IN PARTNERSHIP WITH:
CNRS

Université des sciences et techniques du Languedoc (Montpellier 2)

Université Montpellier 1

Activity Report 2014

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

Table of contents

Project-Team DEMAR

Keywords: Automatic Control, Functional Electrical Stimulation, Human Assistance, Multi-scale Models, Sensors

Creation of the Project-Team: 2003 October 01.

1. Members

Research Scientists

David Guiraud [Team leader, Inria, Senior Researcher, HdR]
Christine Azevedo Coste [Inria, Researcher, HdR]
Anirban Dutta [Inria, Starting Research position]
Mitsuhiro Hayashibe [Inria, Researcher]
Daniel Simon [Inria, Researcher, HdR]

Faculty Members

David Andreu [Univ. Montpellier II, Associate Professor, HdR]
Philippe Fraisse [Univ. Montpellier II, Professor, HdR]
Fabien Soulier [Univ. Montpellier II, Associate Professor]

Engineers

Baptiste Colombani [Inria, from Dec 2014]
Milan Demarcq [Inria, from Jun 2014]
Arthur Hiairrassary [Univ. Montpellier II, from Sep 2014]
Guillaume Magro [Inria, until Oct 2014]
Thibaut Possompes [Inria, until Mar 2014, granted by OSEO Innovation]
Jérémie Salles [Inria, granted by OSEO Innovation]
Thierry Gil [CNRS]
Benoît Sijobert [IJD Inria, fom Sep 2013]

PhD Students

Alejandro Gonzalez de Alba [Inria, until Dec 2014]
Thomas Guiho [Univ. Montpellier II, from Sep 2013]
Hélène Leroux [ENS Cachan, until Aug 2014]
Zhan Li [Inria, until Dec 2014]
Melissa Dali [Inria, from Mar 2014]
Ibrahim Merzoug [AVERROES, Univ. Montpellier II, from Oct 2014]
Wafa Tigra [CIFRE, MXM, from Sep 2013]
Marion Vincent [Inria, from Dec 2013]
Mariam Abdallah [Univ. Montpellier II, from Dec 2012]
Maedeh Aram [Univ. Heidelberg, Germany, from Sep 2014]
Yacine Berranen [CNRS, from Oct. 2011]

Post-Doctoral Fellows

Mourad Benoussaad [Univ. Montpellier II, until Jul 2014]
Olivier Rossel [Inria, granted by OSEO Innovation]
Jija Syamala James [Inria, from Mar 2014]

Visiting Scientists

Saugat Bhattacharyya [ERASMUS, from Sep 2014]
Sourav Chandra [ERASMUS, until Apr 2014]
Roberto de Souza Baptista [Univ. Brasilia, from May 2014 to April 2015]
Emerson Fachin Martins [Univ. Brasilia, from December 2013 to February 2015]

Ryo Hosoda [Univ. Tokyo, from Sep 2014 until Nov 2014]

Administrative Assistant

Annie Aliaga [Inria]

Others

François Bonnetblanc [Univ. Bourgogne, Associate Professor]
Guy Cathébras [Univ. Montpellier II, Professor, HdR]
Charles Fattal [Dijon, Medical Doctor]
Benjamin Gilles [CNRS, Researcher]
Pawel Maciejasz [PostDoc, until Jun 2014]

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 Montréeal.

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. New Software and Platforms

4.1.1. RdP to VHDL tool

Participants: David Andreu, Thierry Gil, Robin Passama, Baptiste Colombani, Thibaut Possompes.

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, 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 interconnected 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)) is regulary updated.

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 (H. Leroux PhD thesis).

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).

4.1.2. SENISManager

Participants: Robin Passama, David Andreu.

We developed a specific software environment called SENISManager 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.

SENISManager (registered at the french Agence de Protection des Programmes (APP) with the industrial partner) has been transferred to the industrial partner that develops a new version according to an Eclipse-based design.

4.1.3. Synergy Neurostimulation Software

Participants: David Andreu, Amandine Pantel, Arthur Hiairrassary.

We are developing a specific software environment called Synergy Neurostimulation Software 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 will be soon registered at the french Agence de Protection des Programmes (APP).

4.1.4. MOS2SENS: Model Optimization and Simulation To Selective Electrical Neural Stimulation

Participants: Melissa Dali, Olivier Rossel, David Guiraud.

Multipolar electric stimulation of the nerve is a main issue, to access selective activation of organ or muscles. Knowing that electrodes configurations have to be specific to the type of nerve and to the organic or muscular targeted, we work on an accurate and flexible nerve modeling (work extension of Jérémy Laforêt PhD thesis, 2009), and we have developed new software MOS2SENS (from Model Optimization and Simulation To Selective Electrical Neural Stimulation) (fig.1). 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.

There are two programs that perform the following functions:

- Generation of 3D geometric model
- Mathematical description of the link between stimulation currents and extracellular voltage present inside the nerve
- Nerve fiber activation prediction based on the current stimulation
- Optimization of the current injected according to the chosen target

The software has been implemented in Matlab with graphical user interface and use OpenMEEG open source software to compute electric fields from the electrode to the fibers.

MOS2SENS is filed in the Agency for the Protection of Programs (APP) under the identifier

IDDN.FR.001.490036.000.S.P.2014.000.31230

4.1.5. SENSBIOTK

As low cost and highly portable sensors, inertial measurements units (IMU) have become increasingly used in different topics, such as gait analysis, embodying an efficient alternative to motion capture systems. Meanwhile, being able to compute reliably accurate spatial parameters using few sensors remains a relatively complex problematic. The use of inertial data calls on various algorithms able to compute from raw sensors (accelerometer, magnetometer and gyrometer) different features (position, angle, etc...). SensbioTK (for Tool Kit) has been implemented using a Python programming environment. This opensource library provides to any IMU user a set of tools enabling the following functions :

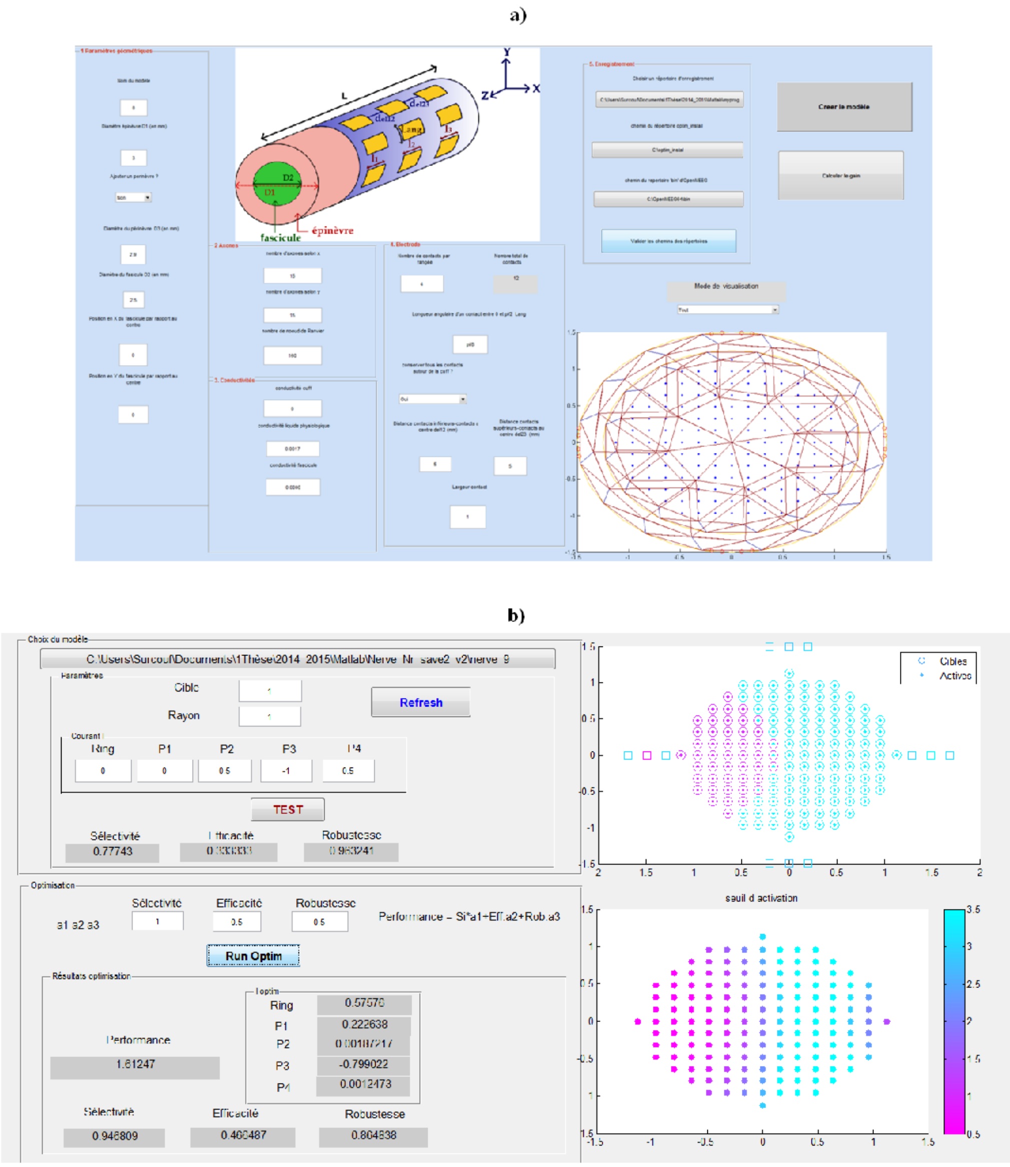

Figure 1. MOS2SENS interface. a) interface for the calculation of the electric field induced by electrical stimulation, b) interface for the configuration optimization

- Conversion from inertial raw data to .csv file
- Computation of optimized scale and offset parameters for inertial sensors calibration (Gauss newton optimization)
- AHRS sensor fusion algorithms (Kalmann filter and gradient descent based) : Madgwick, Mahony and Martin-Salaun implementation
- Stride length calculation from one shank located IMU
- 3D transformations and quaternion library

Many "ready to use" examples with relative data and scripts : goniometer, compass, pedometer, motion capture validation...
https://github.com/sensbio/sensbiotk

5. New Results

5.1. Modelling and identification of the sensory-motor system

5.1.1. Whole Body Center of Mass Estimation with Portable Sensors: Using the Statically Equivalent Serial Chain and a Kinect

Participants: Alejandro Gonzalez de Alba, Mitsuhiro Hayashibe, Vincent Bonnet, Philippe Fraisse.

The trajectory of the whole body center of mass (CoM) is useful as a reliable metric of postural stability. If the evaluation of a subject-specific CoM were available outside of the laboratory environment, it would improve the assessment of the effects of physical rehabilitation. A method is developed tot enable tracking CoM position using low-cost sensors such that it can be moved around by a therapist or easily installed inside a patientâs home. We compare the accuracy of a personalized CoM estimation using the statically equivalent serial chain (SESC) method and measurements obtained with the Kinect to the case of a SESC obtained with high-end equipment (Vicon). We also compare these estimates to literature-based ones for both sensors. The method was validated with seven able-bodied volunteers for whom the SESC was identified using 40 static postures. The literature-based estimation with Vicon measurements had a average error 24.9 $\pm$ 3.7 mm; this error was reduced to 12.8 $\pm$ 9.1 mm with the SESC identification. When using Kinect measurements, the literature-based estimate had an error of 118.4 $\pm$ 50.0 mm, while the SESC error was 26.6 $\pm$ 6.0 mm. The subject-specific SESC estimate using low-cost sensors has an equivalent performance as the literature-based one with high-end sensors. The SESC method can improve CoM estimation of elderly and neurologically impaired subjects by considering variations in their mass distribution.

5.1.2. A Personalized Balance Measurement for Home-based Rehabilitation

Participants: Alejandro Gonzalez de Alba, Philippe Fraisse, Mitsuhiro Hayashibe.

We use the subject-specific center of mass (CoM) estimate offered by the statically equivalent serial chain (SESC) method and the zero rate of change of angular momentum (ZRAM) concept to evaluate balance for a series of dynamic motions. Two healthy subjects were asked to stand on a Wii balance board and their SESC parameters were identified. A set of dynamic motions was to evaluate the rate of change of centroidal angular momentum and the distance of the ZRAM point to the center line of the support polygon. We found a good match between both balance metrics. As an application example, the subjects performed a dynamic motion (such as walking and abruptly stopping) and the stability was determined in real-time using the ZRAM point from the personalized CoM trajectory. This was implemented with a real-time balance visualization tool based on Kinect measurements for home-based rehabilitation.

5.1.3. Methodology for automatic movement cycle extraction using Switching Linear Dynamic System

Participants: Roberto de Souza Baptista, Mitsuhiro Hayashibe, Antônio P. L. Bó [Univ. Brasilia].

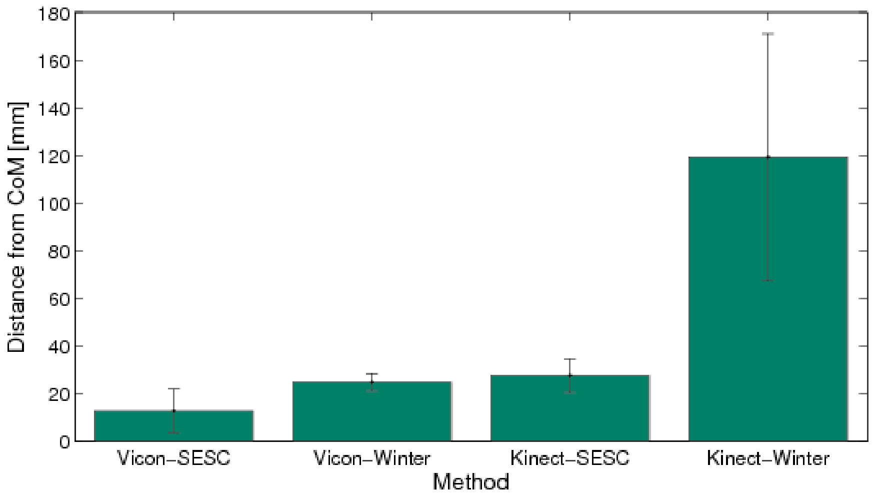

Figure 2. The bars correspond to the averaged results for all seven subjects. We observe an increase in the accuracy of the identified SESCs with respect to the literature estimates; we found that the performance of the Kinect-SESC is equivalent to that of the literature-based estimate using high-end sensors.

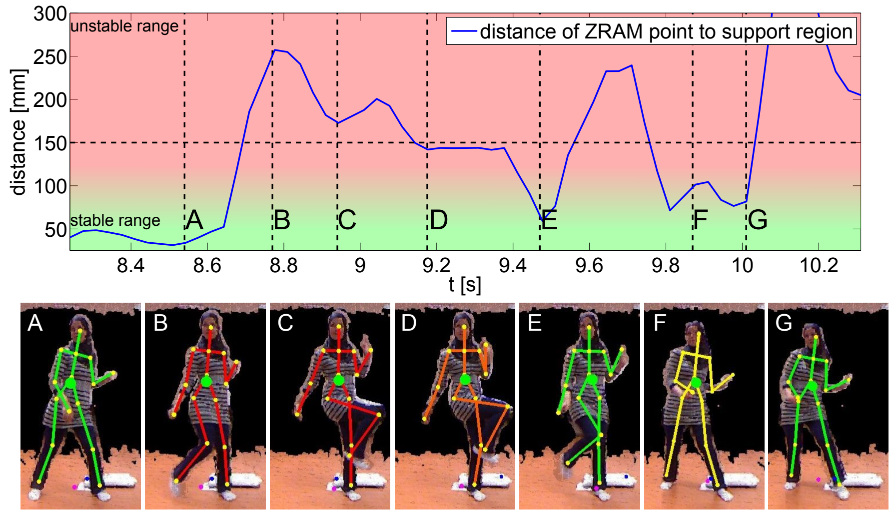

Figure 3. The distance between the ZRAM point and the center of the support polygon can be used to determine balance in real-time and shown as feedback during a physical rehabilitation program. In this example, the subject's skeleton is colored in red to indicate an unstable movement and in green for a stable one.

Human motion assessment is key for motor-control rehabilitation. Using standardized definifions and spatiotemporal features - usually presented as a movement cycle diagram- specialists can associate kinematic measures to progress in rehabilitation therapy or motor impairment due to trauma or disease. Although devices for capturing human motion today are cheap and widespread, the automatic interpretation of kinematic data for rehabilitation is still poor in terms of quantitative performance evaluation. In this paper we present an automatic approach to extract spatiotemporal features from kinematic data and present it as a cycle diagram. This is done by translating standard definitions from human movement analisys into mathematical elements of a Switching Linear Dynamic System model. The result is a straight-forward procedure to learn a tracking model from a sample execution. This model is robust when used to automatically extract the movement cycle diagram of the same motion (the Sit-Stand-Sit, as an example) executed in different subject-specific manner such as his own motion speed.

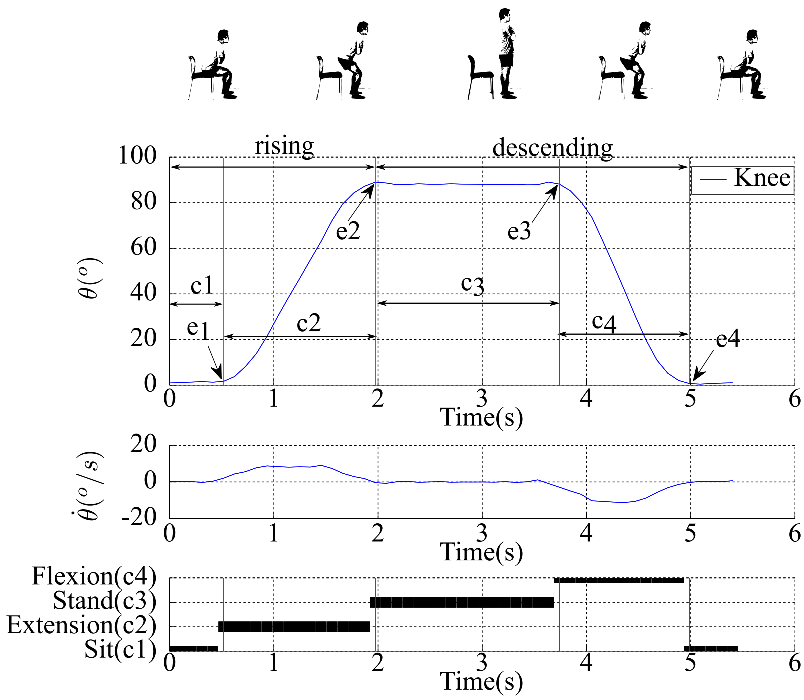

Figure 4. Training dataset consisting of one execution of the Sit-Stand-Sit movement cycle. Events (e_i), components (c_i) and the rising and descending phases are marked. θ and $\dot{\theta}$ indicates angle and angular velocity.

5.1.4. Real-time Muscle Deformation via Decoupled Modeling of Solid and Muscle Fiber Mechanics

Participants: Yacine Berranen, Mitsuhiro Hayashibe, David Guiraud, Benjamin Gilles.

This work presents a novel approach for simulating 3D muscle deformations with complex architectures. The approach consists in choosing the best model formulation in terms of computation cost and accuracy, that mixes a volumetric tissue model based on finite element method (3D FEM), a muscle fiber model (Hill contractile 1D element) and a membrane model accounting for aponeurosis tissue (2D FEM). The separate models are mechanically binded using barycentric embeddings. Our approach allows the computation of several fiber directions in one coarse finite element, and thus, strongly decreases the required finite element resolution to predict muscle deformation during contraction. Using surface registration, fibers tracks of specific architecture can be transferred from a template to subject morphology, and then simulated. As a case study, three different architectures are simulated and compared to their equivalent one dimensional Hill wire model simulations.

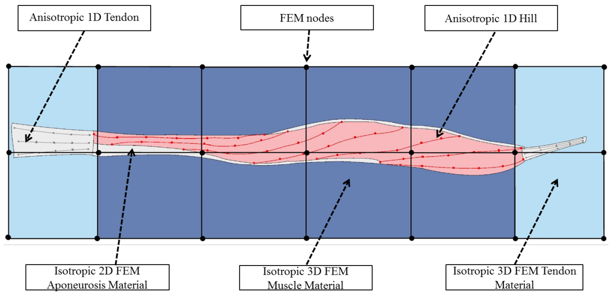

Figure 5. Muscle multi-model scheme: The different models are linked via barycentric embeddings. This approach strongly decreases the required finite element resolution to predict muscle deformation during contraction

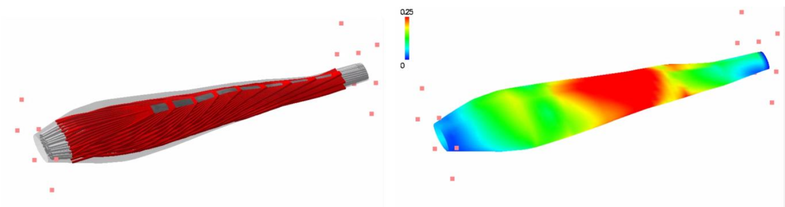

Figure 6. Left: Hybrid model of bipennate muscle, right: internal stress due to isometric contraction

5.1.5. Adaptive model for viscoelastic solids

Participants: Benjamin Gilles, Maxime Tournier, Matthieu Nesme, Francois Faure.

A new adaptive model for viscoelastic solids is presented in [50], [34]. Unlike previous approaches, it allows seamless transitions, and simplifications in deformed states. The deformation field is generated by a set of physically animated frames. Starting from a fine set of frames and mechanical energy integration points, the model can be coarsened by attaching frames to others, and merging integration points. Since frames can be attached in arbitrary relative positions, simplifications can occur seamlessly in deformed states, without returning to the original shape, which can be recovered later after refinement. We propose a new class of velocity-based simplification criterion based on relative velocities. Integration points can be merged to reduce the computation time even more, and we show how to maintain constant elastic forces through the levels of detail. This meshless adaptivity allows significant improvements of computation time.

5.1.6. Functional Brain Stimulation: Filling the gap between micro- and direct electrical stimulation of the brain in order to better understand and innovate

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

Micro-stimulation (MES) and Direct electrical stimulation (DES) of the brain are both used to perform in vivo functional mapping of the brain in fundamental neuroscience and neurosurgery respectively. The former is performed in animal experiments while the latter is performed on humans in the operative room. Very recently, a strong debate occurred to determine whether DES used during "wide-awake surgery" with success is a gold standard to study brain functions (Mandonnet et al., 2010; Borchers et al. 2012; Desmurget et al., 2013). In this debate, confusion is very often made between DES and MES, as these are considered to induce similar effects on the nervous tissues, with comparable behavioural consequences. However, electrical stimulation (ES) parameters used in both techniques are clearly different. More surprisingly, a strong biophysical rational of their choices is lacking. It may be due to historical, methodological and technical constraints that have guided empirically them. These constraints may have strongly shaped and limited experimental protocols in a standard way. By contrast, the gap between MES and DES may reveal a great potential for new experimental paradigms in ES of the brain in vivo. By considering this gap and new technical developments in the design of stimulators, it may be time to move on to alternative and innovative stimulations protocols, especially regarding and inspired from what is performed in functional electrical stimulation (FES) of peripheral nerves, for which more theoretical supports exist.

5.1.7. Modelling of structural and functional brain connectivity networks in Diffuse Low-Grade Glioma (DLGG)

Participants: Jija Syamala James, Anirban Dutta, François Bonnetblanc, David Guiraud, Nicolas Menjot de Champfleur [Department of Neuroradiology,CHU, Montpellier], Emmanuelle Le Bars [Institute of Human Functional Imaging 12 FH, CHU, Montpellier], Hugues Duffau [Neurosurgery Department, CHU, Montpellier].

The impairment of functional brain connectivity networks in Diffuse Low Grade Glioma (DLGG) subjects can lead to distinct functional deficits where the challenge remains in greater understanding of distribution of dynamic brain connectivity. Our multimodality (resting state functional MRI, Diffusion Tensor Imaging and tractography) neuroimaging study aims to evaluate the differences in spatial and temporal patterns of brain connectivity networks in DLGG patients, pre and postoperatively.

In order to identify the brain connectivity networks, we analysed resting state fMRI data of 22 mesio-frontal DLGG patients by using MELODIC (Multivariate Exploratory Linear Optimised Decomposition into Independent Components)-ICA module, implemented in Freesurfer Software Library [FSL] (www.fmrib.ox.ac.uk/fsl). First we evaluated the clinical efficacy of rsfMRI technique to non-invasively map the dynamic functional re-organizations of brain connectivity networks in glioma subjects. Further we observed the existence of altered inter-hemispheric functional connectivity in DLGG subjects postoperatively.

We are currently performing this analysis using larger sample size in order to find out

a) the invivo structure-function relationship of motor, language and visual brain networks by fusing the information from DTI and fMRI.
b) the correlation between brain connectivity networks and neurobehavioural performance.
c) the neuroplastic alterations in topographic organization and strength of connections before and after DLGG surgery.

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

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

For the general public, spinal cord injury (SCI) is often restricted to limb paralysis. In reality, by interrupting communication between encephalon and peripheral organs, medullary wounds lead to physiological deficiencies such as urinary (retention and/or incontinence), gastrointestinal (constipation) or sexual impairments; disorders which are the center of patient's expectations.

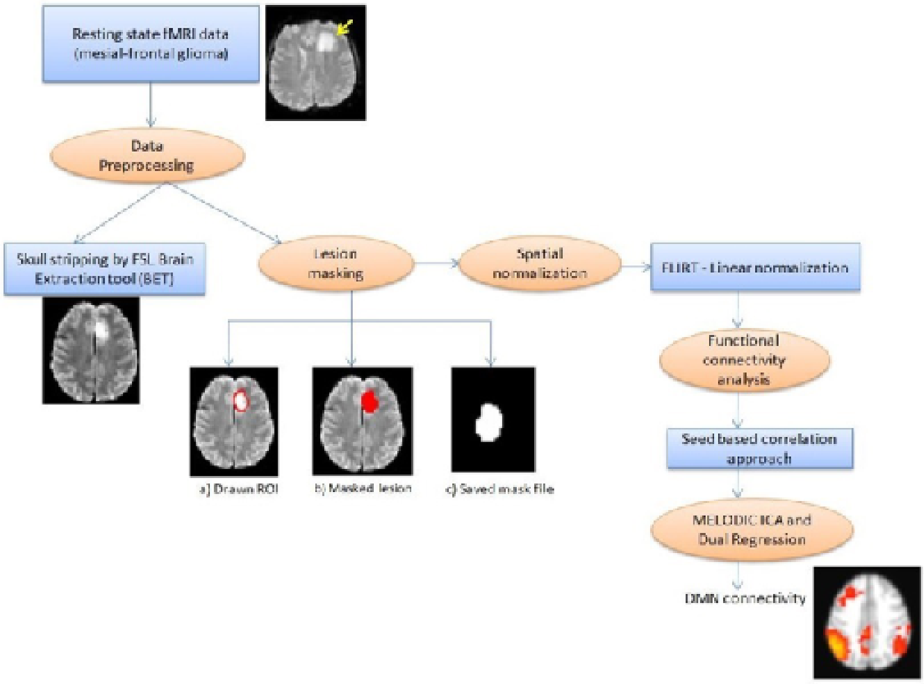

Figure 7. Steps involved in resting state functional connectivity analysis.

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 (few subjects involved) 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.

5.1.8.1. Development of point of care testing (POCT) device for neurovascular coupling from simultaneous recording of EEG and NIRS during non-invasive brain stimulation (NIBS) for closed-loop control of NIBS.

Participants: Mehak Sood, Utkarsh Jindal, Mitsuhiro Hayashibe, Stephane Perrey, Michael A. Nitsche, Abhijit Das, Shubhajit Roy Chowdhury, Anirban Dutta.

Our preliminary work showed that transcranial direct current stimulation (tDCS) can perturb local neuronal activity which can be used for assessing regional neurovascular coupling (NVC) functionality. It was postulated that tDCS leads to rapid dynamic variations of the brain cell microenvironment that perturbs the hemodynamic and electromagnetic responses. Based on these preliminary studies, we developed a POCT device for EEG-NIRS based screening and monitoring of neurovascular coupling functionality under perturbation with tDCS. The stroke case study showed detectable changes in the degree of NVC to a 0.526A/m^2 square-pulse (0-30sec) of anodal tDCS where these alterations in the vascular system may result in secondary changes in the cortical excitability. The objective of this case study was to evaluate an empirical method to assess NVC using cross-correlation function (CCF) between mean (cortical) tissue oxy-haemoglobin concentration time-series and averaged PSD time-course from the EEG spectrogram. The CCF based assessment of the patient-specific status of NVC are currently being studied in a larger cohort with small vessel diseases. The overarching goal is closed-loop control of tDCS based on simultaneous recording of EEG and NIRS during non-invasive brain stimulation.

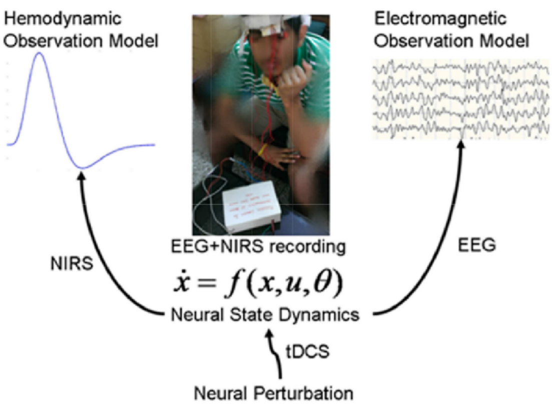

Figure 8. EEG-NIRS based simultaneous recording of the hemodynamic and electromagnetic responses to perturbations with transcranial direct current stimulation (tDCS).

5.2. Synthesis and Control of Human Functions

5.2.1. *Ergonomics of the control by a quadriplegic of hand functions*

Participants: Christine Azevedo Coste, David Guiraud, Wafa Tigra, Charles Fattal.

In subjects with complete Spinal Cord Injury (SCI) above C7, the four limbs are paralyzed (quadriplegia). Recovery of grasping movements is then reported as a priority. Indeed, most activities of daily living are achieved through upper limbs. Thus, restoration of hand and forearm active mobility could significantly increase independence and quality of life of these people and decrease their need of human aid. Although most of the subjects plebiscite pharmacological or biological solutions, only orthotics and Functional Electrical Stimulation (FES) allow, so far, to restore hand movements but they are rarely used. Ergonomics and comfort of piloting mode could partly explain the low usage of these systems. In this context, our aim is to explore possible solutions for subjects to interact with such devices. In this article we propose to evaluate the capacity of active upper limb muscles contraction to be used to intuitively control FES in tetraplegic subjects. In this study, we assessed the ability to gradually contract different muscles: trapezius, deltoid, platysma and biceps. Three subjects with C6 to C7 neurological level of lesion were included. We show that over the active upper limb muscles tested, contraction of the trapezius muscle was considered by the subjects as the most comfortable and could be employed as an intuitive mode of control of functional assistive devices.

5.2.2. *Implementation of filtering, calibration and reconstruction algorithms dedicated to the use of inertial measurement units related to rehabilitation and movement analysis*

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

This work has been done within SENSBIO ADT.

- Stride length estimation

  An algorithm has been implemented for the sep by step stride length calculation from only one shank located sensor algorithm (calibration, segmentation and reconstruction) Experimental validation was done on 10 healthy subjects (error <10%), 12 Parkinson disease subjects, and 7 hemiparetic subjects.

- Comparison of different reconstruction algorithms

  A Python programmed toolbox was developed for movement analysis (SensbioTK) in order to compare the performances of Mahony, Madgwick, Martin-Salaun sensor fusion algorithms.

- Real-time MoCap data processing Matlab based software

  The algorithm is based on Nexus SDK for rotation angle and translation calculation of a tracked object.

5.2.3. *Dominant Component in Muscle Fatigue Induced Hand Tremor during Laparoscopic Surgical Manipulation*

Participants: Sourav Chandra, Mitsuhiro Hayashibe, Asokan Thondiyath [IIT Madras].

Accuracy of laparoscopic surgery gets affected by the hand tremor of the surgeons. Though cognitive load is inevitable in such activity which promotes tremor, muscle fatigue induced tremor is significant among the most important source of tremor. Characteristic of fatigue induced hand tremor and its dominant directional properties are reported in this work. For a fixed laparoscopic tool grip with temporally synchronized predefined task protocols, characteristics of fatigue induced tremors have been studied. Dominant component of tremor is found to be in the sagittal plane in case of both static and dynamic tasks. The results shown in the figure, sagittal plane (z axis) component of hand tremor is higher than the other directions. In order to relate it with the muscle fatigue level, spectral properties of surface electromyography (SEMG) were also investigated simultaneously. A study of transient effect on tool positioning was also included, which conjointly advocates the other experimental results on fatigue induced hand tremor as well. Currently a better metric for muscle fatigue is being analyzed and studied with a purview of relation in between SEMG and hand tremor (fig.9).

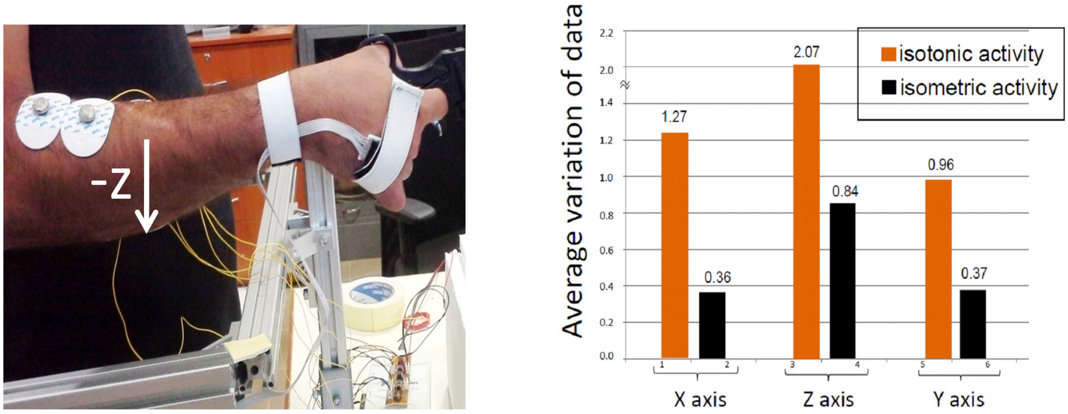

Figure 9. (left) Experimental hand tremor measurement setup (right) Dominant component of hand tremor in all three planes

5.2.4. *Human arm optimal motion analysis in industrial task for improving ergonomics of painful workstations*

Participants: Nahema Sylla, Vincent Bonnet [TUAT, Japan], Nahid Armande [PSA], Philippe Fraisse.

In PSA Peugeot Citroen factories, high precision requirements of workstations make them being manual. One of the main goal of the car manufacturer is to minimize the pain of workers while maintaining high efficiency of production lines. Consequently, assisting operators with an exoskeleton is a potential solution for improving ergonomics of painful workstations while respecting industrial constraints [33]. We have developped a new approach based on inverse optimization to better understand human arm motion in industrial screwing task. The process combines several criteria to minimize such as energy expenditure or trajectory smoothness leading to the optimal trajectory of a typical screwing task, often performed by workers. Estimated joint trajectories are similar with the measured ones, with a mean square error of 4 degrees. The resulting cost-function is mainly composed of energy expenditure and geodesic criteria. Results show the relevance of using composite cost function in human motion planning [52]. This method has been applied to evaluate a 7 DoF exoskeleton in terms of motion control. The results of our study show that the hybrid composition of the free arm movement was accurately determined. At contrary, when wearing the exoskeleton, which produces an arbitrary determined torque compensation, the motion is different from the naturally adopted one. This study is part of the evaluation and comprehension of the complex neuromuscular mechanism resulting in wearing an exoskeleton several hours per day for industrial tasks assistance [49].

5.2.5. *A System for Real-time Online Estimation of Joint Torque with Evoked EMG under Electrical Stimulus*

Participants: Zhan Li, Mitsuhiro Hayashibe, David Andreu, David Guiraud.

Functional electrical stimulation (FES) is a useful rehabilitation technique for restoring motor capability of spinal cord injured (SCI) patients by artificially driving muscle contraction through delivering electrical pulses. Real-time FES systems with online modulation ability are in great demand towards clinic applications. In this work, online estimation of joint torque with evoked electromyography (eEMG) in real-time environment is presented. The eEMG is acquired by National Instrument (NI) acquisition card and the stimulus is produced by wireless stimulator (manufactured by Vivaltis Inc., France). Kalman filter (KF) is adopted and embedded as the online estimator. Such real-time online torque estimation system produces promising results. Currently, the implementation to use EMG signal also from wireless Pod module is under investigation (fig.10).

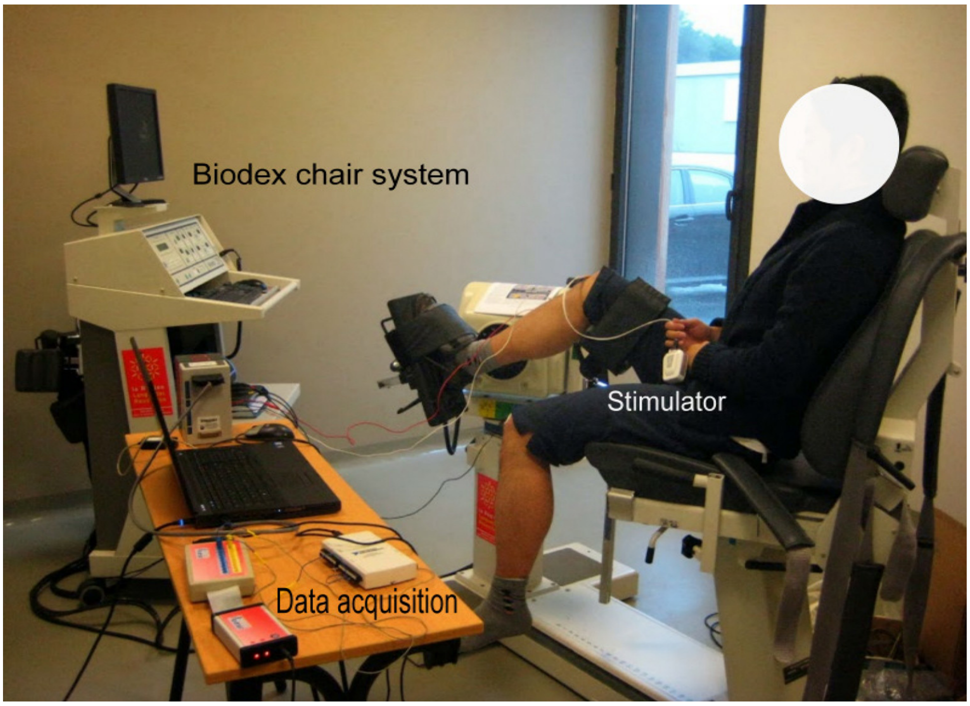

Figure 10. Real-time online FES-induced torque estimation system

5.2.6. Freezing of Gait Analysis and Detection

Participants: Christine Azevedo Coste, Benoît Sijobert, Roger Pissard-Gibollet, Christian Geny [CHU Montepllier, Neurologie].

We have extended and optimized the work on Freezing Of Gait (FOG) and destination detection (Maud Pasquier PhD thesis, 2013). A new software for FOG Criteria based on cadency and stride length calculation has been implemented. Results were compared to Freezing Index (Moore et al., 2008) based on frequencies analysis of legs vertical acceleration. The comparison between detection and reality is done on the basis of video analysis of the performed tasks. A software has been implemented for the video labelization Matlab/VLC based tool, with graphical user interface, for marking and synchronizing events from a video (MovieFOG). 14 Parkinson disease patients were included in the study [12][48] (fig.11).

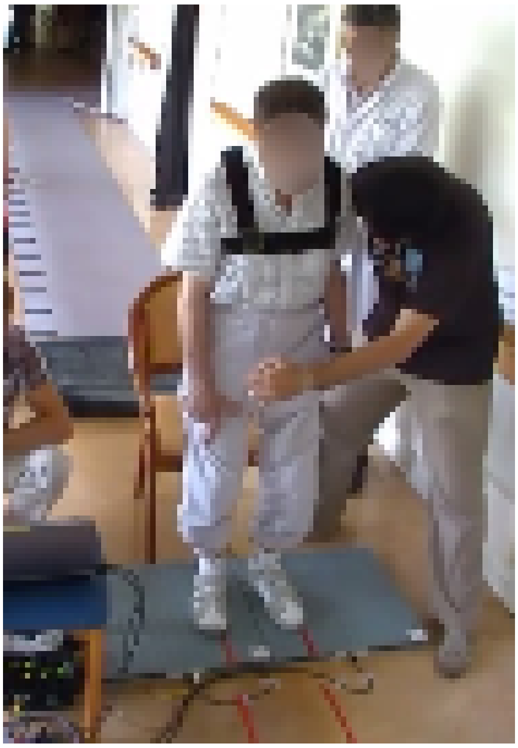

Figure 11. Freezing of Gait Analysis and Detection

5.2.7. A novel brain-computer interfacing paradigm for control of multi-DOFs robot with adaptive EEG decoding and synergetic environment adaptation

Participants: Saugat Bhattacharyya, Shingo Shimoda [RIKEN, Japan], Mitsuhiro Hayashibe.

The study proposes a novel brain-computer interfacing paradigm for control of a multi-joint redundant robot system. Here, the user would determine the direction of end-point movement of a 3-dof robot arm using motor imagery electroencephalography (EEG) signal with co-adaptive decoder while a synergetic motor learning algorithm manages a peripheral redundancy in multi DOF joints toward energy optimality through tacit learning. As in human motor control, torque control paradigm is employed for a robot to be sensitive to the given environment. The dynamic condition of the robot arm is taken into consideration by the learning algorithm. Thus, the user needs to only think about the end-point movement of the robot arm, which allows simultaneous multi-joints control by BCI. The k-Nearest Neighbor based decoder designed for this study is adaptive to the changing mental state of the user. Offline experiments on the decoder reveals that its classification accuracy gradually increases at each learning stage. Online experiments also reveals that the users successfully reach their targets with an average decoder accuracy of more than 65% in different end-point load conditions. The details of the BCI control paradigm, shown in Fig.12, is as follows: Initially, the robot is trained to its dynamic environment using a tacit learning approach for a fixed period of time. In this study, the load carried by the robot is treated as the environmental changes along with link segment inertial configuration changes. As a result, the movement of the joints of the robot adapts to the changing load. After the training of the robot, the subject begins his/her task of visualizing the target and decides on the direction of motion of the robot. Here, we have used left and right movement imagery to move the robot in upward and downward direction, respectively. Subsequently, the EEG signals (corresponding to the movement imagined) are pre-processed and their corresponding features are extracted. These features are used as inputs to the decoder which determines the mental state of the user and sends command to the robot to move in the equivalent direction.

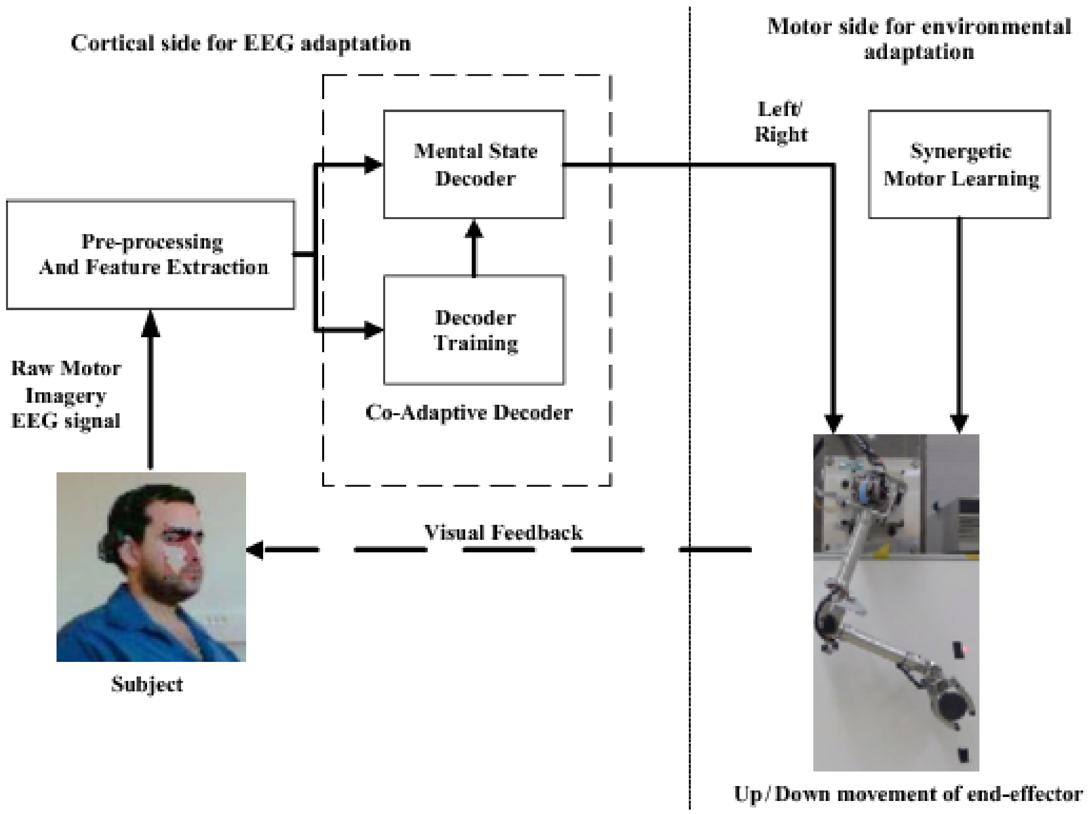

Figure 12. BCI paradigm employed in this study for control of multi-DOFs robot using adaptive left-right motor imagery decoder and synergetic motor learning for peripheric redundancy management (via tacit learning).

5.2.8. Impact of the gaze direction on the skier trajectory

Participants: Christine Azevedo Coste, Benoît Sijobert, Roger Pissard-Gibollet, Nicolas Coulmy [FFS annecy].

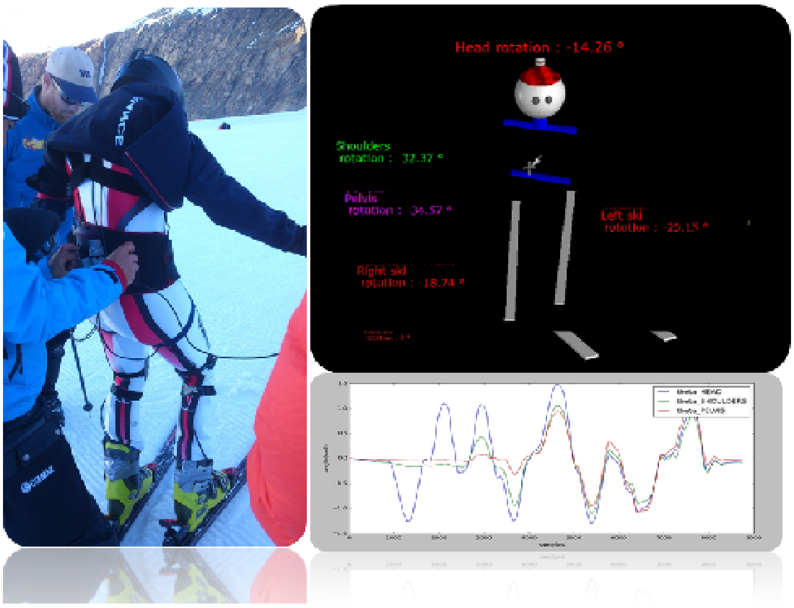

Figure 13. Impact of the gaze direction on the skier trajectory

This work is done within a collaboration with the French Skiing Federation (FFS). Preliminary indoor tests for designing an experimental protocol using motion capture and inertial sensors was realized using a ski simulator and Motion Capture Tool from DEMAR (VICON BONITA). Indoor and outdoor experimentations were done with olympic skiers. In outdoor tests IMUs were combined with SMI eye tracking device. Preliminary analysis and data reconstruction has been done. A VPython script for 3D visualizing of skier movements was developed (fig.13).

5.2.9. Development of a low-cost biofeedback system for electromyogram-triggered functional electrical stimulation therapy in conjunction with non-invasive brain stimulation

Participants: Anirban Dutta, Christine Azevedo Coste, Mitsuhiro Hayashibe, Uttama Lahiri, Abhijit Das, Michael A. Nitsche, David Guiraud.

Functional electrical stimulation (FES) facilitates ambulatory function after paralysis by activating the muscles of the lower extremities. The FES-assisted stepping can either be triggered by a heel-switch, or by an electromyogram-(EMG-) based gait event detector. A group of six chronic (>6 months post-stroke) hemiplegic stroke survivors underwent transcutaneous FES-assisted training for 1 hour on stepping task with EMG biofeedback from paretic tibialis anterior (TA) and medial gastrocnemius (GM) muscles, where the stimulation of the paretic TA or GM was triggered with surface EMG from the same muscle. During the baseline, post-intervention, and 2-day-postintervention assessments, a total of 5 minutes of surface EMG was recorded from paretic GM and TA muscles during volitional treadmill walking. Two-way ANOVA showed significant effects in terms of P-values for the 6 stroke subjects, 0.002, the 3 assessments, 0, and the interaction between subjects and assessments, 6.21E-19. The study showed a significant improvement from baseline in paretic GM and TA muscles coordination during volitional treadmill walking. Moreover, it was found that the EMG-triggered FES-assisted therapy for stand-to-walk transition helped in convergence of the deviation in centroidal angular momentum from the normative value to a quasi-steady state during the double-support phase of the nonparetic. Also, the observational gait analysis showed improvement in ankle plantarflexion during late stance, knee flexion, and ground clearance of the foot during swing phase of the gait. Currently, we are conducting preliminary stroke studies to evaluate non-invasive brain stimulation as an adjunct to EMG-triggered FES therapy for movement rehabilitation [19][22].

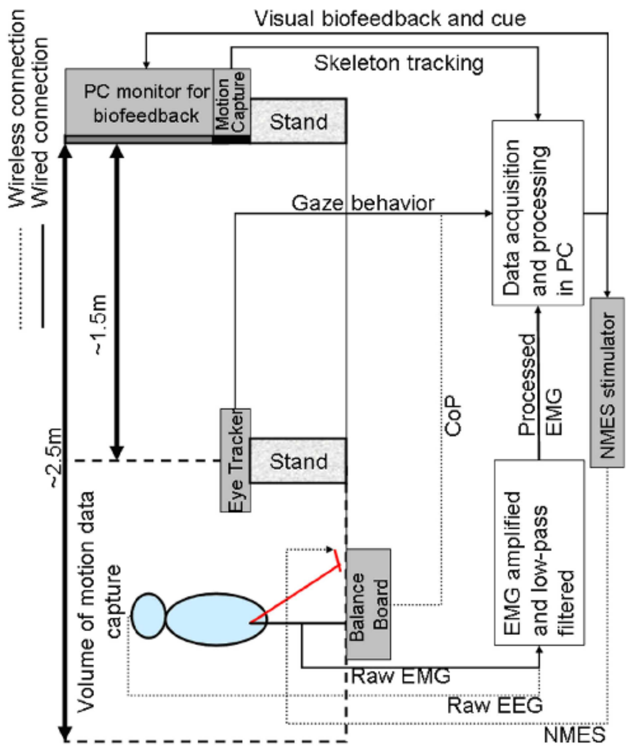

Figure 14. Human-machine-interface integrating low-cost sensors for post-stroke balance rehabilitation

5.2.10. Development and bench-testing of a low-cost eye tracking system (ETS) to measure gaze abnormality in stroke towards virtual reality based visuomotor therapy task.

Participants: Deepesh Kumar, Abhijit Das, David Guiraud, Michael A. Nitsche, Anirban Dutta, Uttama Lahiri.

We conducted a preliminary usability study while incorporating our novel low-cost ETS to measure one's eye gaze indices in response to presented visual task. The ETS provided gaze-related biomarkers which has the potential to be mapped to the probable abnormalities in one's eye movement pattern in stroke. Our preliminary findings with stroke-survivors and age-matched healthy participants indicate the potential of our low-cost

ETS to provide quantitative measures of the difference in gaze-related biomarkers between the two groups of participants. Based on these preliminary results, we are conducting a clinical stroke study on ETS based screening and monitoring of performance during a virtual reality based visuomotor balance therapy task.

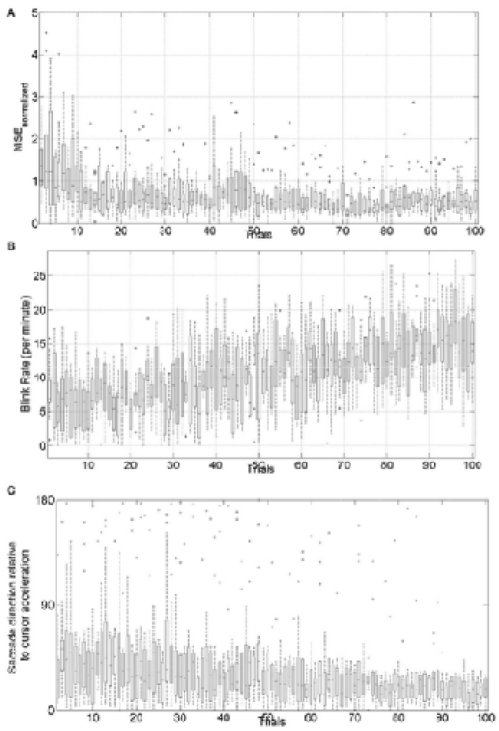

Figure 15. A. Box-plot of normalized mean squared error (MSE) across 10 healthy subjects, B. Box-plot of the blink rate during the visuomotor task, C. Box-plot of saccadic direction relative to the cursor acceleration during the visuomotor task.

5.3. Neuroprostheses and technology

5.3.1. Abstraction and composition for formal design of neuroprotheses

Participants: David Andreu, Hélène Leroux, Karen Godary-Dejean.

In the framework of specification and implementation of complex digital systems on FPGA, we have developed an approach based on components whose behavior and composition are specified by generalized interpreted T-time Petri nets (HILECOP). One of the inherent difficulties for designer is, on the behavioral part, to account for exceptions. This often leads to a complex modeling and is a source of human errors. Indeed, it is intricate to express all the possible situations (i.e. current state of model). We have defined a way to model exception handling by integrating the well-know concept of macroplace into the formalism. The analysability of the model and the efficiency of the implementation on FPGA (reactivity and surface, ie number of logic blocks) have been preserved. An example of macroplace is given in figure 13; it contains a sub-net (set of places of its refinement) from which exception handling is simply described by a dedicated output transition (transition te on fig. 13), whatever is the current state of the sub-net.

We also solved state evolution conflicts introducing (automatically) priorities between transitions, to avoid reaching inconsistent global state while synchronously executing the model.

The new formalism (including all improvements) has been defined [45], as well as the model transformation based equivalent PNML generation for using existing analysis tools. The VHDL code generation has also been defined [59].

All this work has been applied to an industrial example, that of a neural stimulator developed in collaboration with MXM industrial partner. Results have shown the significant contribution of the theoretical approach to the stimulation device reliability, while preserving both surface and power consumption of the given digital part of the device.

Ongoing work, developed through I. Merzoug PhD thesis, concerns the improvement of the analysis of synchronously implemented Petri nets.

5.3.2. New FES dedicated digital processor for neurostimulator

Participants: David Andreu, David Guiraud.

We designed (patent pending) and prototyped a new neural FES dedicated processor and its associated (more compact and efficient) set of instructions, as well as an embedded sequencer for accurate timing in sequencing stimulations to be performed (by the stimulator). The new neural stimulator is based on a dedicated ASIC (Application Specific Integrated Circuit), that is able to drive up to 24 channels of stimulation in absolute synchronization, and with a programmable and controlled current level distribution (patent pending). This ASIC also allows for impedance measurement. The functions of the stimulator are currently implemented in two separate chips: an analog stimulation front-end (ASIC) and a field-programmable gate array (FPGA) embedding the logic control. The FPGA embeds the new FES dedicated processor setting the output stage configuration (poles configuration and current ratio between them) and running potentially complex stimulation profiles (with a 1μs time step and 5 μA current step); example of generated stimulations are shown in Fig.16. It also embeds the protocol stack allowing for remote programming and online control. Online control relies on advanced and efficient modulation mechanisms, e.g. coefficient based modulation preserving balanced stimulation.

And last but not least, it also embeds a monitoring module ensuring the respect of safety constraints stemming both from target tissue protection and electrode integrity preservation; this reference model based monitoring module ensures (configurable) current and quantity of injected charges limits and thus safe stimulation whatever are electrodes to be used (particularly for thin-film micro-electrodes). Safety limits must be defined by users (partners) according to the target and electrodes to be used.

5.3.3. Fast simulation of hybrid dynamical systems

Participants: Abir Ben Khaled [IFPEN], Daniel Simon, Mongi Ben Gaid [IFPEN].

When dealing with the design of complex systems, simulation is an indisputable step between concept design and prototype validation. Realistic simulations allow for the preliminary evaluation, tuning and possibly redesign of proposed solutions ahead of implementation, thus lowering the risks. To be confident in the result, building such simulations needs high fidelity models both for the components and for their interaction. Models of dynamical systems (as, for example, muscular fibers) are often given as a set of Ordinary Differential Equations (ODEs). However, the simulation of high-fidelity models is time consuming, and reaching real-time constraints is out of the capabilities of monotithic simulations running on single cores.

The aim of the on-going work is to speed up the numerical integration of hybrid dynamical systems, eventually until reaching a real-time execution, while keeping the integration errors inside controlled bounds. The basic approach consists in splitting the system into sub-models, which are integrated in parallel. I has been shown that an efficient partition must minimize the interactions between sub-models, in particular by confining discontinuities processing inside each component. Automatic partitioning, based on some particular incidence matrices of the original system, has been investigated to introduce a finely-grained co-simulation method enabling numerical integration speed-ups [14]. It is obtained using a partition across the model into loosely

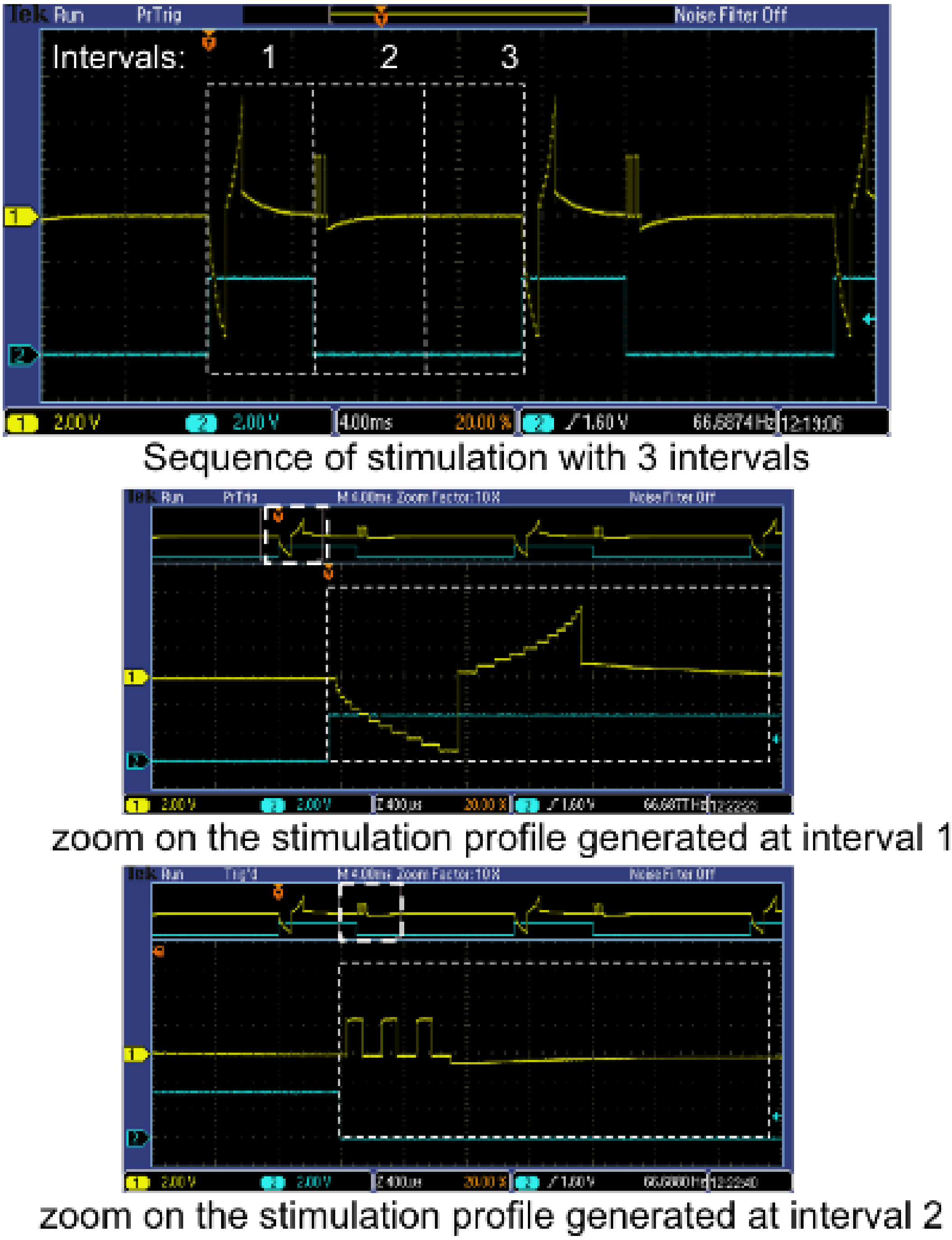

Figure 16. Sequence of stimulation generated by the new neurostimulator

coupled sub-systems with sparse communication between modules. The proposed scheme leads to schedule a large number of operations with a wide range of execution times. A suitable off-line scheduling algorithm, based on the input/output dynamics of the models, is proposed to minimize the simulation errors induced by the parallel execution.The method was tested with an automotive engine model, but it is generic and can be applied to other systems of hybrid ODEs/DAEs, as are large sets of muscular fibers.

However, slack synchronization intervals may generate integration errors in the final result. Rather than using costly small integration and communication steps, an enhanced method uses context-based extrapolation is investigated to improve the trade-off between integration speed-ups, needing large communication steps, and simulation precision, needing frequent updates for the models inputs. the method uses extrapolations of the behavior of the models over the synchronization intervals. Test results on a hybrid dynamical engine model, based on FMI for model exchange, show that well chosen context-based extrapolation allows for significant speed-up of the simulation with negligible computing overheads [37].

5.3.4. Control and scheduling co-design for stimulation systems

Participants: Daniel Simon, David Andreu, Samy Lafnoune [Master2 Robotique].

In the FES distributed system developed by the team and marketed by Vivaltis, external electrodes are sticked on the body to either stimulate a muscle or to measure sensitive information (e.g., EMG). Each electrode is connected to a pod, which can be either a stimulation pod or a measurement pod. These Pods are controlled and coordinated by a controler through wireless radio-frequency (RF) links.

The communication frames between the controler and the pods use frames, each frame contains the receiver address and a code which correspond to the deired action. Simple communication stacks, based on the reduced OSI model, are implemented in each node of the wireless network, and the current version only provides static scheduling of the messages.

In fact static scheduling is not at all optimal when the generation of complex motions needs a tight coordination between several sensors and actuators over closed-loop controllers. The high sensitivity of the RF link with respect to varying networking loads and environment conditions calls for an adaptive scheduling of the messages via the regulation of a QoS criterion. The design of such feedback controllers wil rely on previous work [53], [54].

As any modification of the existing devices can be costly and as experiments involving livings cannot be done easily, a real-time simulation system has been design and implemented. The system includes continuous models of the muscular and skeleton systems, models of the wireless network, simplified communicaion stacks and control code running inside real-time threads. The system is open, running C code inside posix threads under Linux, so that the models can be progressively detailed and enriched when necessary [56].

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

We have signed an industrial technological transfer and research contract with VIVALTIS company (Montpellier, France), on surface FES.

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. AOI PARK DEMAR

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.

7.1.2. 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.

7.2. National Initiatives

7.2.1. DEMAR / MXM Innovation Lab "SoftStim" project

Participants: David Guiraud, David Andreu.

Inria Innovation-Lab "SoftStim" project (2011-2014). 1 engineer (3 y.), 20keuros.

The aim of this Inria national initiative is to favor the scientific collaboration and technological transfer of the innovation between DEMAR and MXM.

Innovation Lab "SoftStim" has ended in december 2014. The aim of this project was to prototype concepts conjointly patented like stimulation unit 's embedded sequencer and processor (new set of instructions), and implantable FES controller with its dedicated software environment.

The industrial transfer has been achieved, notably through the design and realization of prototypes of neural stimulators.

7.2.2. BCI-LIFT: an Inria Project-Lab

Participants: Mitsuhiro Hayashibe BCI-LIFT is a large-scale 4-year research initiative (officially under peer-review evaluation) whose 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.

7.2.3. Cosinus ANR - SoHuSim

Participants: Benjamin Gilles, Mitsuhiro Hayashibe, David Guiraud, Maxime Tournier.

Project SoHuSim on modeling muscle tissue during contraction in 3D movements using SOFA software and functional modeling of the organs. 150 kE. Partners: Inria Evasion, Tecnalia, HPC, CHU Montpellier (Oct. 2010 - Oct. 2014).

7.2.4. 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 âSENSor network ApplicationSâ 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.

7.2.5. INTENSE project

Participants: David Guiraud, Olivier Rossel, Melissa Dali, Christine Azevedo-Coste, David Andreu, Jérémy Salles, Guy Cathébras, Fabien Soulier.

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.

7.2.6. *INSEP FFS*

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

INSEP (Institut National du Sport, de l'Expertise et de la Performance) supports the project "Impact of the gaze direction on the skier trajectory" leaded by the Fédération Française de Ski (FFS).

7.3. European Initiatives

7.3.1. *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: École 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/
Participants: David Guiraud, David Andreu, Thomas Guiho, Arthur Hiairrassarry, Christine Azevedo Coste, Pawel Maciejasz.

7.4. International Initiatives

7.4.1. *Inria Associate Teams*

7.4.1.1. *NEUROPHYS4NEUROREHAB*

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

International Partner (Institution - Laboratory - Researcher):

IITH (INDE)

Duration: 2014 - 2016

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.

7.4.2. 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.

7.4.2.1. Informal International Partners

Katja Mombaur, Heidelberg University (Germany). Research Group Optimization in Robotics and Biomechanics, IWR Robotics Lab.

7.5. International Research Visitors

7.5.1. Visits of International Scientists

Emerson Fachin Martins. Brazilian program: Science without borders (Ciências sem fronteiras) CAPES, Scholarship: BEX 3160/13-0 (Montpellier/France - December 2013 - February 2015)

7.5.1.1. 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.

7.5.2. Visits to International Teams

Mitsuhiro Hayashibe was Visiting Researcher at RIKEN BSI-TOYOYA research institute and worked on "Tacit Synergetic Motor Learning for rehabilitation" (Jul.-Aug. 2014).
M. Hayashibe was invited to talk at International Workshop on Human Assistive Systems Based on Human Modeling in Tokyo, on December 14, 2014, organized by Prof. Toshiaki Tsuji, Saitama University, Prof. Yuichi Kurita, Hiroshima University

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events organisation

8.1.1.1. General chair, scientific chair

D. Guiraud is the conference chair of IEEE EMBS Neural Engineering Conference to be held in Montpellier in April 2015.
D. Andreu is co-organizer of the working group on Control Architectures of Robots of the french GdR Robotique.
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/

8.1.1.2. Member of the organizing committee

M. Hayashibe and P. Fraisse organized Workshop on Human Motion Modeling and Human-inspired Motor Control together with Emel Demircan, Oussama Khatib (Stanford Univ.) at IEEE HUMANOIDS 2014, Madrid, Spain.

8.1.2. Scientific events selection

8.1.2.1. Chair of conference program committee

C. Azevedo Coste is program chair of IEEE EMBS Neural Engineering Conference to be held in Montpellier in APril 2015.

8.1.2.2. Member of the conference program committee

Daniel Simon was member of the RTNS'14 (Real Time Networks and Systems) and ETFA'14 (Emerging Technologies and Factory Automation) int. conference program commitees

8.1.2.3. Reviewer

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

8.1.3. Journal

8.1.3.1. Member of the editorial board

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).

8.1.3.2. Reviewer

The members of the team reviewed numerous papers for numerous international conferences.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Master: Mitsuhiro Hayashibe, Neuroprotheses II (module coordinator),EMG signal processing and its use for rehabilitation, 6h, Master STIC pour la Santé , Univ. Montpellier 2, France;

Master: Mitsuhiro Hayashibe, Modele et Regulation, Identification and Control in Biomechanics (module coordinator), 6h, Master STIC pour la Santé , Univ. Montpellier 2, France;

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

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

8.2.2. Supervision

HDR

HdR: Christine Azevedo Coste, "Assistance fonctionnelle : exploiter les fonctions résiduelles du système sensori-moteur déficient", Université Montpellier 2, 14/02/2014

PhD

PhD: Abir Ben Khaled, "Distributed real-time simulation of numerical models : application to powertrains", IFPEN, May 27th 2014, D. Simon and M. Ben Gaid (IFPEN)

PhD: Alejandro Gonzàlez de Alba, "Versatile whole-body center of mass identification for balance assessment in home rehabilitation", Université Montpellier 2, Dec. 11, M. Hayashibe and P. Fraisse

PhD: Hélène Leroux,"Méthodologie de conception d'architectures numériques complexes: du formalisme à l'implémentation en passant par l'analyse, préservation de la conformité. Application aux neuroprothèses", Université Montpellier 2, Oct. 28th 2014, D. Andreu and K. Godary

PhD: Zhan Li, "Real-time EMG-Feedback Torque Prediction and Muscle Activation Control toward New Modality in FES", Université Montpellier 2, Dec. 8, M. Hayashibe and D. Guiraud

PhD in progress: Yacine Berranen, "Modélisation volumique du muscle avec représentation des fonctions physiologiques", Oct. 2011, D. Guiraud, M. Hayashibe and B. Gilles

PhD in progress: Wafa Tigra, "Vers la commande intuitive d'une neuroprothèse dédiée à la préhension chez le sujet tétraplégique", Sept. 2013, C. Azevedo and D. 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: Maedeh Aram, "Online optimization for functional electrical stimulation of hemiplegic patients", Aug. 2014, K. Mombaur (Heidelberg Univ., Germany) and C. Azevedo.

PhD in progress: Melissa Dali, "Modèle 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.

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

PhD in progress: Mariam Abdallah, "Système d'acquisition de signaux bioélectriques multicanal, programmable et implantable", Oct. 2012, G. Cathébras and F. Soulier.

Engineers

David Andreu supervised Guillaume Magro. "Spécification et prototypage d'un contrôleur de SEF implantable". Industrial Informatics Engineer, Inria Expert Engineer contract (3 years contract, Inria).

David Andreu supervised Thibaut Possompes. "HILECOP development". Computer engineering, Inria Research Engineer contract (4 month contract, Inria).

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 supervises Arthur Hiairrassary on "Development of a stimulation real-time controller", Industrial Informatics Engineer, Research Engineer (2 years contract, UM2).

Christine Azevedo Coste supervises Benoît Sijobert on "SENSBIO project development", IJD Engineer, Research Engineer (2 years contract, Inria).

Engineers internships

David Andreu supervised Arthur Hiairrassary on "Architecture logicielle temps-réel d'un contrôleur de SEF implantable", Engineer final internship, from March. 2014 to Sep. 2014.

David Andreu supervised Charles Bernard on "Conception et implémentation de fonctions sur un dispositif de Stimulation Electrique Fonctionnelle", Licence Professionnelle internship, from Feb 2014 to Jun 2014.

David Andreu supervised Pascal Wagner on "Conception et Implémentation d'une solution de communication avec un dispositif médical actif", Licence Professionnelle internship, from Feb 2014 to Jun 2014.

Karen Godary and David Andreu supervised Lila Kaci on "Etude de la gestion d'exception dans un modèle formel au coeur de dispositifs médicaux", Master internship, from March 2014 to July 2014.

David Andreu supervised Amandine Pantel on "Contribution à la conception et l'implémentation d'une solution de communication avec un dispositif médical actif, et à son interface d'exploitation", Engineer student, CPE Lyon, from June 2014 to September 2014.

Christine Azevedo Coste and Benoît Sijobert supervised Jennifer Denys on "La détection des épisodes de freezing dans la maladie de Parkinson", MASTER M2, Technologie pour la Santé, from March to July 2014.

Christine Azevedo Coste and Lionel Lapierre (EXPLORE, LIRMM) supervised Geoffrey Gicquel on "Mobile Platform for Parkinson Disease Walk Analysis", DUT Génie Electrique et Informatique, St Etienne, from April to June 2014.

Daniel Simon and David Andreu supervised Samy Lafnoune on "Contrôle d'ordonnancement dans un système de stimulation électrique distribué", Master2 Robotique UM2 internship from Apr. to Sep. 2014.

8.2.3. Juries

D. Simon was member of the PhD defense of Yiming Zhan (Univ. Rouen, Apr. 17)

D. Simon was member of the PhD defense of Abir Ben Khaled (Univ. Grenoble, May 27)

D. Simon was member of the PhD defense of Maissa Abdallah (Univ. Nantes, June 18).

Christine Azevedo Coste was reviewer of Antoine Marin PhD thesis defense "Le mouvement Segmentaire au service du déplacement dans la marche : analyse couplée des deux niveaux", Thesis, Université Rennes 2.

Christine Azevedo Coste was examiner of Alejandro Gonzalez de Alba PhD thesis defense "Estimation des paramètres du centre de masse corps complet : vers l'évaluation de l'équilibre pour une application de rééducation à domicile.", Thesis, Université Montpellier 2.

Christine Azevedo Coste was member of the committee for Inria CR2 competition (Monbtbonnot Center).

David Andreu was examiner of Zhan Li PhD thesis defense "Real-time EMG-Feedback Torque Prediction and Muscle Activation Control toward New Modality in FES". Thesis, Université Montpellier 2.

9. Bibliography

Major publications by the team in recent years

[1] D. ANDREU, D. GUIRAUD, G. SOUQUET. *A Distributed Architecture for Activating the Peripheral Nervous System*, in "Jounal of Neural Engineering", February 2009, vol. 6, pp. 001-018 [*DOI :* 10.1088/1741-2560/6/2/026001], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00361686

[2] M. BENOUSSAAD, P. POIGNET, M. HAYASHIBE, C. AZEVEDO COSTE, C. FATTAL, D. GUIRAUD. *Experimental parameter identification of a multi-scale musculoskeletal model controlled by electrical stimulation: application to patients with spinal cord injury*, in "Medical and Biological Engineering and Computing", June 2013, vol. 51, n^{o} 6, pp. 617-31 [*DOI :* 10.1007/S11517-013-1032-Y], https://hal.archives-ouvertes.fr/hal-00908533

[3] S. COTTON, A. MURRAY, P. FRAISSE. *Estimation of the Center of Mass: From Humanoid Robots to Human Beings*, in "IEEE/ASME Transactions on Mechatronics", December 2009, vol. 14, n^{o} 6, pp. 707-712, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00413022

[4] M. DJILAS, C. AZEVEDO COSTE, D. GUIRAUD, K. YOSHIDA. *Interpretation of muscle spindle afferent nerve response to passive muscle stretch recorded with thin-film longitudinal intrafascicular electrodes*, in "IEEE TNSRE", December 2009, vol. 17, n^{o} 5, pp. 445-453, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00411814

[5] H. EL MAKSSOUD, D. GUIRAUD, P. POIGNET, M. HAYASHIBE, P.-B. WIEBER, K. YOSHIDA, C. AZEVEDO COSTE. *Multiscale modeling of skeletal muscle properties and experimental validations in isometric conditions*, in "Biological Cybernetics", July 2011, vol. 105, pp. 121-138 [*DOI :* 10.1007/S00422-011-0445-7], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00631528

[6] D. GUIRAUD, C. AZEVEDO COSTE, M. BENOUSSAAD, C. FATTAL. *Implanted functional electrical stimulation: case report of a paraplegic patient with complete SCI after 9 years*, in "Journal of NeuroEngineering and Rehabilitation", February 2014, vol. 11, n^{o} 15, 10 p. [*DOI :* 10.1186/1743-0003-11-15], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00951769

[7] D. GUIRAUD, T. STIEGLITZ, G. TARONI, J.-L. DIVOUX. *Original Electronic Design to Perform Epimysial and Neural Stimulation in Paraplegia*, in "Journal of Neural Engineering", 2006, vol. 3, pp. 276-286, This work was supported by the European Community through the SUAW project under Grant BMH4-CT965-1501 [*DOI :* 10.1088/1741-2560/3/4/004], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00145807

[8] M. HAYASHIBE, Q. ZHANG, D. GUIRAUD, C. FATTAL. *Evoked EMG-based torque prediction under muscle fatigue in implanted neural stimulation*, in "Journal of Neural Engineering", October 2011, vol. 8, n^{o} 6, 7 p. [*DOI :* 10.1088/1741-2560/8/6/064001], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00630237

[9] J. LAFORET, D. GUIRAUD, D. ANDREU, H. TAILLADES, C. AZEVEDO COSTE. *Smooth muscle modeling and experimental identification: application to bladder isometric contraction*, in "Journal of Neural Engineering", May 2011, vol. 8, n^o^ 3, 13 p. [*DOI :* 10.1088/1741-2560/8/3/036024], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00597214

[10] M. PAPAIORDANIDOU, D. GUIRAUD, A. VARRAY. *Kinetics of Neuromuscular Changes during Low-Frequency Electrical Stimulation*, in "Muscle and Nerve", 2010, vol. 41, pp. 54-62 [*DOI :* 10.1002/MUS.21427], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00405225

Publications of the year

Articles in International Peer-Reviewed Journals

[11] 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, 10 p. [*DOI :* 10.1186/1743-0003-11-118], https://hal.inria.fr/hal-01060086

[12] C. AZEVEDO COSTE, B. SIJOBERT, R. PISSARD-GIBOLLET, M. PASQUIER, B. ESPIAU, C. GENY. *Detection of freezing of gait in Parkinson disease: preliminary results*, in "Sensors", 2014, vol. 14, n^o^ 4, pp. 6819-6827 [*DOI :* 10.3390/S140406819], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00977973

[13] A. BANERJEE, B. KHATTAR, A. DUTTA. *A Low-Cost Biofeedback System for Electromyogram-Triggered Functional Electrical Stimulation Therapy: An Indo-German Feasibility Study*, in "International Scholarly Research Notices", June 2014, 13 p. [*DOI :* 10.1155/2014/827453], https://hal.inria.fr/hal-01100745

[14] A. BEN KHALED, M. E. M. BEN GAÏD, N. PERNET, D. SIMON. *Fast multi-core co-simulation of Cyber-Physical Systems : application to internal combustion engines*, in "Simulation Modelling Practice and Theory", September 2014, vol. 47, n^o^ September, pp. 79-91 [*DOI :* 10.1016/J.SIMPAT.2014.05.002], https://hal-ifp.archives-ouvertes.fr/hal-01018348

[15] G. BIRGAND, C. AZEVEDO COSTE, G. TOUPET, R. PISSARD-GIBOLLET, B. GRANDBASTIEN, E. FLEURY, J.-C. LUCET. *Attitude and infectious risk in the operating room - The ARIBO study protocol*, in "BMJ Open", January 2014, vol. 4, n^o^ 1, 8 p. [*DOI :* 10.1136/BMJOPEN-2013-004274], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00916840

[16] V. BONNET, A. GONZALEZ, C. AZEVEDO COSTE, M. HAYASHIBE, S. COTTON, P. FRAISSE. *Determination of subject specific whole-body centre of mass using the 3D Statically Equivalent Serial Chain*, in "Gait and Posture", September 2014, 6 p. [*DOI :* 10.1016/J.GAITPOST.2014.08.017], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01068117

[17] V. BONNET, S. RAMDANI, C. AZEVEDO COSTE, P. FRAISSE, C. MAZZA, A. CAPPOZZO. *Integration of Human Walking Gyroscopic Data Using Empirical Mode Decomposition*, in "Sensors", 2014, vol. 14, n^o^ 1, pp. 370-381 [*DOI :* 10.3390/S140100370], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00922705

[18] F. BONNETBLANC, G. HERBET, P. CHARRAS, M. HAYASHIBE, D. GUIRAUD, H. DUFFAU, B. POULIN-CHARRONNAT. *Asymmetric interhemispheric excitability evidenced by event-related potential amplitude patterns after "wide-awake surgery" of brain tumours*, in "Experimental Brain Research", August 2014, vol. 232, n^o^ 12, pp. 3907-3918 [*DOI :* 10.1007/S00221-014-4075-X], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01103379

[19] A. DUTTA, S. CHUGH, A. BANERJEE, A. DUTTA. *Point-of-care-testing of standing posture with Wii balance board and Microsoft Kinect during transcranial direct current stimulation: a feasibility study*, in "NeuroRehabilitation", April 2014, vol. 34, n^o 4, pp. 789-798 [*DOI :* 10.3233/NRE-141077], https://hal.inria.fr/hal-01100746

[20] A. DUTTA, A. JACOB, S. ROY CHOWDHURY, A. DAS, M. NITSCHE. *EEG-NIRS based assessment of neurovascular coupling during anodal transcranial direct current stimulation - a stroke case series*, in "Journal of Medical Systems", October 2014, forthcoming, https://hal.inria.fr/hal-01100750

[21] A. DUTTA, U. LAHIRI, A. DAS, M. NITSCHE, D. GUIRAUD. *Post-stroke balance rehabilitation under multi-level electrotherapy: a conceptual review*, in "Frontiers in Neuroscience", December 2014, 18 p. [*DOI :* 10.3389/FNINS.2014.00403], https://hal.inria.fr/hal-01100748

[22] A. DUTTA, W. PAULUS, M. NITSCHE. *Facilitating myoelectric-control with transcranial direct current stimulation: a preliminary study in healthy humans*, in "Journal of NeuroEngineering and Rehabilitation", 2014, vol. 11, n^o 1, 13 p. [*DOI :* 10.1186/1743-0003-11-13], https://hal.inria.fr/hal-00950706

[23] A. GONZÁLEZ, M. HAYASHIBE, V. BONNET, P. FRAISSE. *Whole Body Center of Mass Estimation with Portable Sensors: Using the Statically Equivalent Serial Chain and a Kinect*, in "Sensors", September 2014, vol. 14, pp. 16955-16971 [*DOI :* 10.3390/s140916955], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01063479

[24] D. GUIRAUD, C. AZEVEDO COSTE, M. BENOUSSAAD, C. FATTAL. *Implanted functional electrical stimulation: case report of a paraplegic patient with complete SCI after 9 years*, in "Journal of NeuroEngineering and Rehabilitation", February 2014, vol. 11, n^o 15, 10 p. [*DOI :* 10.1186/1743-0003-11-15], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00951769

[25] M. HAYASHIBE, S. SHIMODA. *Synergetic motor control paradigm for optimizing energy efficiency of multijoint reaching via tacit learning*, in "Frontiers in Computational Neuroscience", February 2014, vol. 8, n^o 21 [*DOI :* 10.3389/FNCOM.2014.00021], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00979632

[26] U. JINDAL, M. SOOD, A. DUTTA, S. ROY CHOWDHURY. *Development of point of care testing device for neurovascular coupling from simultaneous recording of EEG and NIRS during anodal transcranial direct current stimulation*, in "IEEE Journal of Translational Engineering in Health and Medicine", December 2014, forthcoming, https://hal.inria.fr/hal-01100749

[27] Z. LI, D. GUIRAUD, M. HAYASHIBE. *Inverse Estimation of Multiple Muscle Activations from Joint Moment with Muscle Synergy Extraction*, in "IEEE Journal of Biomedical and Health Informatics", October 2014, forthcoming, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01037874

[28] 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], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00980641

[29] P. MACIEJASZ, J. ESCHWEILER, K. GERLACH-HAHN, A. JANSEN-TROY, S. LEONHARDT. *A survey on robotic devices for upper limb rehabilitation*, in "Journal of NeuroEngineering and Rehabilitation", January 2014, vol. 11, n^o 3, 29 p. [*DOI :* 10.1186/1743-0003-11-3], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00946858

[30] A. PADILHA LANARI BO, C. AZEVEDO COSTE, C. GENY, P. POIGNET, C. FATTAL. *On the Use of Fixed-Intensity Functional Electrical Stimulation for Attenuating Essential Tremor*, in "Artificial Organs", 2014, 8 p. [*DOI :* 10.1111/AOR.12261], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00951194

[31] M. PAPAIORDANIDOU, M. HAYASHIBE, A. VARRAY, C. FATTAL, D. GUIRAUD. *A new method for muscle fatigue assessment: Online model identification techniques*, in "Muscle & Nerve", January 2014, vol. 50, n^{o} 4, pp. 556-563 [*DOI :* 10.1002/MUS.24190], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00952416

[32] M. PAPAIORDANIDOU, A. VARRAY, C. FATTAL, D. GUIRAUD. *Neural and muscular mechanisms of electrically induced fatigue in patients with spinal cord injury*, in "Spinal Cord", January 2014, vol. 52, pp. 246-250 [*DOI :* 10.1038/SC.2013.172], http://hal-lirmm.ccsd.cnrs.fr/lirmm-00952423

[33] N. SYLLA, V. BONNET, F. COLLEDANI, P. FRAISSE. *Ergonomic contribution of ABLE exoskeleton in automotive industry*, in "International Journal of Industrial Ergonomics", July 2014, vol. 44, n^{o} 4, pp. 475-481 [*DOI :* 10.1016/J.ERGON.2014.03.008], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01111273

[34] M. TOURNIER, M. NESME, F. FAURE, B. GILLES. *Velocity-based Adaptivity of Deformable Models*, in "Computers and Graphics", December 2014, vol. 45, pp. 75 - 85 [*DOI :* 10.1016/J.CAG.2014.08.004], https://hal.inria.fr/hal-01076338

[35] B. YANG, W.-K. WONG, C. LIU, P. POIGNET. *3D soft-tissue tracking using spatial-color joint probability distribution and thin-plate spline model*, in "Pattern Recognition", September 2014, vol. 47, n^{o} 9, pp. 2962-2973 [*DOI :* 10.1016/J.PATCOG.2014.03.020], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01008788

International Conferences with Proceedings

[36] A. BAUER, F. ULLIANA, A. H. DICKO, B. GILLES, O. PALOMBI, F. FAURE. *My Corporis Fabrica : Making Anatomy Easy*, in "Siggraph 2014 Talks", Vancouver, Canada, August 2014, https://hal.inria.fr/hal-00987439

[37] A. BEN KHALED, L. DUVAL, M. E. M. BEN GAÏD, D. SIMON. *Context-based polynomial extrapolation and slackened synchronization for fast multi-core simulation using FMI*, in "10th International Modelica Conference 2014", Lund, Sweden, Linköping University Electronic Press, March 2014, pp. 225-234 [*DOI :* 10.3384/ECP14096225], https://hal.inria.fr/hal-00968895

[38] V. BERENZ, M. HAYASHIBE, F. ALNAJJAR, S. SHIMODA. *Generalization of the Tacit Learning Controller Based on Periodic Tuning Functions*, in "IEEE RAS/EMBS 5th International Conference on Biomedical Robotics and Biomechatronics", Sao Paulo, Brazil, August 2014, pp. 893-898, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01102491

[39] J.-P. BERNARD, B. GILLES, C. GODIN. *Combining Finite Element Method and L-Systems Using Natural Information Flow Propagation to Simulate Growing Dynamical Systems*, in "Theory and Practice of Natural Computing", Granada, Spain, A.-H. DEDIU, M. LOZANO, C. MARTIN-VIDE (editors), Springer, December 2014, vol. 8890, pp. 218 - 230 [*DOI :* 10.1007/978-3-319-13749-0_19], https://hal.inria.fr/hal-01096602

[40] Y. BERRANEN, M. HAYASHIBE, D. GUIRAUD, B. GILLES. *Real-time Muscle Deformation via Decoupled Modeling of Solid and Muscle Fiber Mechanics*, in "MICCAI'20141: 7th International Conference on Medical Image Computing and Computer-Assisted Intervention", Boston, MA, United States, Part II, September 2014, vol. LNCS, n^{o} 8674, pp. 65-72 [*DOI :* 10.1007/978-3-319-10470-6_9], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01102481

[41] V. Bonnet, N. Sylla, A. Cherubini, A. Gonzalez, C. Azevedo Coste, P. Fraisse, G. Venture. *Toward an Affordable and User-Friendly Visual Motion Capture System*, in "EMBC'14: 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society", Chicago, Illinois, United States, August 2014, 6 p. , http://hal-lirmm.ccsd.cnrs.fr/lirmm-01006396

[42] S. Chandra, M. Hayashibe, A. Thondiyath. *Dominant Component in Muscle Fatigue Induced Hand Tremor during Laparoscopic Surgical Manipulation*, in "EMBC'2014: 36th Annual International Conference of Engineering in Medicine and Biology Society", Chicago, IL, United States, August 2014, pp. 6539-6542 [*DOI :* 10.1109/EMBC.2014.6945126], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01102489

[43] D. Galdeano, A. Chemori, S. Krut, P. Fraisse. *Task-based whole-body control of humanoid robots with ZMP regulation, real-time application to a squat-like motion*, in "IEEE SSD - 11th International Conference on Systems, Analysis and Automatic Control", Castelldefels-Barcelona, Spain, February 2014, 6 p. , http://hal-lirmm.ccsd.cnrs.fr/lirmm-00945690

[44] C. Geny, C. Azevedo Coste, A. Gabelle-Deloustal, C. Fattal, P. Poignet, A. Padilha Lanari Bo. *Contribution Of Different Drawing Tasks In The Assessment Of Essential Tremor*, in "MDS'14: 18th International Congress of Parkinson's Disease and Movement Disorders", Stockholm, Sweden, June 2014, vol. 29 (Suppl. 1:1133), http://hal-lirmm.ccsd.cnrs.fr/lirmm-01006392

[45] H. Leroux, K. Godary-Dejean, D. Andreu. *Integrating Implementation Properties in Analysis of Petri Nets Handling Exceptions*, in "WODES'14: 12th IFAC - IEEE International Workshop on Discrete Event Systems", École Normale Supérieure de Cachan, France, May 2014, pp. 1-6, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01064146

[46] Z. Li, M. Hayashibe, D. Andreu, D. Guiraud. *A system for real-time estimation of joint torque with evoked EMG under electrical stimulation*, in "2nd International Conference on NeuroRehabilitation", AAlborg, Denmark, June 2014, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00983717

[47] H. Romero Ugalde, V. Le Rolle, A. Bel, J.-L. Bonnet, D. Andreu, P. Mabo, G. Carrault, A. I. Hernández. *On-off closed-loop control of vagus nerve stimulation for the adaptation of heart rate*, in "36th Annual International Conference of the IEEE - Engineering in Medicine and Biology Society (EMBC)", Chicago, United States, August 2014 [*DOI :* 10.1109/EMBC.2014.6945060], https://hal-univ-rennes1.archives-ouvertes.fr/hal-01100914

[48] B. Sijobert, C. Azevedo Coste, J. Denys, C. Geny. *IMU Based Detection of Freezing of Gait and Festination in Parkinson's Disease*, in "19th International Functional Electrical Stimulation Society Annual Conference (IFESS)", Kuala Lumpur, Malaysia, September 2014 [*DOI :* 10.13140/2.1.1587.1366], https://hal.inria.fr/hal-01096479

[49] N. Sylla, V. Bonnet, G. Venture, N. Armande, P. Fraisse. *Assessing neuromuscular mechanisms in human-exoskeleton interaction*, in "EMBC'2014: 36th Annual International Conference of Engineering in Medicine and Biology Society", Chicago, IL, United States, IEEE, August 2014, pp. 1210-1213 [*DOI :* 10.1109/EMBC.2014.6943814], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01111277

[50] M. Tournier, M. Nesme, F. Faure, B. Gilles. *Seamless Adaptivity of Elastic Models*, in "Graphics Interface", Montréal, Canada, P. G. Kry, A. Bunt (editors), Canadian Information Processing Society Toronto, May 2014, pp. 17-24, https://hal.inria.fr/hal-00975220

Conferences without Proceedings

[51] D. GALDEANO, A. CHEMORI, S. KRUT, P. FRAISSE. *Human based hybrid kinematic/dynamic whole-body control in humanoid robotics*, in "French-German-Japanese Conference on Humanoid and Legged Robots (HLR 2014)", Heidelberg, Germany, May 2014, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00993302

[52] N. SYLLA, V. BONNET, G. VENTURE, N. ARMANDE, P. FRAISSE. *Human arm optimal motion analysis in industrial screwing task*, in "BioRob'2014: 5th International Conference on Biomedical Robotics and Biomechatronics", São Paulo, Brazil, IEEE RAS & EMBS, August 2015, pp. 964-969 [*DOI :* 10.1109/BIOROB.2014.6913905], http://hal-lirmm.ccsd.cnrs.fr/lirmm-01111274

Scientific Books (or Scientific Book chapters)

[53] D. SIMON, Y.-Q. SONG, O. SENAME. *Conception conjointe commande-ordonnancement*, in "Ordonnancement dans les systèmes temps réel", M. CHETTO (editor), ISTE Editions, June 2014, pp. 293-324, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01017944

[54] D. SIMON, Y.-Q. SONG, O. SENAME. *Control and Scheduling Joint Design*, in "Real-time Systems Scheduling", M. CHETTO (editor), ISTE Editions, September 2014, vol. 2 "Focuses", pp. 53-96, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01067487

Research Reports

[55] A. JACOB, M. A. NITSCHE, A. DUTTA. *Use of tDCS for stroke rehabilitation*, Lirmm, August 2014, https://hal.inria.fr/hal-01062445

[56] S. LAFNOUNE. *Contrôle d'ordonnancement dans un système de stimulation électrique distribué*, Master 2 Robotique, Université Montpellier 2, August 2014, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01096604

[57] R. SIDI BOULENOUAR, M. HAYASHIBE, A. DUTTA. *EEG-EMG features extraction for brain computer interface*, February 2014, https://hal.inria.fr/hal-01063815

Other Publications

[58] A. GONZÁLEZ, P. FRAISSE, M. HAYASHIBE. *Adaptive Interface for Personalized Center of Mass Self-Identification in Home Rehabilitation*, April 2014, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01096525

[59] H. LEROUX, K. GODARY-DEJEAN, G. COPPEY, D. ANDREU. *Automatic Handling of Conflicts in Synchronous Interpreted Time Petri Nets Implementation*, IEEE, July 2014, ISVLSI'14: Computer Society Annual Symposium on VLSI, http://hal-lirmm.ccsd.cnrs.fr/lirmm-01064174