR" ALROB (Architectures Logicielles pour la ROBotique autonome et les systèmes adaptables)of the CNRS, implying the french GdR Robotique and GdR Génie de la Programmation et du Logiciel

7.1.2. Scientific events selection

All the team members are involved in reviewing articles for various conferences and journals both in engineering and biomedical fields.

7.1.2.1. Chair of conference program committees

D. Andreu has been Chair of Corporate Partnerships & Exhibits, IEEE EMBS Conference on Neural Engineering (NERÕ15)

C. Azevedo Coste was program chair of IEEE EMBS Neural Engineering Conference held in Montpellier in April 2015.

7.1.2.2. Member of the conference program committees

Daniel Simon was member of the RTNS'15 (Real Time Networks and Systems), ETFA'15 (Emerging Technologies and Factory Automation) and ICINCO'15 (International Conference on Informatics in Control, Automation and Robotics) int. conference program commitees.

Mitsuhiro Hayashibe was Associate Editor of IEEE ICRA'16 (International Conference on Robotics and Automation) in charge of handling reviews on 6 papers in Oct.2015.

7.1.2.3. Reviewer

Daniel Simon was reviewer for the CDC'15 (Ieee Conf. on Decision and Control).

7.1.3. Journal

7.1.3.1. Member of the editorial boards

M. Hayashibe is member of the Editorial Board of the International Journal of Advanced Robotic Systems, in Rehabilitation Robotics. M. Hayashibe is Guest Associate Editor, Frontiers in Neuroprosthetics, Biosig- nal processing and computational methods to enhance sensory motor neuroprosthetics, with David Guiraud, Dario Farina, and Jose L. Pons. http://journal.frontiersin.org/ResearchTopic/1639

C. Azevedo Coste is Associate Editor of Paladyn Journal Behavioral Robotics (Assistive robotics).

7.1.3.2. Reviewer - Reviewing activities

The members of the team reviewed numerous papers for numerous international conferences. Daniel Simon was reviewer for the 'Simulation: Transactions of the Society for Modeling and Simulation International' journal.

7.1.4. Invited talks

Daniel Simon gave talks about "real-time simulation of hybrid systems" at ALROB meeting (LIP6, december 7) and about "Feedback control and slacken real-time" at the Inria meeting on probabilistic scheduling (Paris, december 8).

Mitsuhiro Hayashibe was invited to give a talk about "Personalized Neuroprosthetics and Personalized Home Rehabilitation" at Faculty seminer, Portsmouth University, UK on 11th March 2015.

Mitsuhiro Hayashibe was invited to give a talk about "Personalized Neuroprosthetics - Evoked EMG based Muscle Activation Closed-loop Control in Electrical Stimulation" at ERC (European Research Council) DEMOVE Symposium on 12th June 2015 at University Medical Center Gottingen, Germany (Prof. Dario Farina) http://4th-demove-symposium.bccn.uni-goettingen.de/.

Mitsuhiro Hayashibe was invited to give a talk about Personalized Neuroprosthetics and Synergetic Learning Control" at 3rd Symposium on Embodied- Brain Systems Science, University of Tokyo, Japan on 21th August 2015.

Christine AZEVEDO COSTE was invited by CEFIPRA (India) to a workshop "Understanding and faciliation of neural plasticity for enhancing post stroke recovery" in New Delhi in October 2015.

Christine AZEVEDO COSTE was invited to give a presentation during the "Simpósio Internacional em Eletroestimulacão Aplicada a Tecnologia Assistiva" in Brasilia, Brazil in December 2015.

Christine AZEVEDO COSTE gave a talk during scientific seminar of the "Institut du Mouvement Humain et Cybernétique" (Montpellier, France) in November 2015 "Analyse, modélisation et assistance du mouvement".

Christine AZEVEDO COSTE gave a talk during "Journées scientifiques Inria", in June 2015 (Nancy, France) "Contrôle artificiel du mouvement humain : observer, interpréter, assister".

7.2. Teaching - Supervision - Juries

7.2.1. Teaching

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

Master: Christine Azevedo Coste, Ethics in bioengineering research, 3h, Master STIC pour la Sant, Univ. Montpellier 2, France;

Master: Mitsuhiro Hayashibe, Neuroprotheses I and II (module coordinator), EMG and EEG signal processing and other rehabilitation modeling issues, 12h, Master STIC pour la Sante, Univ. de Montpellier, France;

Christine AZEVEDO COSTE gave a lecture in December 2015 at University of Brasilia, "Functional Electro-stimulation (FES) and artificial control of Human Motion".

7.2.2. Supervision

HDR : Mitsuhiro Hayashibe, "Computational Modeling and Control for Personalized Neuroprosthetics and Rehabilitation", Oct. 12th 2015, Univ. de Montpellier

PhD : Yacine Berranen, "Modélisation volumique du muscle avec représentation des fonctions physiologiques", Dec. 2015, D. Guiraud, M. Hayashibe and B. Gilles

PhD : Mariam Abdallah, "Système d'acquisition de signaux bioélectriques multicanal, programmable et implantable", Dec. 2015, G. Cathébras and F. Soulier.

PhD in progress : Sijobert Benoît, Stimulation Electro-fonctionnelle pour l'assistance aux mouvements des membres inférieurs dans les situations de déficiences sensori-motrices , 01/12/2015, Christine Azevedo Coste, David Andreu

PhD in progress : Tigra Wafa, Assistance à la prehension par stimulation électrique fonctionnelle chez le patient tétraplégique,11/2013, Christine Azevedo Coste, David Guiraud

PhD in progress: Thomas Guiho, "Stimulation électrique médullaire en vue de la restauration des fonctions urinaires, intestinales et sexuelles chez le patient blessé médullaire", Sept. 2013, C. Azevedo and D. Guiraud.

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

PhD in progress: Melissa Dali, "Modle d'interaction électrode-nerf et optimisation en vue d'améliorer la stimulation sélective", Oct. 2014, O. Rossel and D. Guiraud.

PhD in progress: Marion Vincent, "Précision et modélisation des effets de la stimulation électrique directe lors des opérations de chirugie éveillée des gliomes de bas-grade", Dec. 2013, F. Bonnetblanc and D. Guiraud.

Engineers : David Andreu supervises Baptiste Colombani. "HILECOP development". Computer engineering, Inria Expert Engineer (2 years contract, Inria).
David Andreu and David Guiraud supervise Milan Demarcq on "Implantable network design", Electronics, Engineer (1 year contract, Inria).
David Andreu and David Guiraud supervise Guillaume Souquet on "Design of implantable stimulator", Industrial Informatics Doctor, Research Engineer (1 year contract, Inria).
David Andreu supervises Arthur Hiairrassary on "Development of a stimulation real-time controller", Industrial Informatics Engineer, Research Engineer (2 years contract, UM).
David Andreu supervises Ronald Reboul on "Design of complex digital system". Electronics, Engineer (2 years contract, Inria).

7.2.3. Juries

Christine Azevedo Coste was member of the PhD thesis committee of Michelle RABELO, Universidade de Brasilia, "Confiabilidade das medidas de dinamometria isocinetica computorizada para movimentos do tronco em sobreviventes de acidente vascular enceflico com hemiparesia crnica.", december 2015

Christine Azevedo Coste was member of the phd thesis committee of Franssis BARBOSA DE OLIVEIRA, Universidade de Braslia, "Opes diagnosticas no monitoramento de neuropatias diabticas: em busca de parmetros para tomada de decises clinicas.", december 2015

D. Simon was reviewer and member of the PhD defense jury of Mohamed Ould Sass ("Le modèle BGW pour les systèmes temps réel surchargés", IRCCyN Nantes) and member of the jury for Mihaly Berekmeri ("Modeling and control of cloud services Application to MapReduce performance and dependability ",GIPSA-lab Grenoble).

Christine Azevedo Coste was reviewer of Nadia Khalfa Cheikh phd thesis "Ayant pour sujet : Détection de ruptures de signaux physiologiques en situation in vivo via la méthode FDpV : Cas de la fréquence cardiaque et de l'activité électrodermale de marathoniens" in september 2015 (UMPC Paris France / INSAT Tunis)

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Major publications by the team in recent years

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] Y. BERRANEN. *Simulation volumique temps-réel du muscle squelettique en découplant les modèles d'architecture des fibres et élastique*, École Doctorale Information, Structures et Systèmes, Université de Montpellier, 2015

[12] M. HAYASHIBE. *Computational Modeling and Control for Personalized Neuroprosthetics and Rehabilitation*, École Doctorale Information, Structures et Systèmes, Université de Montpellier, 2015, Habilitation à Diriger des Recherches

Articles in International Peer-Reviewed Journals

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