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Activity Report 2012

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 Medicine and Neurosciences

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Project-Team DEMAR

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

Creation of the Project-Team: October 01, 2003 .

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2. Overall Objectives

2.1. Introduction

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

Currently, FES is the only way to restore motor function even though biological solutions are studied, but not yet successfully tested on humans. Few teams carry out researches on implanted FES and the functional results remain poor. Nevertheless, the technique has proved to be useable and needs enhancements that we address in DEMAR. Regarding technology, complex electrode geometries associated with complex stimulus waveforms provide a way to perform fibre type selectivity and spatial localisation of the stimuli in the nerves. These features are not yet implemented and demand new hardware and software architectures. Several teams in Denmark (SMI U. Aalborg), Germany (IBMT Franhaufer Institute), England (U. College of London), Belgium (U. Catholique de Louvain), United States (Cleveland FES centre), and Canada (Ecole Polytechnique de Montréal), work on multi-polar neural stimulation but mainly on electrode aspect, except Polystim Lab of Montréal.
Such a complex system needs advanced control theory tools coupled with a deep understanding of the underlying neurophysiological processes. This major area of research will be also an important part of the DEMAR objectives.
Besides, experiments are necessary to: improve neurophysiology knowledge, identify and validate models, evaluate control strategies or test neuroprostheses. Our experiments are carried on valid and non-valid individuals in clinical environment, but also on animals. Nevertheless, it 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: both 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...

2.2. Highlights of the Year

- David Andreu received the 1rst Price 2012 of the FIEEC-OSEO on Applied Research, for his research and innovation transfer with Vivaltis company.

3. Scientific Foundations

3.1. Modelling and identification of the sensory-motor system

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

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 contribution 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 to 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 teams 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, Guy Cathébras, Fabien Soulier, Serge Bernard.

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 system 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. Application Domains

4.1. Objective quantification and understanding of movement disorders

One main advantage of developping a model based on a physical description of the system is that the parameters are meaningful. Therefore, these parameters when identified on a given individual (valid or deficient), give objective and quantitative data that characterize the system and thus can be used for diagnosis purposes.
Modelling provides a way to simulate movements for a given patient and therefore based on an identification procedure it becomes possible to analyse and then understand his pathology. In order to describe complex pathology such as spasticity that appears on paraplegic patients, you need not only to model the biomechanics parts - including muscles -, but also parts of the peripheral nervous system - including natural sensors - to assess reflex problems. One important application is then to explore deficiencies globally due to both muscles and peripheral neural nets disorders.

4.2. Palliative solutions for movement deficiencies

Functional electrical stimulation is one possibility to restore or control motor functions in an evolutive and reversible way. Pacemaker, cochlear implants, deep brain stimulation (DBS) are successful examples. DEMAR focuses on movement disorder restoration in paraplegic and quadriplegic patients, enhancements in hemiplegic patients, and some other motor disorders such as bladder and bowel control. Nevertheless, since some advances in neuroprosthetic devices can be exploited for the next generation of cochlear implants, the team also contributes to technological and scientific improvements in this domain.
The possibility to interface the sensory motor system, both activating neural structure with implanted FES, and sensing through implanted neural signal recordings open a wide application area:

- Restoring motor function such as grasping for quadriplegic patient, standing and walking for paraplegic patient, compensating foot drop for hemiplegic patients. These applications can be firstly used in a clinical environment to provide physiotherapist with a new efficient FES based therapy (using mainly surface electrodes) in the rehabilitation process. Secondly, with a more sophisticated technology such as implanted neuroprostheses, systems can be used at home by the patient himself without a clinical staff.
- Modulating motor function such as tremors in Parkinsonian patient using DBS. Techniques are very similar but for the moment, modelling is not achieved because it implies the central nervous system modelling in which we are not implied.
- Sensing the afferent pathways such as muscle's spindles, will be used to provide a closed loop control of FES through natural sensing and then a complete implanted solution. Sensing the neural system is a necessity in some complex motor controls such as the bladder control. Indeed, antagonist muscle's contractions, and sensory feedbacks interfere with FES when applied directly on the sacral root nerve concerned. Thus, enhanced activation waveforms and sensing feedback or feedforward signals are needed to perform a highly selective stimulation.

To achieve such objectives, experimentations in animals and humans are necessary. This research takes therefore a long time in order to go from theoretical results to real applications. This process is a key issue in biomedical research and is based on: i) design of complex experimental protocols and setups both for animals and humans, ii) ethical attitude both for humans and animals, with ethical committee approval for human experiments iii) volunteers and selected, both disabled and healthy, persons to perform experiments with the adequate medical staff.

5. Software

5.1. Software

5.1.1. RdP to VHDL tool

Participants: Gregory Angles, David Andreu, Thierry Gil.

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 unit's 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 inter-connected as well as signals it exports or imports. The interconnection of those components, from a behavioral point out view, consists in the interconnection of places and/or transitions according to well-defined mechanisms: interconnection by means of oriented arcs or by means of the "merging" operator (existing for both places and transitions).

GALS (Globally Asynchronous Locally Synchronous) systems can be specified, connecting different clocks to HILECOP components, and interconnecting them by means of asynchronous signals.

Undergoing work includes the modification of the formalism in order to allow behavior agregation as well as exception handling.

The Eclipse-based version of HILECOP is regulary updated. The last version of HILECOP (registered at the french Agence de Protection des Programmes (APP)) is accessible to the academic community (http://www.lirmm.fr/ gil/Temp/).

5.1.2. 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.

A new version of SENISManager is under development according to an Eclipse-based design. This new version should be available in 2013.

6. New Results

6.1. Modelling and Identification

6.1.1. Subject-specific Center of Mass estimation in human subjects

Participants: Alejandro González, Mitsuhiro Hayashibe, Philippe Fraisse.

Center of mass position (CoM) in humanoid robots can be used to generate a joint trajectory suitable for walking and standing. Oscillations of the CoM while maintaining a standing posture have been observed in older patients. These oscillations are thought to occur due a change in the subject's balancing strategy. This is why the motion of the CoM in generally considered as good metric to be used while diagnosing pathologies which affect gait. With this in mind we propose the use of the statically equivalent serial chain (SESC) to provide a subject specific estimate of CoM position. The state of the art techniques for CoM estimation in humans involve the use of expensive equipment in a laboratory setting, making it difficult to use as a clinical tool or inside the home environment. Current work for diagnosing a subject's balance moves away from this, focusing on wearable and minimally invasive sensors that obtain information during the subject's daily activities. We propose the use of widely available sensors like the Kinect camera, for tracking the subject's movements, and the Wii balance board during the calibration of the SESC.

a) b)

Figure 1. Center of mass estimation can be done using the statically equivalent serial chain. We assume a 9 rigid-link model (a) with spherical joints, capable of three dimensional movements. The SESC estimation can be performed in real time and is driven by joint angular measurements (b).

We have focused in improving the reliability of the identification during a study of the CoM trajectory in the sagital plane [14]. We studies small value for the condition number of the used data as well as of the parameter relative standard deviation ($\sigma_{\hat{\mathbf{R}}_r}\%$) are useful to determine the validity of the estimate. Subsequent works have extended the human model to three-dimensional motion (Fig. 1.a). In order to observe the tracking of the center of mass, we have developed a 3D visualization tool which represents the subject's skeleton and SESC in real time (Fig. 1.b) [16]; it is also possible to observe the CoM history. Finally we are now comparing the performance of the inexpensive Kinect sensor and the traditional video based motion capture Vicon system, with reasonably good results [15]. Current work is also focused in improving the speed of the identification phase by simplifying the assumed human model and using physical constraints to reduce the complexity of the SESC. Also the development of a simple to follow identification protocol which takes into account multiple supporting surfaces is desired.

6.1.2. Recursive estimation of SESC parameters for human Center of Mass estimation

Participants: Alejandro González, Mitsuhiro Hayashibe, Philippe Fraisse.

A human's center of mass (CoM) trajectory is useful to evaluate the dynamic stability during daily life activities such as walking and standing up. To estimate the subject-specific CoM position in the home environment, we make use of a statically equivalent serial chain (SESC) developed with a portable mesurement system. In order to adapt to the subject's physical capacities we implement a constrained Kalman filter to achieve an online parameter estimation of the SESC parameters. By accounting for the human body bilateral symmetry we hope to reduce the identification time. This results in constrainig SESC parameters to be consistent with the human skeletal model used. The Kinect camera is used as a markerless motion capture system for measuring limb orientations while the Wii board is used to measure the subject's center of pressure (CoP) during the identification phase. For his experiment CoP measurements and Kinect data were recorded for five able-bodied subjects. The data was then given to the proposed recursive algorithm to identify the parameters of the SESC online (Fig.2). This method of online identification allows the subject or the therapist to know the quality of the on-going CoM identification while giving postures; by doing this the time needed to perform the identification can be reduced. A cross-validation was performed to verify the identification performance.

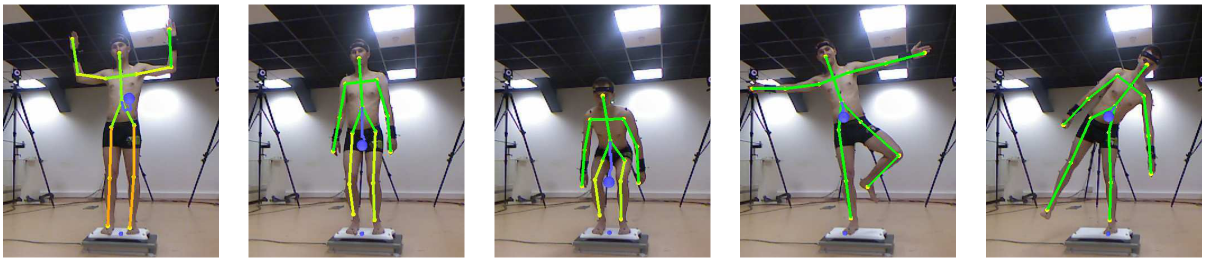

Figure 2. Online statically equivalent serial chain (SESC) parameter estimation. The length of each of the SESC's link is updated when a static pose has been found and can be observed in real time. The color of the skeleton can be updated as a cue to the subject and/or therapist.

6.1.3. FES-Induced Torque Prediction with Evoked EMG Synthesized by Recurrent Neural Network

Participants: Zhan Li, Mitsuhiro Hayashibe, David Guiraud.

A NARX-type recurrent neural network (NARX-RNN) model is proposed for identification and prediction of FES-induced muscular dynamics with eEMG. Such NARX-RNN model is with a novel architecture for prediction, with robust prediction performance. To make fast convergence for identification of such NARXRNN, directly-learning pattern is exploited during the learning phase. Due to difficulty of choosing a proper forgetting factor of Kalman filter for predicting time-variant torque with eEMG, such NARX-RNN may be considered to be a better alternative as torque predictor. Data gathered from two SCI patients is used to evaluate the proposed NARX-RNN model. The NARX-RNN model shows promising estimation and prediction performance only based on eEMG [23].

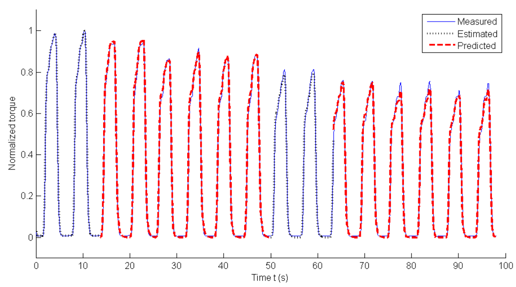

Figure 3. Performance of NARX-RNN model with eEMG for prediction with identification on periodically

6.1.4. Inverse Estimation of Muscle Activations with Weights Optimization

Participants: Zhan Li, Mitsuhiro Hayashibe, David Guiraud.

Inverse estimation of activations of muscle groups at human lower leg in random movement condition is investigated with merely the ankle joint torque used. Optimization technique for the relationship between muscle activations and torque is exploited. Such optimization is able to rebuilt the relationship between muscle activations and torque inversely based on experimental data obtained from five healthy subjects, and the optimal weight matrix can indicate each muscle's contribution for producing the torque. Further cross-validation on prediction of muscle activations with joint torque with optimal weights shows such approach may possess promising performance [22].

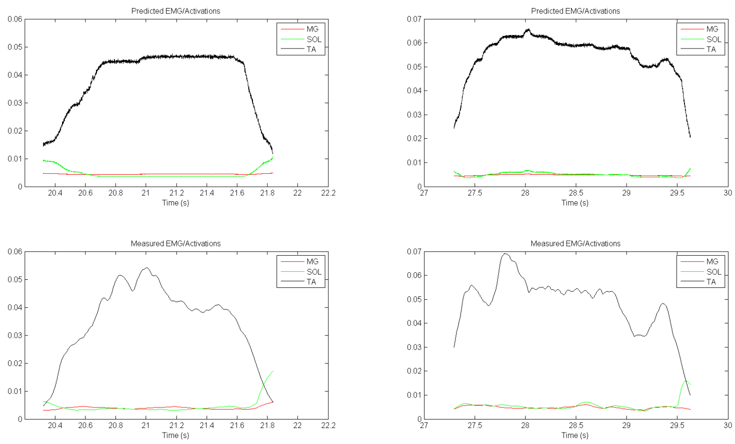

Figure 4. Prediction of muscle activations

6.1.5. 3D Volumetric Muscle Modeling For Real-time Deformation Analysis With FEM

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

Computer simulators are promising numerical tools to study muscle volumetric deformations but most models are facing very long computation time and thus are based on simplified Hill model versions. The purpose of this study is to develop a real-time three-dimensional biomechanical model of fusiform muscle based on modified Hill model for the active stress which is controlled from EMG recordings. Finite element model is used to estimate the passive behavior of the muscle and tendons during contraction. We show that this 3D model implementation is very cost effective with respect to the computation time and the simulation gives good results compared to real measured data. Thus, this effective implementation will allow implementing much more complex and realistic models, with moderate computation time.

6.1.6. Principal Geodesic Dynamics

Participants: Maxime Tournier, Lionel Reveret.

This paper presents a new integration of a data-driven approach using dimension reduction and a physically-based simulation for real-time character animation. We exploit Lie group statistical analysis techniques (Principal Geodesic Analysis, PGA) to approximate the pose manifold of a motion capture sequence by a reduced set of pose geodesics. We integrate this kinematic parametrization into a physically-based animation approach of virtual characters, by using the PGA-reduced parametrization directly as generalized coordinates

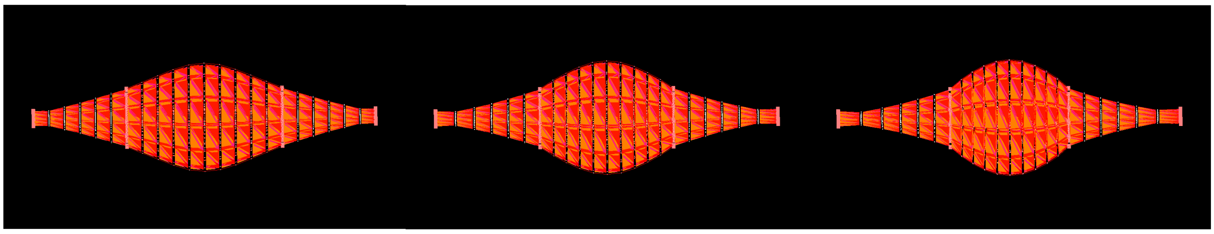

Figure 5. Real-time Simulation of Volumetric Muscle Deformation.

of a Lagrangian formulation of mechanics. In order to achieve real-time without sacrificing stability, we derive an explicit time integrator by approximating existing variational integrators. Finally, we test our approach in task-space motion control. By formulating both physical simulation and inverse kinematics time stepping schemes as two quadratic programs, we propose a features-based control algorithm that interpolates between the two metrics. This allows for an intuitive trade-off between realistic physical simulation and controllable kinematic manipulation.

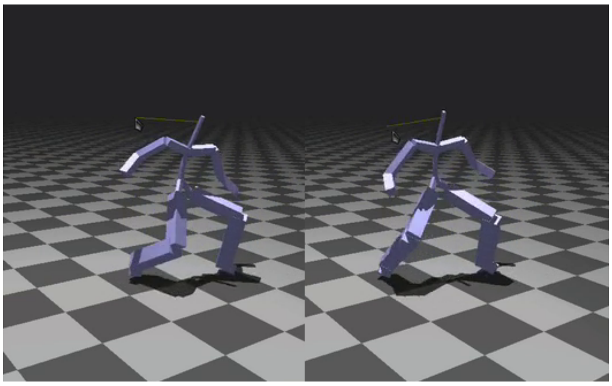

Figure 6. Real-time user interaction with a virtual character maintaining balance, animated using our approach: based on a break-dance motion capture sequence, our dimension reduction process allows one to compute both dynamics and task-space control in a low-dimensional, data-driven subspace.

6.1.7. An improved kinematic model of the spine for three-dimensional motion analysis in the Vicon system

Participants: Pawel Maciejasz, Wieslaw Chwala (University School of Physical Education, Krakow), Miroslawa Dlugosz, Daria Panek, Witold Alda (AGH University of Science and Technology, Krakow).

The mechanism of creation and pathomechanics of lateral spinal deformation is still not fully explained. Modern medical imaging techniques give scientists possibility to understand some aspects, but vast majority of those techniques is based on static trials. A motion capture system belongs to techniques which enable visualization of a spine during dynamic trials; however, due to lack of appropriate computational model, it is unsuitable for scoliosis imaging.

A few years ago a kinematic model of the spine has been proposed to be used with Vicon Motion Capture System (Master thesis of P. Maciejasz). This model was based on Bézier curves and allowed for much more precise investigation of spinal kinematics during dynamic trials as compared with other computational models. However, it did not allowed to restrict only selected movements for particular segments of the spine (e.g. axial rotation for lumbar spine). The aim of the current work is to improve the proposed model in order to be able to restrict selected movements according to the knowledge concerning spinal anatomy and spinal range of motion. The new kinematic model of the spine was written in BodyBuilder for Biomechanics Language. For the purpose of visualization also an accurate graphical representation of each vertebra (polygon mesh) was computed and adapted to be compatible with the kinematic model. Using a new version of the model it is possible to perform precise analysis of movement of all vertebrae during such dynamic activities as e.g. gait and forward or lateral bending, as well as to present the results not only on the charts, but also as a 3D animation of movements of a realistically looking spine [12].

6.1.8. Methodology of automated detection and classification of action potentials in nerve fiber based on multichannel recordings

Participants: Thomas Guiho, Pawel Maciejasz, David Guiraud.

For some neuroprosthetic applications it would be beneficial to be able to automatically detect when particular nerve fibers (axons) are in "firing" (i.e. when an action potential is propagating along them). Due to limitations of currently available recording electrodes on one side, and the attempt to be as little invasive as possible, at the moment in practical application it is not possible to record signals coming from a single nerve fiber. In signal recorded using typical electrodes placed close to nerve fibers, action potentials coming from various nerve fibers, as well as noise coming from outside of the nerve, may be detected. One of the possibilities allowing to distinguish action potentials coming from various nerve fibers in such a case is to record signals at a few places along the nerve and compare them.

We have proposed an algorithm that allows to automatically detect and classify evoked action potentials in a simple earthworm model. The signals were recorded concurrently at 2 places along the giant nerve fibers. In the first step the algorithm tries to identify only does recordings in which action potentials generated by various nerve fibers can be easily distinguished. Afterwards, the most significant features (such as amplitude, duration, propagation velocity, etc.) to distinguish between different populations of fibers are identified. Finally, the action potentials in all signals are identified and classified using the features determined in the previous step.

The proposed method was implemented using MATLAB software and tested on the file containing almost 200 signals record in response to various stimuli. The same data ware later inspected manually and the action potentials were manually classified. More than 99% of action potentials were classified to the same nerve fiber when performing automatic and manual classification.

6.2. Function control and synthesis

6.2.1. FES assisted sitting pivot transfer

Participants: Jovana Jovic, Christine Azevedo Coste, Philippe Fraisse, Sebastien Lengagne, Charles Fattal.

Transferring from a wheelchair to a treatment table, bed, tub/shower bench, toilet seat, car seat and vice versa represent typical Sitting Pivot Transfer (SPT) realized by individuals with Spinal Cord Injury (SCI). Individuals with SCI, perform this postural task around fifteen times a day using upper extremities. In the chronic stage after SCI, soft tissue structures are exposed to overuse in activities of daily living, such as, transfer task in which the shoulder becomes a weight-bearing joint. Therefore, the risk of shoulder pain and musculoskeletal disorders is higher in persons with paraplegia compared with an able-bodied population. A lot of scientific effort has been focused on experimental studies in which the kinetic and the kinematic of the SPT movement have been analyzed. To our best knowledge, the scientists have focused their attention only on the performance of SPT; the influence of Functional Electrical Stimulation (FES) on SPT maneuver has not been investigated so far.

Therefore, we investigate the influence of FES on SPT motion of a paraplegic person. First, we develop dynamic optimization method in order to predict SPT motion of an able-bodied subject. This approach have been validated by comparing computed SPT trajectories with the ones measured during the experiment with an able-bodied subject (see Fig. 7). After validating our method, we used the optimization tool for analyzing the influence of FES on SPT maneuver in paraplegic persons. Our results suggest that FES can decrease arm participations during the transfer motion of a paraplegic person. [6], [21].

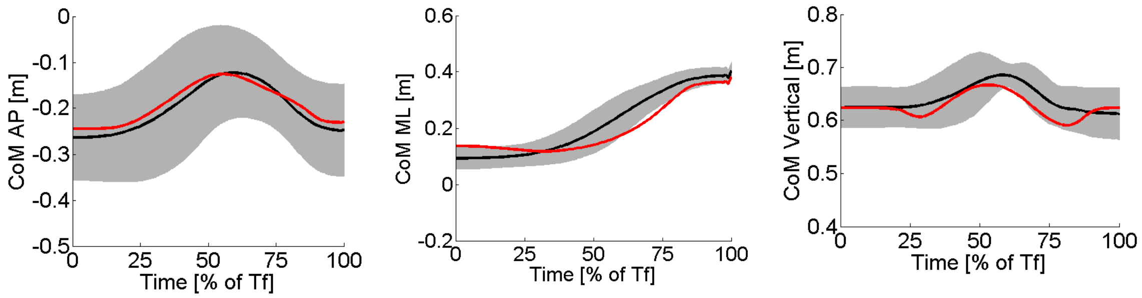

Figure 7. Computed (red line) CoM position, mean value of CoM positions estimated from experimental data (black line) and its plus/minus standard deviation (gray line) in AP, ML, and vertical direction in able-bodied subject.

6.2.2. FES assisted prolonged standing

Participants: Jovana Jovic, Philippe Fraisse, Christine Azevedo Coste, Charles Fattal.

Prolonged immobilization which occurs after spinal cord injury results in many physiological problems. Standing therapy can ameliorate many of those problems. The approaches proposed in the literature for restoration of standing in paraplegic population based on Functional Electrical Stimulation (FES) focuse on the control of each individual joint, i.e. joint space control. In those cases the balance of the postural system is not directly controlled. This could be problematic especially when only the lower limbs are controlled. During paraplegic's quiet standing two concurrent controllers are acting in parallel, the physiological system under control of Central Nervous System (CNS), and artificial FES system. Upper part of the paraplegic's body is under voluntary control, therefore artificial controllers should be designed in the way to take into account actions of the intact part of the body and to assist users in their task.

For human beings the Center of Mass (CoM) provides an indicator of stability and it is an essential parameter in human postural stability. By controlling CoM position in paraplegic person the voluntary motions under CNS control are taken into account. Therefore, in we propose a whole body controller based on control of the CoM position. The goal was to develop a simple balance controller which would, by means of FES, enable quiet standing of individuals suffering from SCI while taking into account the voluntary motion of the upper limbs. The controller should enable prolonged standing by simulating the behavior of an able-bodied subject during the standing task, i.e. by imposing posture switching and in that way allowing the stimulated muscles to relax. The proposed approach is based on a 10 DoF biomechanical model and Proportioan Integral (PI) controller (see Fig. 8). The validity of the approach is tested, in computer simulations, using human CoM trajectories estimated from experimental data and by applying perturbations in simulation during quiet standing in order to simulate voluntary upper body movements.The results show that proposed controller is able to track desired CoM position with sufficient precision and to maintain stability even in the presence of simulated movements of the upper body [20].

6.2.3. Bimanual reeducation assisted by FES in post-stroke patients

Participants: Nader Rouis, Christine Azevedo Coste, Philippe Fraisse, Isabelle Laffont, Denis Mottet.

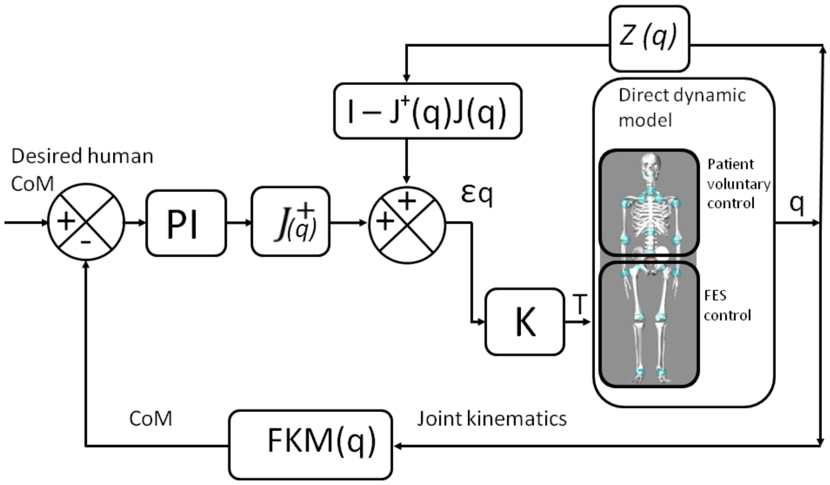

Figure 8. Block diagram of the proposed postural controller. Controller follows desired 3D CoM positions and controls the lower limbs by applying torque at ankle, knee and hip joints (10 DoF).

This starting project will investigate the possibility to stimulate the deficient upper limb of a post-stroke patient in order to reproduce the movements observed on the valid upper limb or in order to achieve a bimanual task in cooperation with the valid upper limb. The aim is to improve the bimanual training tasks classically used in fictional rehabilitation. Both embedded sensors and kinect type systems will be investigated as possible ways to observe the valid upper limbs.

6.2.4. Freezing detection in Parkinson Disease patients

Participants: Maud Pasquier, Christine Azevedo Coste, Christian Geny, Bernard Espiau.

This work intends to apply the results of Maud Pasquier thesis about data segmentation and locomotion analysis to the detection as soon as possible of freezing episodes in Parkinson Disease (PD) patients. PD is a chronic degenerative disease of the central nervous system. One of the consequence is walking troubles and increased postural instability and falling risks. Freezing concerns at least half of PD patients, it is characterized by the transitory incapacity to make a step. It classically occurs at the gait initiation, turn around and passing doors. This freezing of gait (FOG) strongly impacts patient's mobility. As an example, in figure 9, data recorded by an inertial sensor placed at the ankle is presented.

Assistive devices have been proposed, it has been shown that providing the patient with an auditory metronome or visual lines on the ground allows to reduce FOG occurrence but the effects are not maintained within the time. An approach would be to present this signals only when a freezing episode occurs and this implies to be able to detect it. Several authors have shown that FOG are in general associated to walking rhythm variability. Moore et al have used an accelerometer placed on lower limv in order to detect the presence of high frequencies. Indeed, the tremor pattern which can be observed during freezing is located at 3 et 8Hz, whereas normal locomotion is around 3Hz. These authors are able to detect a large part of the FOG but only those presenting high frequency patterns which is not systematic. Furthermore the detection delay (FFT) is very high and cannot be compatible with assistive device control constraints. We have proposed to observe stride properties in an online manner and compute a criterion which value informs about the FOG occurrence. The criterion is based on two variables: the stride length and the cadence. When stride length diminishes and cadence increases a FOG may be upcoming. 3 patients have been involved in this study and the criterion

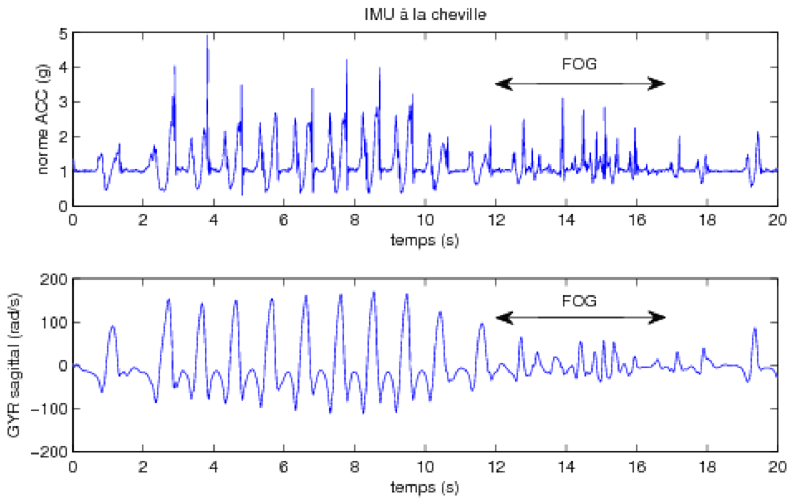

Figure 9. Signals recorded with an inertial sensor placed at the ankle during a walking trial. Top: acceleration norm, Bottom: sagittal plane rotation velocity

proposed has been shown to be as efficient than Moore's method in terms of number of detected FOG but the detection time is strongly improve with our method.

6.2.5. "Awake surgery" of slow-growing tumors and cortical excitability measured by EEG recordings.

Participants: François Bonnetblanc, Guillaume Herbet, Pom Charras, Mitsuhiro Hayashibe, David Guiraud, Hugues Duffau, Bénédicte Poulin-Charronnat.

Using direct electrical stimulation, real-time functional mapping of the brain can be used to perform resections of slow-growing infiltrative tumors in awake patients and to prevent the resection of essential areas near the tumor. To investigate interhemispheric imbalance following " awake surgeries" of slow-growing tumors we recorded EEG in a visuo- manual RT paradigm. Increase of cortical excitability within the ipsilesional hemisphere was signed by increased event related potentials (ERPs) amplitude for two patients. The cortical excitability in the lesioned hemisphere may be increased to maintain performances and cerebral plasticity.

6.3. Neuroprostheses

6.3.1. Distributed Measurement Unit for Closed-Loop Functional Electrical Stimulation: Prototype for Muscular Activity Detection

Participants: Guillaume Coppey, David Andreu, David Guiraud.

One way to face centralized Functional Electrical Stimulation (FES) architecture limitations is to distribute electronics close to electrodes. These Distributed Stimulation and Measurement Units (DSU and DMU) are interconnected by a network. Different DSU have been designed and prototyped. We started the design and prototyping of a DMU dedicated to ElectroMyoGramm (EMG) activity reading.

To validate both the digital architecture of the DMU and the digital processing it performs, we prototyped a DMU in charge of muscular activity detection. This DMU is able to detect a threshold crossing on an EMG input signal. The experimental setup is schematically represented on figure 11, showing also the digital architecture of the prototyped DMU.

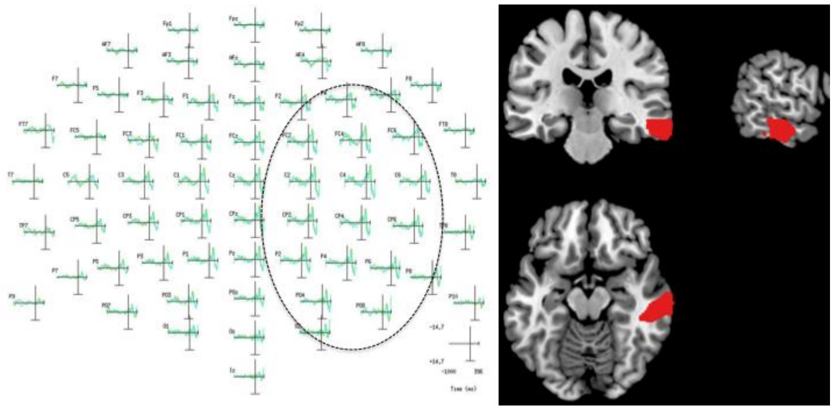

Figure 10. Left : Post-operative Event-Related Potentials (ERPs) for Patient 1. Increased ERPs amplitude can be seen in the right ipsilesional hemisphere (ellipse) in comparison to the contralesional hemisphere and homologous recording sites. The patient had to respond to visual stimuli occurring in the right or left hemifield with his right hand. The vertical line on each ERP indicates the occurrence of the visual go- signal Right : Lesion mapping for the same patient after the surgery.

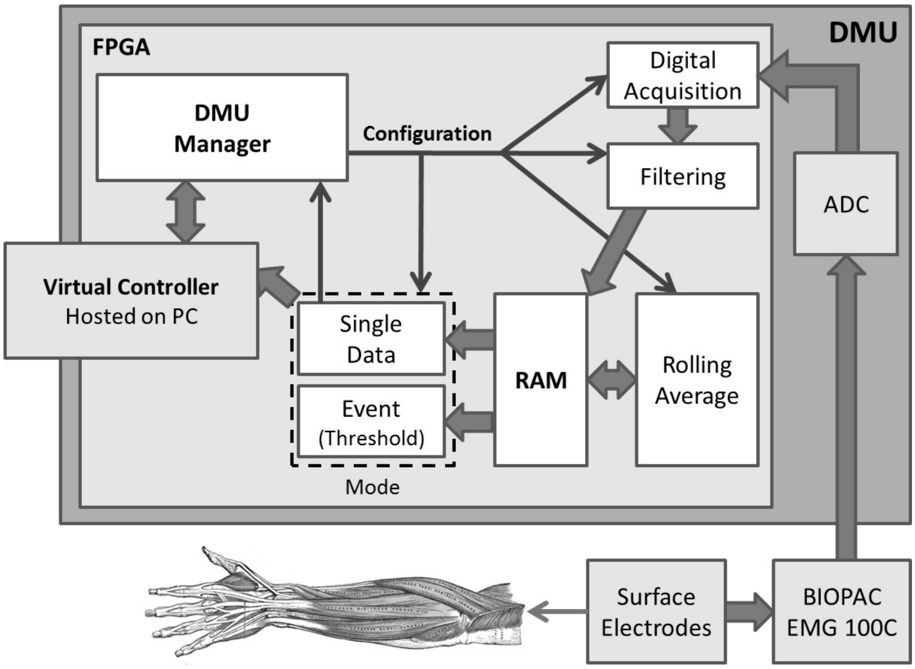

Figure 11. Experimental setup

This DMU is able to accurately detect EMG activity after filtering and then processing a rolling average. Figure 12 shows intermediate signals: (a) is the absolute value of the filtered EMG signal, (b) is the rolling average, and (c) is the threshold used for activity detection.

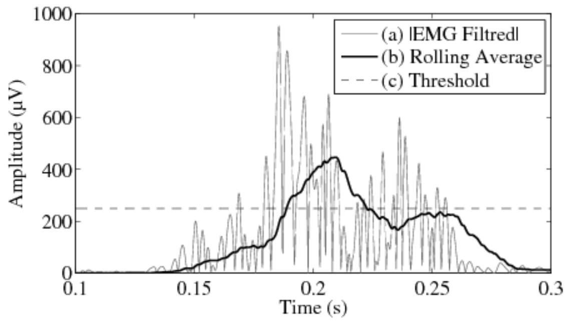

Figure 12. Intermediate signals for muscular activity detection on extensor digitorum communis

This DMU prototype showed that digital processing chain dedicated to EMG activity detection can be embedded within a distributed measurement unit using a programmable logical device (FPGA), like we did for distributed stimulation unit. The embedded architecture of this unit is designed according to a Petri Net based methodology. This allows to exploit effective parallelism offered by FPGA devices, and to reach expected performances even at low frequency. The embedded processing chain is configurable and parameters can be adjusted, in order to optimize performance.

Future works will consist in adding the protocol stack to the digital architecture of the DMU, allowing integrating it within our distributed FES architecture. This will allow us to measure effective latencies and other performances from a closed-loop point of view. This work is necessary to ensure that such a distributed EMG activity detection is adequate with FES requirements. After that, we will investigate the trade-off between the global performances versus the implantable device constraints, like its size and power consumption.

6.3.2. Abstraction and composition for formal design of neuroprotheses

Participants: Hélène Leroux, David Andreu, Karen Godary.

In the framework of specification and implementation of complex digital systems on FPGA, we have developped an approach based on components whose behavior and composition are specified by generalized interpreted T-time Petri nets. One of the inherent difficulties for designer is to take into account, on the behavioral part, exceptions. This leads often 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 t_e on fig. 13), whatever is the current state of the sub-net.

6.3.3. Increasing stimulation selectivity using the Transversal Intrafascicular Multichannel Electrode (TIME)

Participants: Pawel Maciejasz, David Andreu, David Guiraud, Xavier Navarro, Jordi Badia (Universitat Autònoma de Barcelona), Winnie Jensen, Kristian Rauhe Harreby, Aritra Kundu, Bo Geng (Aalborg University), Thomas Stieglitz, Tim Boretius (University of Freiburg), Ken Yoshida (Purdue University Indianapolis).

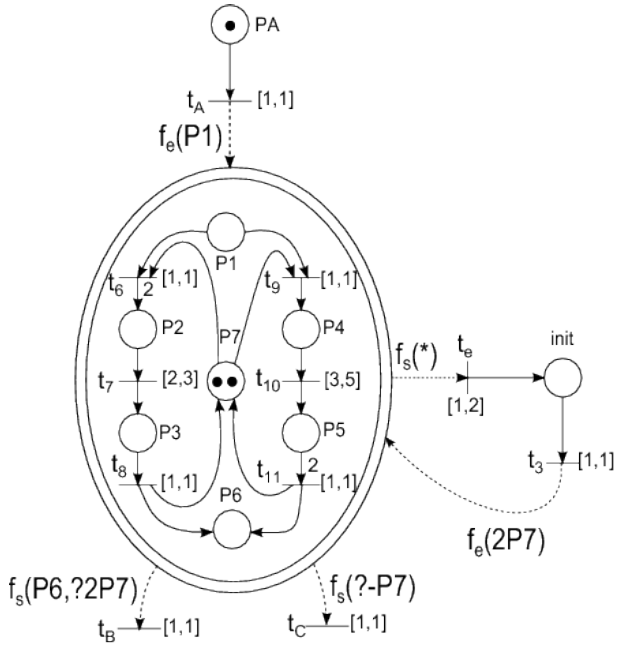

Figure 13. An example of macroplace and exception catching

The electrical stimulation of nerve fibres may allow to restore or augment some body functions lost due to disease or injury. However, in typical peripheral nerves there are thousands of nerve fibres innervating various organs. Therefore, it is necessary to develop interfaces and methods allowing for selective activation of only desired population of nerve fibres. Various neural interfaces have been already proposed for that purpose, including multipolar cuff electrodes, longitudinal intrafascicular electrodes (LIFE) and the Utah Slanted Electrode Array (USEA), all with different selectivity and invasiveness ratios. Recently a new electrode concept of a transversal intrafascicular multichannel electrode (TIME) has been proposed (Fig. 14). This electrode has been developed in frame of the European Project TIME in which the DEMAR team is participating (grant CP-FP-INFSO 224012 from the European Union). It is intended to be implanted transversally in the nerve and address several fascicles or subgroups of nerve fibres with one device. It has longitudinal shape and has several independent stimulation sites equally spread on both sides of the electrode.

It has been already shown that TIME allows to achieve high selectivity of stimulation when using monopolar configuration, i.e. when current is delivered through one of the sites of the TIME against small needle electrode placed in the proximity of the nerve. We have performed investigation in the sciatic nerve of rat to verify if the use of bipolar configuration, i.e. when current is delivered through one of the TIME sites against an other site of the same electrode, could allow to further enhance selectivity of stimulation. The results of our studies suggest that using bipolar configuration do allow to increase selectivity of stimulation. However, higher charge of the stimulation may be necessary to achieve similar level of muscle activation, as compared to the monopolar configuration [24].

When applied in the rat model the Transverse Intrafascicular Multi-channel Electrode (TIME) showed selective nerve fascicle recruitment. But results from the larger and poly-fasicular median nerves in pigs indicated that a single TIME could not reach the entire nerve and could only selectively recruit a subset of the nerve fasicles. The use of multiple TIME structures could offer a means to achieve highly selective fascicular stimulation while reaching a larger percentage of the fascicles in the nerve. Therefore we have investigated the

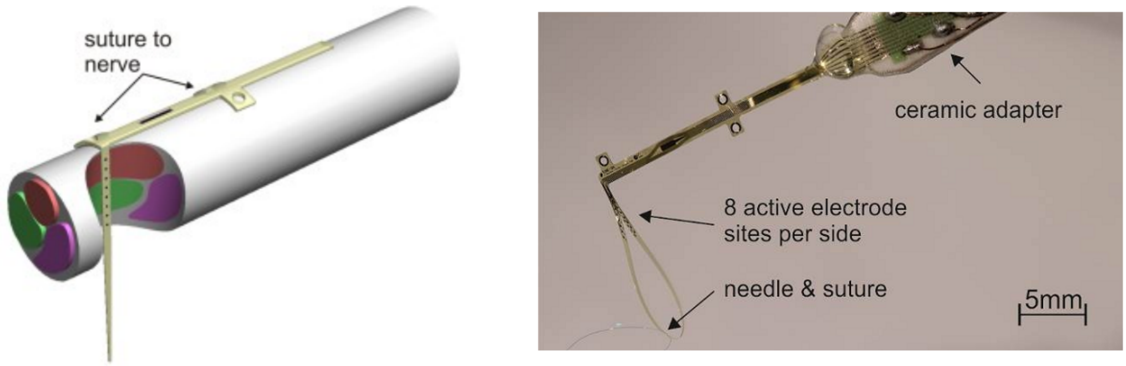

Figure 14. Left: The schematic representation of the TIME electrode implanted into the peripheral nerve. Right: detailed photograph of an TIME-3H electrode with pre-attached loop-thread (Source: Boretius et al. Proc. IEEE Biomedical Robotics and Biomechatronics Conference, Rome 2012)

use of pairs of TIMEs implanted in the median nerves of anesthesized pigs. TIME structures were implanted at different angles relative to each other or in parallel with one another. Electrical stimuli was passed through each contact of each TIME and the resulting electromyograms were recorded from seven muscles innervated by the median nerve. The ability to recruit these muscles was used to assess the stimulation selectivity of each contact using a selectivity index comparing the root-mean-square of the the evoked EMG of individul muscles. Results showed a signifcant increase in the selectivity index, when using two TIMEs compared to one. The optimal improvement was obeserved when TIMEs were placed in parallel to each other in such a way that they interfaced non-overlapping nerve regions [18].

6.3.4. Nerve model for ENG recording

Participants: Olivier Rossel, Guy Cathébras, Fabien Soulier, Serge Bernard.

In the context of selective electroneurogram recording, we showed last year the efficiency of a *small tripole* filtering (the distance between contacts is $375\,\mu\mathrm{m}$) thanks to simulated signals. This recording is locally sensitive and greatly increases the selectivity of the electrode. This year, we realized an experiment to verify the simulated results. Theoritical study of the *small tripole* sensitivity was realized for a single-fiber action potential (SFAP). We wanted to proceed in the same way for the experiment by trying to measure a SFAP.

However, actual biological SFAP would be hardly measurable by a *small tripole* in an in-vitro experiment. So, we decided to choose an approach based on an artificial axon. In this artificial model, every parameter is under control. The position of the fiber, the nodes of Ranvier, the position of the measuring electrode, as well as the involved currents are perfectly known. This allows us to implement and to estimate with accuracy the filtering realized by the *small tripole* with exactly the same configurations as in simulations. And by performing measures for several radial distances, we can verify the influence of this distance, in order to estimate the sensibility the *small tripole*. Moreover, we can increase the activity amplitude to be higher than in real fiber and then achieve a beneficial signal to noise ratio.

6.3.4.1. Method

The experimental setup consists in an artificial model emulating an axon and in a system measuring the action potential across the surrounding medium, as sketched in Fig. 15. Biological tissues are modeled by a saline solution having a conductivity close to the human body. The space and time behavior of the current generated by a natural axon is reproduced on the artificial axon. The latter is emulated by an cochlear electrode. It exhibits 20 contacts, being an accurate image of the nodes of Ranvier on an axon of $8.7\,\mu\mathrm{m}$ diameter regarding the spatial periodicity.

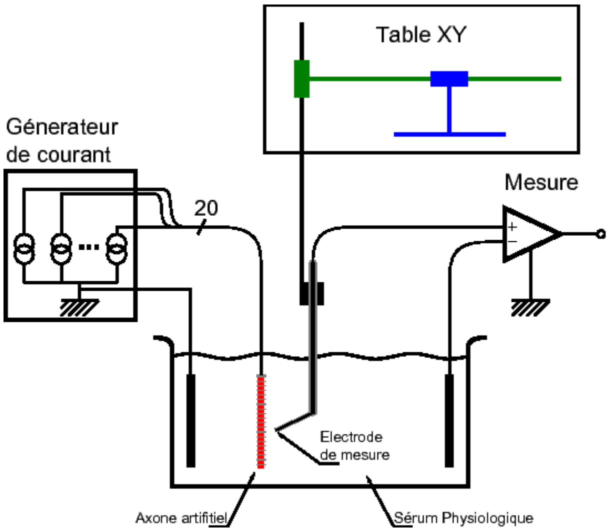

Figure 15. Principle of the experimental setup using the artificial axon.

In order to generate electric activity on several contacts that can be compared to the one of several nodes of Ranvier during the conduction of an action potential, we realized a custom multi-current generator with asynchronous outputs. The chosen amplitude was $35 \cdot 10^4$ times that of an human axon.

The measure of the SFAP in the space, is done using a punctual monopolar electrode. The position of the measuring electrode relative to the fiber is automatically set by a programmable micromanipulator. Then, the measure is repeated every $50\,\mu\mathrm{m}$ along $2\,mm$ on the radial axis.

6.3.4.2. Monopolar and tripolar sensitivity

To verify quantitatively the sensibility results obtained by simulation for monopolar and tripolar electrodes, we have first estimated the amplitude of a SFAP measured by a monopolar electrode. The measured SFAP amplitude directly gives the monopolar recording that varies according to the radial distance between the artificial axon and the electrode. Then, the *small-tripole* recording results from an off-line process combining three points of measure spaced out of $375\,\mu\mathrm{m}$. The two kind of recordings are represented in Fig. 16.

By comparing the recording sensitivities either estimated or measured, we can conclude that measures perfectly fit the theoretical results. We can also notice that the attenuation relative to the radial distance is more important for the *small tripole* than for the monopolar measure. This confirms that the measure performed by one *small tripole* electrode is exclusively sensitive to the closest fibers.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- An industrial technological transfer contract is ongoing with the MXM company that develops cochlear implant and artificial lens implant. MXM can perform also Ethylene Oxyde sterilization necessary for all our experimental setups used during surgery. Two DSU prototypes (named Stim'3D and Stim'nD), one miniaturized DSU (named USR24*1000) and an external controler have been developed within this frame. The associated programming environment (SENIS Manager, cf. section 5.1.2) has also been developed in this context.

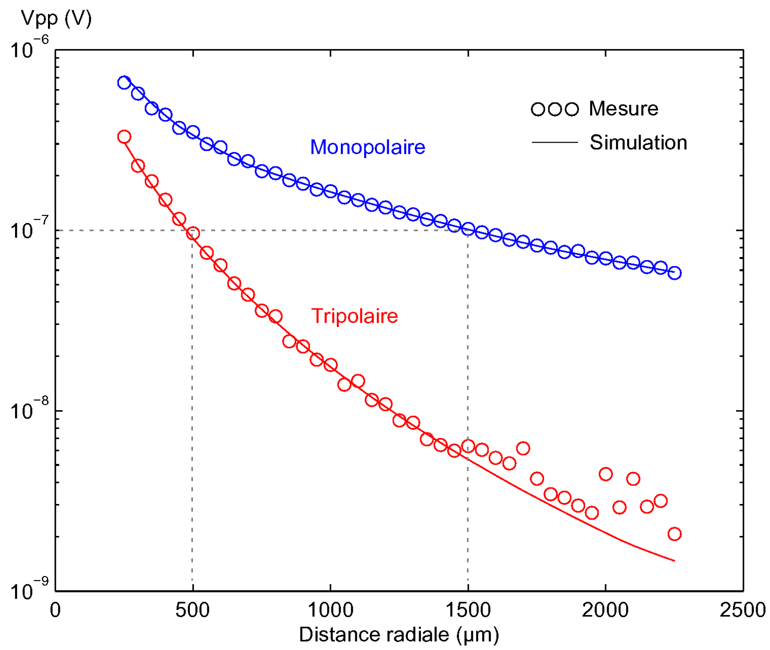

Figure 16. Comparison between monopolar and small-tripolar recording sensitivities. Measures are plotted with circles and simulation results are solid lines. The monopolar data are in blue and tripolar are in red.

- The contract with Vivaltis company that is specialized in the development of external stimulators, has been completed. We jointly developed a new advanced external FES system dedicated to clinical rehabilitation; this first wireless external stimulation architecture is now CE marked, and commercialized by Vivaltis.

  This work has been awarded by the 1st Prize 2012 of the FIEEC-OSEO on Applied Research.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. SANOFI (Montpellier financial support)

Participants: Christian Geny (CHU Montpellier), Christine Azevedo-Coste, René Zapata (LIRMM), Lionel Lapierre (LIRMM).

Project SANOFI on developing a robot carrying a video camera for gait analysis of patients with neurological disorders.

8.1.2. CGS Merri (Languedoc-Roussillon - Montpellier)

Participants: Christian Geny (CHU Montpellier), Christine Azevedo-Coste, Simone Dalla Bella (UM1 M2H).

Developement and evaluation of controlled assistive device for freezing of gait in Parkinson Disease, 30keuros.

8.2. National Initiatives

8.2.1. 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's national initiative is to favor the scientific collaboration and technological transfer of the innovation between DEMAR and MXM.

The aim of this project is 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.

8.2.2. 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).

8.2.3. ADT SENSAS - SENSBIO

Participants: Christine Azevedo-Coste, David Andreu.

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

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

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

8.2.4. Programme de recherche en qualité hospitaliere (PREQHOS)

Participants: Leader: Jean-Christophe LUCET (GH Bichat - Claude Bernard), Christine Azevedo-Coste, Eric Fleury (Inria), Bruno Grandsebastien (CHRU Lille).

Project: Surgery room behaviour and impact on infectious risks (ARIBO : Attitudes et Risque Infectieux au Bloc Operatoire)

8.2.5. INTENSE project

Participants: David Guiraud, Pawel Maciejasz, Olivier Rossel, Christine Azevedo-Coste, David Andreu, 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.

8.3. European Initiatives

8.3.1. FP7 European project TIME

Participants: David Guiraud, David Andreu, Fabien Soulier, Pawel Maciejasz.

(2008-2012). 375keuros, "*Transverse, Intrafascicular Multichannel Electrode system for induction of sensation and treatment of phantom limb pain in amputees*". Partners : AAU (Aalborg, Denmark), MXM (Vallauris, France), SSSA (Pisa, Italy), IMTEK (Freiburg, Germany), UAB (Barcelona, Spain), UCBM (Roma, Italy), IUPUI (Indianapolis, USA).

8.4. International Initiatives

8.4.1. Inria Associate Teams

8.4.1.1. WALK

Title: Artificial Walking

Inria principal investigator: Philippe Fraisse

International Partner (Institution - Laboratory - Researcher):

Stanford University (United States) - Artifical Intelligence Lab

Duration: 2010 - 2012

See also: http://www.lirmm.fr/~fraisse/@WALK/

The motivation approach is the complementary research works of these teams. Indeed, a collaborative project should give an additional value to their research results. On one hand, the DEMAR Project Team has experience in Functional Electrical Stimulation to restore or modulate movements on spinal cord injured patients and post stroke patients. In both pathologies researches on assisted gait using FES (for paraplegics with a walker and hemiplegics) are carried out in the team. On the other hand, the Robotics research group (Stanford) carries out manipulation tasks with a humanoid robot under equilibrium constraints. Within the framework of the previous collaboration, the crossed visits and seminars last year led us to work on two different directions: - FES muscle modeling in Opensim framework - Control mechanisms underlying age-related changes in motor control strategies during Sit-To-Stand.

8.4.2. Inria International Partners

- Collaborative Research agreement on Academic Co-operation (contrat sans financement) "Neuromuscular function analysis and identification for Rehabilitation" Partner: University of Tokyo (Prof. Yoshihiko Nakamura) Duration: 2011 - 2014

8.4.3. Participation In International Programs

8.4.3.1. STIC AmSud

Title: CARAT (Computer Aided Rehabilitation Algorithms and Tools)

Inria principal investigator: Mitsuhiro Hayashibe

International Partner (Institution - Researcher):

Universidade de Brasília (UnB,Brazil) - Antônio P.L. Bó, Geovany Borges

Pontificia Universidad Católica del Perú (PUCP,Brazil) - Dante Elias

Duration: 2012 - 2013

Throughout the world there is an increasing need for better technologies for rehabilitation and assistance. These new solutions must present improved performance in terms of therapy effectiveness, while at the same time minimizing the corresponding costs. In this scenario, computer-aided methods represent a promising alternative for the challenges currently faced by the rehabilitation domain. Within this collaborative research project, we focus on the following research topics: - Algorithms for human motion analysis for both clinical and residential settings based on portable and external sensing technologies - Sensory feedback devices to improve effectiveness on rehabilitation procedures - Robotic platforms for rehabilitation - Software development for telerehabilitation

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Prof. Keisuke Morishima (Professor, Osaka University) visited and presented his work on "Emergent Functionality of Cellular Buildup Wet Robotics" (15th, June 2012).
- Prof. Antônio P.L. Bó (Professor, Universidade de Brasília) visited and presented his work on "Human Centered robotics at UnB" (18th, July 2012).
- Prof. Thomas Stieglitz (Professor, Laboratory for Biomedical Microtechnology, Department of Microsystems Engineering - IMTEK, University of Freiburg) visited and presented his work on "Microtechnologies for Neural Implants" (17th, October 2012).
- Prof. Jessica Rose (Associate Professor, Department of Orthopedic Surgery, Stanford University and Director, Motion and Gait Analysis Lab, Lucile Packard Children's Hospital) visited and presented her work on "Gait Analysis in Cerebral Palsy: Applications for Artificial Walking Technologies" (17th, October 2012).
- Prof. Dejan B. Popović (Professor, University of Belgrade, Serbia and Aalborg University, Denmark) visited and presented his work on "Neuroprosthesis: A tool for neurorehabiliation or functional compensation?" (25th, October 2012).

8.5.2. Visits to International Teams

- Mitsuhiro Hayashibe gave invited talk at the Institute of Perception, Action and Behaviour (IPAB), University of Edinburgh, "Identification and Control of the Human Neuromuscular Dynamics toward Advanced Neuroprosthetics", February 2nd 2012.
- Mitsuhiro Hayashibe was Visiting Researcher at Nakamura lab, University of Tokyo and Tokyo University of Agriculture and Technology for JSPS-Inria Ayame project and worked on "Muscle Strength and Mass Distribution Identification Toward Subject-Specific Musculoskeletal Modeling" (March 2012).
- Mitsuhiro Hayashibe gave invited talk at workshop on EMG Technology and Application, Shanghai Jiao Tong University, May 7th 2012.
- Mitsuhiro Hayashibe visited the Laboratory of Automation and Robotics (LARA), Universidade de Brasília for STIC Amsud - CARAT project and made a seminer on "Modeling and identification for Neuroprosthetic systems and some related works for CARAT program" (20th May 2012 -4th June 2012).
- Mitsuhiro Hayashibe was Visiting Researcher at RIKEN BSI-TOYOYA research institute and worked on "Tacit Motor learning for rehabilitation" (Aug.-Sep. 2012).

9. Dissemination

9.1. Scientific Animation

+ D. Guiraud
  1. Associate editor for Journal of Neural Eng. and EMBC'12 conference
  2. Member of the steering committee of "Institut des Technologies pour la Santé"
  3. Chair of the Labex Numev "Aide à la personne malade et déficiente" specific action

+ C. Azevedo-Coste
    1. Board member of IFESS society (international functional electrical stimulation society)
    2. Associate Editor of Paladyn Behavioral Robotics Journal
+ D. Andreu
    1. Co-organizer of the french working group on Control Architectures of Robots of the french GdR Robotique
    2. assitant manager of the Robotic Department (LIRMM)
+ F. Soulier
    - Local coordinator of the Belem (BioElectronics for Medical Engineering) intensive programme for the University of Montpellier 2. Belem is funded by the European Community in the framework of the Erasmus programme.
    - Publication chair and the “parallel-session” supervisor at DCIS’12 (27th conference on Design of Circuits and Integrated Systems) that includes a session on biomedical application and a special session on biomedical systems and devices.
    - Organizing commitee of the workshop “Systèmes Embarqués pour la Santé” that takes place in Paris in December, the 6th and 7th 2012. The workshop is part of the CNRS’s DEFI-SENS inter-disciplinary initiative on sensory deficiencies and personalized supplementation.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- **UE "medical robotics"** from Institut Telecom / Mines specialisation "Tic santé". David Guiraud teaches the basics of neurophysiology and neuroprosthetics about 10h per year.
- **UE "neuroprotheses"** master 1 & 2 "Tic et santé" and master 2 Human Movement Sciences. David Guiraud teaches muscle function, modeling and the basics for the control through FES and neuroprosthesis about 20h per year.
- **collège de France** june 2012 about neuroprosthesis during a dedicated day to "medical robotics" organized by Jean Paul Laumond.
- **Summer school Université d’Aalborg** "Fourth Annual Aalborg Symposium on The Advances in Neurophysiology and Neural Rehabilitation Engineering of Movement " 11-12 juin 2012, talk about neuroprotheses. https://smi.hst.aau.dk/events/anres2012.
- David Andreu, Associate Professor, 200h/y, Engineering school Polytech Montpellier and Master degree, Software engineering, real time OS, discrete event systems, networks, neuroprosthesis.
- Christine Azevedo-Coste, University of Montpellier, Master STIC pour la Sante, Neuroprotheses II, Neurophysiology, 6h/y.
- Christine Azevedo-Coste, University of Montpellier, Master STIC pour la Sante, Neuroprotheses I, Neurophysiology, 1,5h/y.
- Christine Azevedo-Coste, Institut Telecom, Neurophysiology, 1,5h/y.
- Mitsuhiro Hayashibe, University of Montpellier, Master STIC pour la Sante, NeuroprothesesII, EMG signal processing and its use for rehabilitation, 3h/y.
- Mitsuhiro Hayashibe, University of Montpellier, Master STIC pour la Sante, Modele et Regulation, Identification and Control in Biomechanics, 4.5h/y.
- Fabien Soulier, assistant professor at Polytech’ Montpellier (ERII) teaching electronics and signal processing.

9.2.2. Thesis Defenses

1. Christine Azevedo-Coste, Philippe Fraisse and Charles Fattal supervise **Jovana Jovic**, *Vers une assistance fonctionnelle du transfert et de la posture chez le sujet paraplégique sous électrostimulation : de la simulation a l'expérimentation.* defended on 26th Oct. in Montpellier.
2. Guy Cathébras and Fabien Soulier supervise **Olivier Rossel**, *Dispositifs de mesure et d'interprétation de l'activité d'un nerf.* defended on 26th Nov. in Montpellier.
3. Jérôme Bourien (INM, Montpellier) and Christine Azevedo-Coste supervise **Christophe Michel**, *Modélisation de l'efférence latérale du système auditif périphérique.* defended on 13th Dec. in Montpellier.

9.2.3. Ongoing theses

1. Christine Azevedo-Coste and Bernard Espiau supervise **Maud Pasquier**, *Observation et contrôle de mouvements non cycliques des membres inférieurs et supérieurs en assistance fonctionnelle.*, ANM.
2. David Andreu and Karen Godary supervise **Hélène Leroux**, *Abstraction et composition pour la conception formelle de neuroprothèses*, Thesis ENS, 2011-2014.
3. David Guiraud and David Andreu supervise **Guillaume Coppey**, *Unité implantable de mesure répartie pour suppléance fonctionnelle en boucle fermée*, Thesis CIFRE MXM, 2011-2014.
4. Mitsuhiro Hayashibe and Philippe Fraisse supervise **Alejandro González**, *Closed-loop whole body posture control and stability analysis in FES.*, European Comission:CORDIS, 2011-2014.
5. Mitsuhiro Hayashibe, Benjamin Gilles and David Guiraud supervise **Yacine Berranen**, *Volumetric musculoskeletal modeling and simulation.*, CNRS Handicap, 2011-2014.
6. Mitsuhiro Hayashibe and David Guiraud supervise **Zhan Li**, *Computational rehabilitation and neuromuscular control based on reinforcement learning.*, China Scholarship Council (CSC), 2011-2014.
7. Philippe Fraisse supervises **Nahema Khadija Sylla**, *Contribution à l'assistance au geste au travail : Une approche ergonomique intégrée.*, Thesis CIFRE DEMAR/PSA, 2012-2015.
8. Guy Cathébras, Fabien Soulier and Serge Bernard supervise **Mariam Abdallah**, *Système d'acquisition de signaux bioélectriques multicanal, programmable et implantable.*, Thesis MENRT, 2012-2015.
9. P. Fraisse, C. Azevedo Coste, I. Laffont (CHRU Montpellier, M2H, Euromov, UM1), D. Mottet (M2H, Euromov, UM1) supervise **Nader Rouis**, *Étude et développement de méthodes de rééducation du membre supérieur assistées par stimulation électrique fonctionnelle.*, Thesis NUMEV UM2, 2012-2015.

9.2.4. PostDoc

- Christine Azevedo Coste, David Guiraud and David Andreu supervise Pawel Maciejasz, "Selective neural electo-stimulation" (TIME project).
- François Bonneblanc and Hugues Duffau supervise Pom Charras, "The validation on pre, post and intra-operative evaluations of patients during awake neurosurgeries of slow-growing tumors in the brain", contract Association pour la Recherche sur le Cancer (ARC-France) 'subvention-libre N°3184', post-doctoral fellowship.
- Benjamin Gilles and Mitsuhiro Hayashibe supervise Maxime Tournier, "Constraint-based simulation of the musculoskeletal system" (ANR SoHuSim project).

9.2.5. Internships

- David Guiraud and Pawel Maciejasz supervised Thomas Guiho on "Proposing and implementing the algorithm forautomated detection and classification of action potentials in nerve fiber based on multichannel recordings", Master student project and afterwards 3 month training, from Oct. 2011 to Jun. 2012.

- David Andreu supervised Ronald Reboul on "Prototypage d'un séquenceur embarqué au sein d'un implant de stimulation", Engineer final internship, from Apr. 2012 to Sep. 2012.
- David Andreu supervised Jean-François Happe on "Etude de stratégies d'économie d'énergie pour implant de stimulation", Engineer final internship, from Apr. 2012 to Sep. 2012.
- David Andreu supervised Quinchuan Mo on "Traduction automatique de Réseau de Petri en VHDL : optimisation du code en termes de consommation et de surface", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2012 to Feb. 2013.
- David Andreu supervised Yuchen He on "Conception et développement d'un logiciel d'exploitation d'une plateforme de mesure de consommation d'un implant médical", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2012 to Feb. 2013.
- David Andreu supervised Julien Serodes on "Etude de l'architecture numérique basée composants d'un implant médical et de son impact sur la consommation", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2012 to Feb. 2013.
- David Guiraud, Christine Azevedo, Charles Fattal supervised Tigra WAFA on "Implanted electrical stimulation of upper limb in tetraplegic patients", Projet Master 2 TIC SANTÉ, from Oct. 2012 to Jan. 2013.
- David Guiraud, Christine Azevedo, Luc Bauchet, Charles Fattal supervised Thomas GUIHO on "Epidural functional electrical stimulation", Projet Master 2 TIC SANTÉ, from Oct. 2012 to Jan. 2013.

9.2.6. Contract Engineers

- David Andreu supervises Grégory Angles. “Conception et réalisation d'un environnement logiciel, basé sur Eclipse, pour le prototypage rapide sur composants électroniques programmables (HILECOP)". Computer Science Engineer, Babylone contract (3 years contract, Inria).
- David Andreu supervises Guillaume Magro. "Spécification et prototypage d'un contrôleur de SEF implantable". Industrial Informatics Engineer, Inria Expert Engineer contract (3 years contract, Inria).
- Guy Cathébras, Serge Bernard and Fabien Soulier co-supervise Jérémy Salles "Correction de la version 2 et développement de la version 3 de l'ASIC de stimulation 12 pôles" Microelectronics Design Engineer (1 year contract, NEUROCOM financial support).

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

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[2] V. Bonnet, C. Mazza, P. Fraisse, A. Cappozzo. *A least-squares identification algorithm for estimating squat exercise mechanics using a single inertial measurement unit*, in "Journal of Biomechanics", 2012, vol. 45, n^{o} 8, p. 1472 - 1477 [*DOI :* 10.1016/j.jbiomech.2012.02.014], http://www.sciencedirect.com/science/article/pii/S0021929012001145.

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International Conferences with Proceedings

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sal Intrafascicular Multichannel Electrode (TIME) - Preliminary results, in "ICNR'2012: International Conference on NeuroRehabilitation", Toledo, Spain, November 2012, 2, http://hal.inria.fr/lirmm-00723839.

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