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Activity Report 2013

Project-Team DEMAR

Artificial movement and gait restoration

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

RESEARCH CENTER
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THEME
Computational Neuroscience and Medecine

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Project-Team DEMAR

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

Creation of the Project-Team: 2003 October 01.

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2. Overall Objectives

2.1. Overall Objectives

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

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

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

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

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

DEMAR research is organized as follows:

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

3. Research Program

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 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, 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 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. 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, one needs 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 on 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 persons, both disabled and healthy, to perform experiments with the adequate medical staff.

5. Software and Platforms

5.1. Software and Platforms

5.1.1. RdP to VHDL tool

Participants: Gregory Angles, David Andreu, Thierry Gil, Robin Passama.

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, both for analysis and implementation sides.

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.

SENISManager has been transferred to the industrial partner and a new version is under development according to an Eclipse-based design. This new version should be available by the end of 2014.

6. New Results

6.1. Modelling and Identification

6.1.1. Emergence of Motor Synergy in Reaching Task via Tacit Learning -computational motor control

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

The dynamics of multijoint limbs often causes complex dynamic interaction torques which are the inertial effect of other joints motion. It is known that Cerebellum takes important role in a motor learning by developing the internal model. We propose a novel computational control paradigm in vertical reaching task which involves the management of interaction torques and gravitational effect. The obtained results demonstrate that the proposed method is valid for acquiring motor synergy in the system with actuation redundancy and resulted in the energy efficient solutions. It is highlighted that the tacit learning in vertical reaching task can bring computational adaptability and optimality with model-free and cost-function-free approach differently from previous studies.

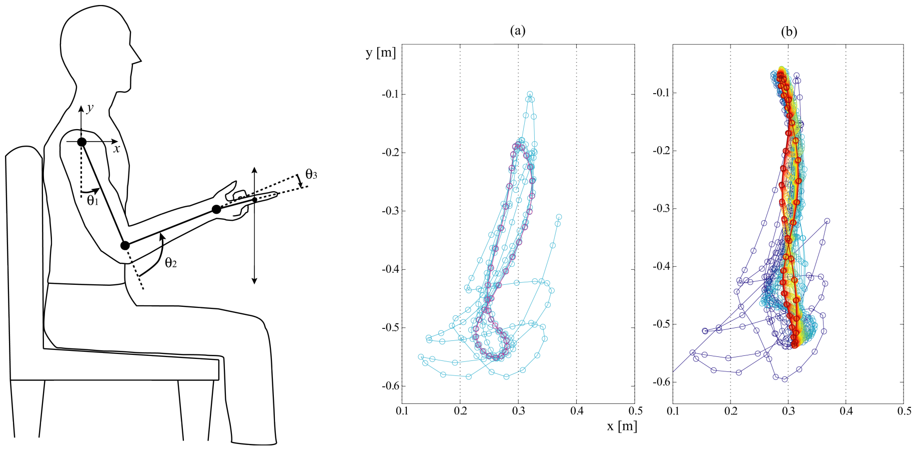

Figure 1. (left)Schematic representation of vertical reaching task. (right)End point transition. (a) only with PD feedback control (b) with tacit learning in addition to the PD control.

6.1.2. Anatomy Transfer

Participants: Dicko Ali-Hamadi, Tiantian Liu, Benjamin Gilles, Ladislav Kavan, Francois Faure, Olivier Palombi, Marie-Paule Cani.

Characters with precise internal anatomy are important in film and visual effects, as well as in medical applications. We propose the first semi-automatic method for creating anatomical structures, such as bones, muscles, viscera and fat tissues. This is done by transferring a reference anatomical model from an input template to an arbitrary target character, only defined by its boundary representation (skin). The fat distribution of the target character needs to be specified. We can either infer this information from MRI data, or allow the users to express their creative intent through a new editing tool. The rest of our method runs automatically: it first transfers the bones to the target character, while maintaining their structure as much as possible. The bone layer, along with the target skin eroded using the fat thickness information, are then used to define a volume where we map the internal anatomy of the source model using harmonic (Laplacian) deformation. This way, we are able to quickly generate anatomical models for a large range of target characters, while maintaining anatomical constraints.

6.1.3. Center of Mass Estimation in Multicontact Situations: Simulation

Participants: Alejandro González, Mitsuhiro Hayashibe, Emel Demircan [Stanford Univ.], Philippe Fraisse.

Center of mass (CoM) estimation can be used to evaluate human stability during rehabilitation. A personalized estimation can be obtained using the serial equivalent static chain (SESC) method, calibrated using a series of static postures. The estimation accuracy is dependent on the number and quality of poses used during calibration. Currently, this limits the method's application to unimpaired individuals. We present a preliminary

Figure 2. A reference anatomy (left) is automatically transferred to arbitrary humanoid characters. This is achieved by combining interpolated skin correspondences with anatomical rules.

study of a SESC identified in a multi-contact scenario during a Sit-to-Stand task. Stanford's SAI (Simulation and Active Interface) platform was used to emulate human motion and predict relevant reaction forces. The CoM estimation obtained is valid for motions similar to those used during identification. Since the SAI's human model is fully defined, in terms of mass and limb lenths, its exact center of mass is known. Using a 3-dimensional model, the estimated mean error was less than 26 mm for a Sit-to-Stand task involving displacements along all axes. As such, personalized CoM estimation can be available for patients with a limited range of whole body motion.

Fig. 3 shows the identification results [27]. Even with a limited motion, it was possible to estimate the position of the simulated robot's CoM projected to onto the ground. This estimation errors are likely due to the lack of an exciting trajectory for identification. Nonetheless, if the postures used during identification describe a patient's range of motion, the CoM estimation can still be valuable.

6.1.4. Interface for identification of the Statically Equivalent Serial Chain's parameters and Balance Assessment

Participants: Alejandro González, Mitsuhiro Hayashibe, Philippe Fraisse.

CoM trajectory can be used to improve the current rehabilitation standards. After an identification phase, a personalized CoM estimate can be obtained using a SESC. Furthermore, using low-cost sensors (Kinect and Wii balance board), make the personalized estimate feasible inside a patient's home. This work focuses on the effect that a visual adaptive interface can have on the SESC identification phase. Specifically on improving its speed and quality. A study conducted on 6 subjects showed a faster convergence and a lower root mean square error (rmse) when the adaptive interface is applied. We find that for the same error (30 mm), the identification with the interface was performed in half the time (86 s) than the one without it (163 s). Similarly, for the same session length (120 s), rmse was of 24.5 mm using the interface and of 34.5 mm without it.

Additionally CoM dynamics may be used to determine stability. Fig. 4 shows an example of this during a squat task. The zero rate of angular momentum (ZRAM) can be used to determine the dynamic stability of a humanoid robot. It can be used to determine the position foot placement to avoid falls.

6.1.5. Forward Estimation of Joint Torque from EMG Signal through Muscle Synergy Combinations

Participants: Zhan Li, Mitsuhiro Hayashibe, David Guiraud.

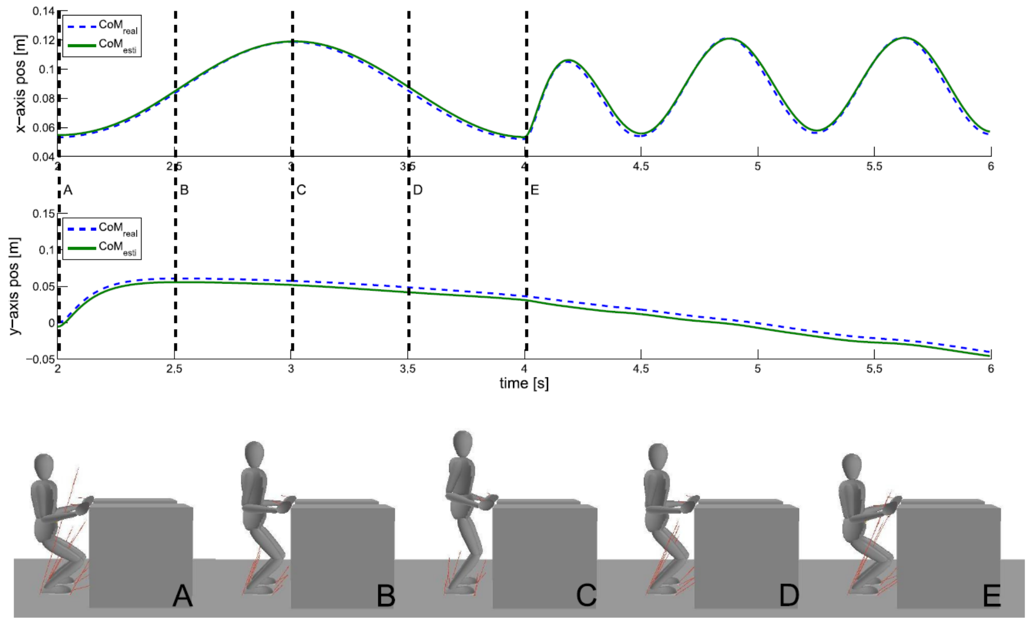

Figure 3. After identifying the SESC parameter of the humanoid (Stanbot), it is possible to estimate the position of its CoM. SESC identification was performed with a reduced number of postures, to mimic a patient in need of additional support to maintain a standing pose.

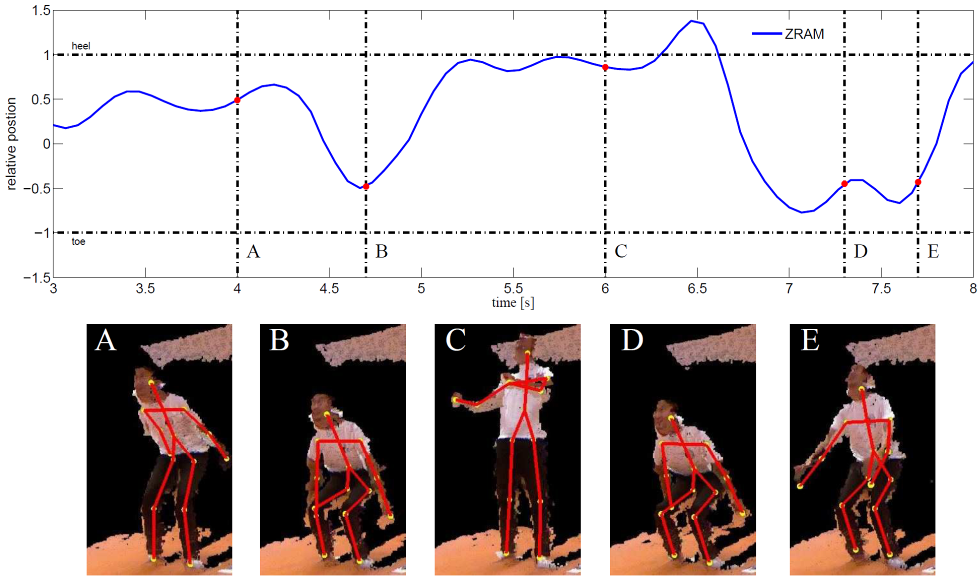

Figure 4. We show the trajectory of the zero rate of angular momentum (ZRAM) for a sqat task. When the ZRAM is found inside the support polygon, the movement can be considered stable. Unstablle movements (C-D) do not determine a fall. The subject may still recover using a balancing strategy; or by taking a step.

We investigate the approaches of estimating the ankle joint torque from EMG/activations of associated muscle groups. The approaches discussed fall into two main categories: i) full utilization of both of extension and flexion EMG/activations for estimating the joint torque; ii) exploitation of muscle synergy extraction of EMG/actvations and consequent usage of extracted components in reduced space for estimating the joint torque. Comparison is made between the two methods with experimental data of five able-bodied subjects. From the results we conclude that, method ii) with muscle synergy extraction may not degrade the performance of method i) but meanwhile show the muscle synergic ratios for generating the joint torque, and involvement of joint position and velocity information can improve the estimation for both methods.

6.1.6. Prediction of hand tremor through EMG-based fatigue tracking

Participants: Sourav Chandra, Mitsuhiro Hayashibe, Thondiyath Asokan [IITMadras, India].

Laparoscopic surgical procedure is a very tiring procedure for a surgeon due to the specialized prolonged arm movement with a modular tool. Prolonged activity of arm muscle in such condition induces muscle fatigue which induces hand tremor. Hand tremor not only drastically affects positional accuracy; it also increases the collateral tissue damage. Nullification of this tremor has been the area of active research topic in surgical robotics for last few decades. Though Surface ElectroMyoGram (SEMG) has been used for modeling hand tremor of microsugeons, a single model for predicting amplitude and frequency of such tremor has not been investigated for laparoscopy so far. A model of muscle fatigue induced hand tremor in laparoscopic activity is necessary in order to nullify this hand tremor effect and increase positional accuracy. SEMG is a crucial biopotential in order to get the estimation of the muscle fatigue state. A positive correlation was found among sEMG and hand tremor in frequency domain as shown in Fig. 6 below. In this work, a model based prediction of fatigue induced hand tremor will be investigated with the vicinity of SEMG and other wearable inertial sensor data. The model is intended to have a dynamic structure, which can capture the complexity of the muscle fatigue state to some extent and its effect on the hand tremor amplitude and frequency.

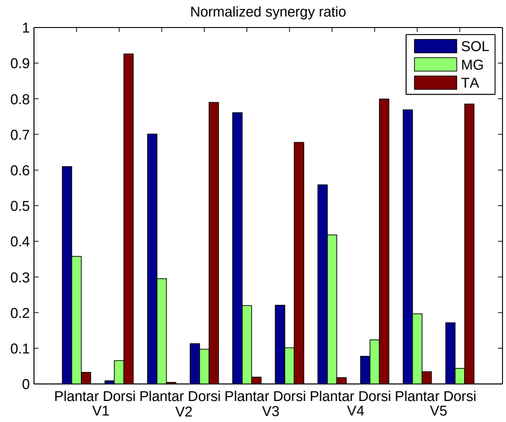

Figure 5. Normalized muscle synergy ratios of the five subjects, under isotonic situation with 10Nm plantar load and 5Nm dorsi load

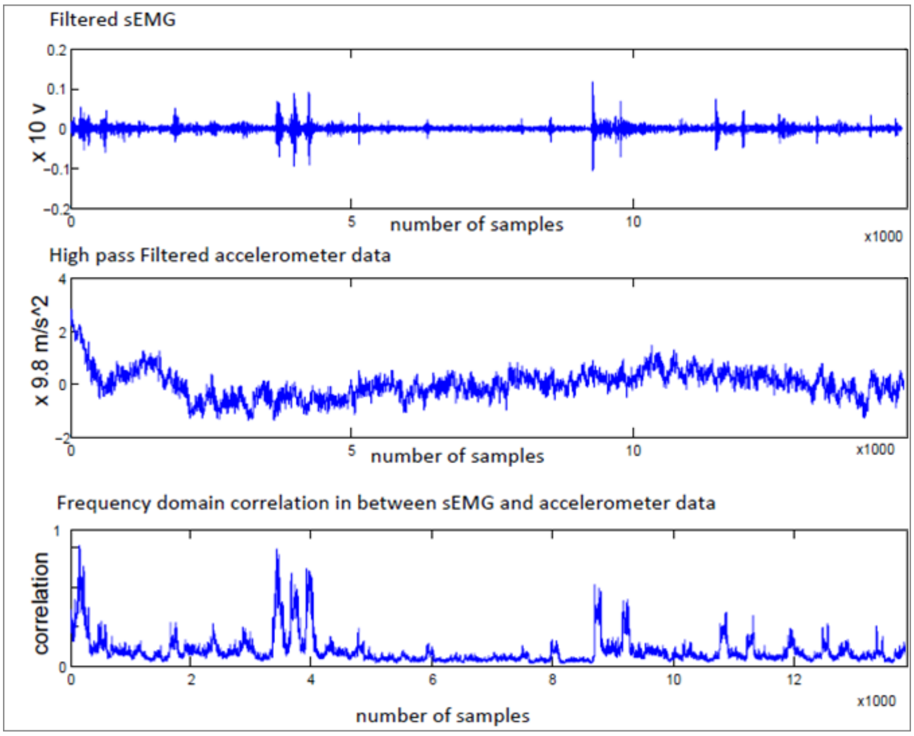

Figure 6. Frequency domain correlation of sEMG and hand tremor during prolonged arm movement

6.1.7. Mobile gait analysis

Participants: Vincent Bonnet [M2H, UM1, Montpellier], Christine Azevedo Coste, Christian Geny [CHU Montpellier], Lionel Lapierre [LIRMM, Montpellier], René Zapata [LIRMM, Montpellier].

The Video-Kinect-Bot, an affordable mobile platform for pathological gait analysis was developed to assess pathological spatio-temporal parameters. The system, drove by a Kinect sensor, is able to follow a patient at constant distance on his own defined path, and to estimate gait spatio-temporal parameters. Robust Tracking-Learning-Detection algorithm estimates the positions of targets attached to the trunk and heels of the patient. Real-condition experimental validation including corridor, occlusion cases, and illumination change was performed. A gold standard stereophotogrammetric system was also used and shown a good tracking of patient and an accuracy in stride length estimate of 2%.
The Empirical Mode Decomposition (EMD) method was evaluated to estimate the 3D orientation of the lower trunk during walking using the angular velocity signals generated by a wearable inertial measurement unit (IMU) and notably flawed by drift. The IMU was mounted on the lower trunk (L4-L5) with its active axes aligned with the relevant anatomical axes. The proposed method performs an offline analysis but has the advantage of not requiring any parameter tuning. The method was validated in two groups of 15 subjects, one during overground walking, with 180° turnings, and the other during treadmill walking, both for steady-state and transient speeds, using stereophotogrammetric data. Comparative analysis of the results showed that the IMU/EMD method is able to successfully detrend the integrated angular velocities and estimate lateral bending, flexion-extension as well as axial rotations of the lower trunk during walking with RMS errors of 1 deg for straight walking and lower than 2.5 deg for walking with turnings. This work was accepted for publication in Sensors journal for a special issue concerning wearable-sensor for gait analysis in 2014 with the following collaborators V. Bonnet, S. Ramdani, C. Azevedo-Coste, P. Fraisse, C. Mazzà and A. Cappozzo. Data relative to the pitch, roll and yaw angles obtained for one randomly selected treadmill walking trial. The integrated angular velocities (grey line) and the resulting trends (black line) are estimated using EMD (a) during all the trial; zoom over 20 s on the corresponding detrended angles are thereafter estimated (black line) and compared with those obtained using stereophotogrammetry (grey line).

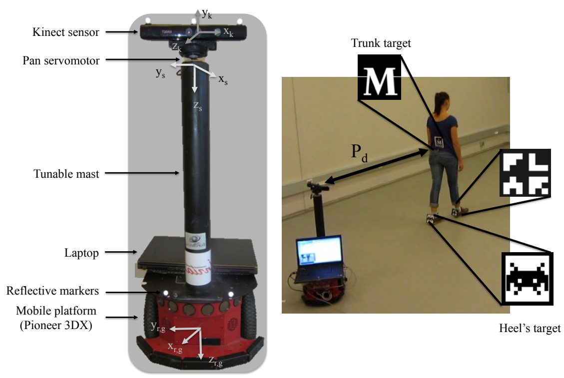

*Figure 7. (**Left:**) Detail of the Video-Kinect-Bot system and experimental setup (**Right:**) example of subject tracking in real-environement.*

This work is supported by a NOVARTIS funding (see Partnerships and Cooperations section).

6.2. Function control and synthesis

6.2.1. Analysis of infection risk in surgery block

Participants: Christine Azevedo Coste, Roger Pissard Gibollet [SED Inria Grenoble Rhône-Alpes], Gabriel Birgand [Bichat Hospital, Paris], Jean-Christophe Lucet [Bichat Hospital, Paris], Gaelle Toupet [Bichat Hospital, Paris].

Despite the increasing implementation of preventive measures, surgical-site infection still induces a substantial burden. Inappropriate staff behaviors can lead to environmental contamination in the operating room and subsequent surgical site infection. The present study focuses on the continued assessment of operating room staff behavior using a motion tracking system, and the evaluation of the impact of this behavior on the surgical-site infection risk during surgical procedures.
A multicenter observational study has been done in 2013, including 10 operating rooms of cardiac and orthopedic surgery in 12 healthcare facilities. A motion tracking system including 8 optical cameras (VICON-Bonita®) recorded movements of reflective markers placed on the surgical caps/hoods of each person entering the room. Different configurations of markers positioning were used to distinguish between staff category. Doors opening were observed as well by means of wireless inertial sensors fixed on the doors and synchronized with the motion tracking system. We have collected information on the operating room staff, surgical procedures and surgical environment characteristics ([2]).
Recorded data will be analyzed and staff behaviors will be assessed by the quantification of displacements within the operating room. Results will aim at bringing a rational to the prevention of airborne microorganism transmission by the description of best behaviors rules in the operating room.
This protocol was approved by the Institutional Review Board of the (IRB) of Paris North Hospitals, Paris 7 University, AP-HP (n° 11-113, April 6 2012). The work is supported by Inria SENSBIO ADT and ARIBO Preqhos project.

6.2.2. Drop-foot correction in post-stroke hemiplegic patients

Participants: Christine Azevedo Coste, Roger Pissard-Gibollet [SED Inria Grenoble Rhône-Alpes], Jérôme Froger [Nîmes Hospital, Le Grau du Roi], Claire Delablachelerie [Nîmes Hospital, Le Grau du Roi].

Electrical stimulation has been proven to have orthotic and carryover effects on individuals with post-stroke hemiplegia with a foot drop syndrome. One of the drawbacks of the technique is the lack of adaptability to changes in gait (speed, type of floor, stairs, dorsiflexion quality etc). But, real-time modification of stimulation patterns is not feasible using gait event detection like proposed in all available stimulators. In the present study we investigate two questions: 1) is it possible to validate on individuals with foot drop an algorithm able to estimate online the continuous gait cycle phase from a unique wireless sensor placed on lower limbs and 2) is it possible to trig a drop foot stimulator based on events extracted from this phase information.

Methods : 20 subjects with post-stroke hemiplegia participated to the study. A wireless inertial measurement unit was placed on the unaffected leg of the subjects and was used to estimate the gait phase on a distant labtop. The subjects performed 3 trials in each of the 3 following conditions: **C1** no stimulation aid, **C2** electrical stimulation assistance triggered by heel switch **C3** electrical stimulation assistance wirelessly triggered based on the proposed algorithm.

Results : 1) the proposed algorithm was able to estimate online the continuous gait cycle phase, 2) events could be extracted from this phase information in order to trig an electrical stimulator using this algorithm instead of heel switch.

Conclusion : the online estimation of continuous gait cycle phase on individuals with stroke is possible. Events can be extracted from the phase information in order to trig a stimulator **C3** instead of using heel switch detection **C2**. The robustness of the proposed solution to gait modifications is intrinsically guaranteed by the use of automatic control theory. These results open promising applications using programmable stimulators which parameters could be modified online based on gait phase observation.

This protocol was approved by Nîmes Ethical Committee, AFSSAPS and CNIL. The work is supported by Inria SENSBIO ADT.

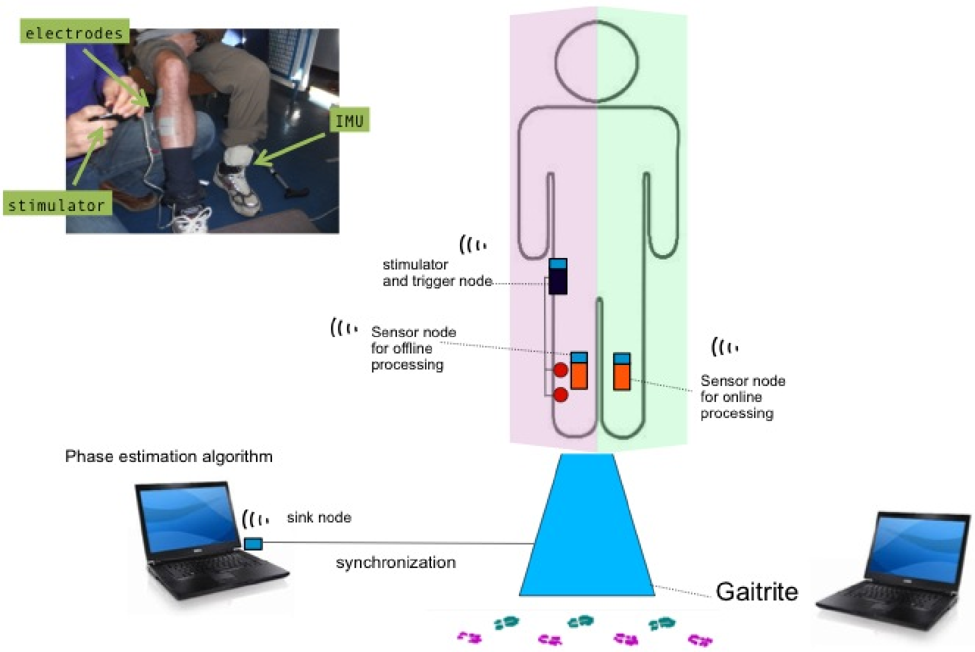

Figure 8. ***System architecture****. Description of the system architecture used in the study. A sensor node (inertial measurement unit (IMU)) is placed on the unaffected side shank. Data is sent to the sink node of the laptop. Data is processed on the laptop and a gait phase is estimated. Depending on the phase value the stimulator is switched ON through its trigger node. An extra sensor node is also sending data to the sink node and data is saved for offline processing.*

6.2.3. Freezing of Gait detection in Parkinsonian individuals

Participants: Christine Azevedo Coste, Christian Geny [CHU Montpellier], Maud Pasquier [Inria Grenoble Rhône-Alpes], Benoît Sijobert.

Parkinson's disease (PD) is the second most common neurodegenerative disorder. This chronic disease can lead to gait disturbances and falls inducing important reduction of the quality of life. One common symptom is the Freezing of Gait (FOG), an episodic inability to generate effective stepping in the absence of any known cause other than Parkinsonism. It can occur during initiation of the first step, turning, dual task, walking through narrow spaces, reaching destinations or passing through doorways. It is an episodic absence or marked reduction of forward progression of the feet despite the intention to walk. FOG are reported by the patient as a subjective feeling of "the feet being glued to the ground". Clinical evaluation of video recordings of patients by one to three observers is the gold standard to identify FOG events. The evaluation of clinical effects of the treatments would benefit from objective, standardized FOG measures. Moore et al. (2008;2013) have proposed a technique to identify FOG episodes based on the frequency properties of leg vertical accelerations (fig.9). The approach is based on the hypothesis that FOG occurrences are associated to trembling motion, which affect limb acceleration signal. They have introduced the so-called freeze index (FI): the ratio between the signal power in the trembling band (3 Hz - 8 Hz) and the signal power in the locomotor band (0.5 Hz-3 Hz). The FI method was validated using one to 7 accelerometers mounted on patients with satisfactory detection results. If many FOG episodes can be associated to festination (trampling) it is not the case for all of them. Therefore, we claim that all the FOG episodes cannot be detected by the FI method. In the present paper we propose a complementary index in order to take into account not only festination but also other freezing characteristics. Furthermore we intend to propose a solution based on a minimal number of embedded sensors and detection algorithms for future real-time applications.
This work is supported by SENSBIO Inria ADT and DEMARPARK AOI (see Partnerships and Cooperations section).

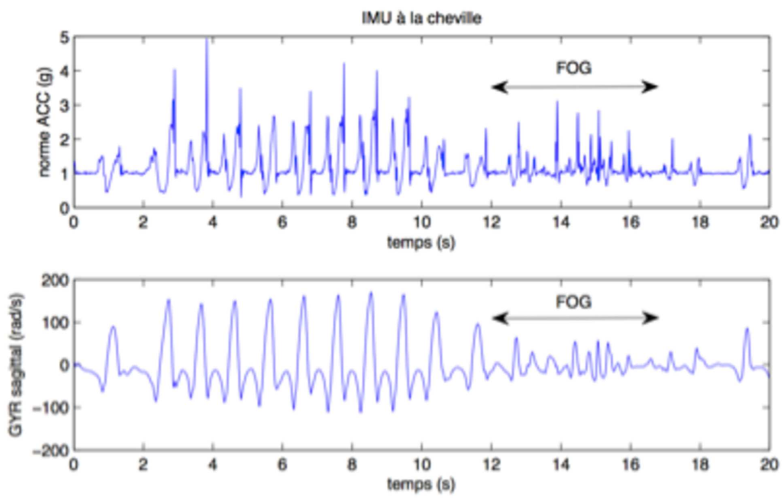

Figure 9. Freezing of Gait observation using inertial sensors.

6.2.4. Effects of direct electrical stimulation of the brain during awake surgeries: towards improvements of the functional mapping

Participants: François Bonnetblanc, David Guiraud, Marion Vincent, Mitsuhiro Hayashibe, Hugues Duffau [Neurosurgery department, CHU-Gui de Chauliac], Guillaume Herbet [Neurosurgery department, CHU-Gui de Chauliac], Benedicte Poulin-Charronnat [LEAD, Univ. Dijon].

« Awake surgery » consists in removing some infiltrative and slow-growing brain tumoral tissu in an awake patient. The neurosurgeon performs an anatomo-functional mapping of the brain by electrically stimulating brain areas near the tumor to discriminate functional vs. non functional areas. This stimulation is both made cortically and sub-cortically to preserve the functional connectivity. During the surgery itself, the patients are also involved by performing some tasks. Their recovery remains impressive with respect to the lesional volume. Despite the slow-growth of the lesion is invoked, these observations question our understanding of brain plasticity phenomena. Our multi-disciplinary approach aims to (i) better understand the effects of direct electrical stimulation of the brain to improve the functional mapping and also (ii) to build new functional assessments performed by the patient and based on new technologies applied to Health. By systematically performing these precise assessments before, after and during the surgery we hope to better understand brain functions, plasticity and dynamics in order to improve the surgical planning, functional mapping, rehabilitation procedures and quality of life of the patients.

6.2.5. Translational research and stroke

Participants: Anirban Dutta, David Guiraud.

Stroke is caused when an artery carrying blood from heart to an area in the brain bursts or a clot obstructs the blood flow thereby preventing delivery of oxygen and nutrients. About half of the stroke survivors are left with some degree of disability where the impairment of walking has been mentioned most frequently as the most important disability. There is, therefore, a pressing need to leverage insights from animal and human studies to address the complexity in clinical translation of rational multi-level electrotherapy protocols where the ability to customize such novel electrotherapy protocols has only recently become possible with advanced computational tools. Therefore the challenge is to develop advanced computational modeling tools at Inria, France, to design and customize innovative electrotherapy protocols to patient-specific needs, and then closely integrate them to drive (perhaps the first) individualized non-invasive electrotherapy program for clinical validation. The ongoing steps are i) Develop computational methods to identifying neural circuits related to the recovery from stroke [26], ii) Develop a computational method for online targeting of neural circuits and related pathways with non-invasive electrotherapy [21],[25], iii) Validate individualized multi-level non-invasive electrotherapy program with NIBS as an adjuvant treatment to NMES-assisted gait rehabilitation following stroke.

6.2.6. Projet PERIMED

Participants: Thomas Guiho, Christine Azevedo, Luc Bauchet, Charles Fattal, David Guiraud, Jean-Rodolphe Vignes.

Born in the 70's, Spinal cord stimulation is a general term including both peridural and intradural stimulation. Encouraged by Harkema's clinical result (in one paraplegic patient with step-like EMG activity) [43], several recent studies in rodents elicited locomotor synergies, bladder/bowel improvements and, in certain circumstances, restoration of supraspinal control after spinal cord injury [45]. Based on this previous work, our approach, mainly focused on bladder and bowel functions, aims both at asserting these discoveries in an intermediate model (pigs weighing between 50 and 60 kgs) and at providing further insight in spinal cord circuitries.

6.2.7. Investigation of strategies for selective small nerve fiber stimulation in an animal model

Participants: Paweł Maciejasz, Olivier Rossel, Christine Azevedo Coste, David Andreu, David Guiraud, Hubert Taillades [Institute of Biology, Montpellier].

The electrical stimulation of nerve fibers 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 fibers with various diameters and functions. When standard rectangular pulses are used for nerve fiber stimulation, the big fibers are activated before smaller ones. However, for many clinical applications it would be beneficial if small fibers could be activated without activation of the big ones.

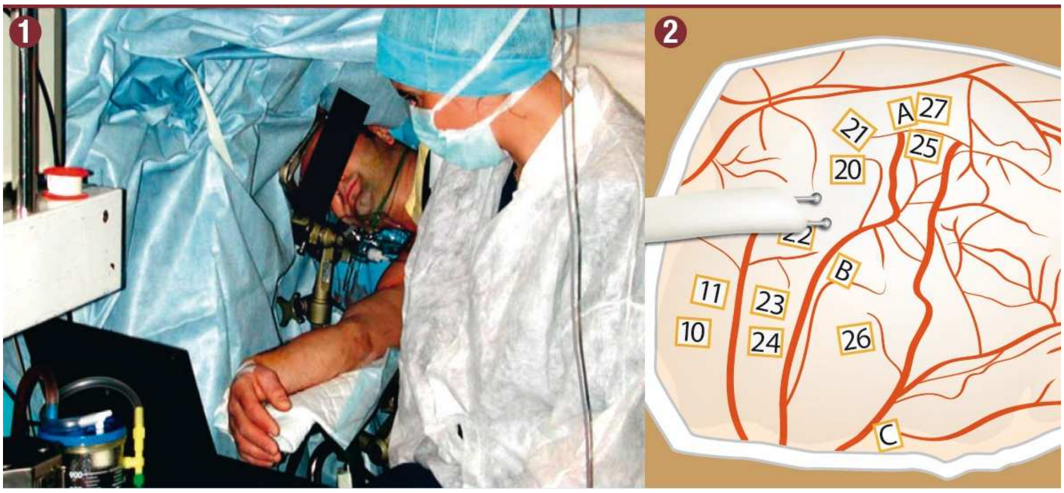

Figure 10. Awake brain surgery and functional mapping.

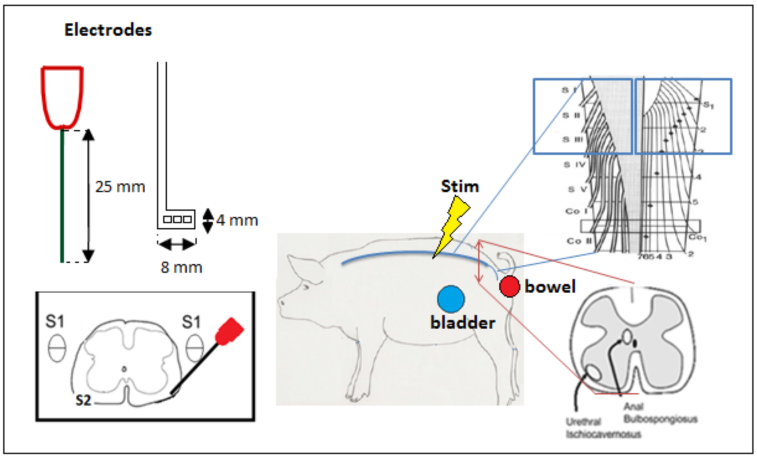

Figure 11. Supraspinal cord stimulation .

Already many stimulation techniques have been proposed for fiber type and diameter selective stimulation, e.g. analog block, slowly rising pulses, high frequency block. However, due to limited efficiency of those techniques, they are still not used in clinical practice. Based on the results of the computer simulations and the experiments performed previously in the earthworm model by our team, we have proposed some modification to the existing techniques, that may increase their efficiency.

In order to verify if the proposed modifications allow for increased selectivity of stimulation as compared to the techniques already proposed, a series of experiments in rabbit model has been scheduled. The experiment consists of two phases. The objective of the first one (3-6 rabbits), the preliminary one, is to determine an adequate method to evaluate the effects of stimulation, i.e. to find out a reliable method that would allow for discrimination between various types of fibers being activated by the stimulation. The objective of the second phase (5-15 rabbits), the exploratory one, is to compare and quantify the performance of various strategies for fiber type selective stimulation.

The experiments have been performed by the DEMAR team in rabbits in the Institute of Biology in Montpellier. During this experiment the sciatic nerve of the rabbit has been stimulated using tripolar nerve cuff electrode, whereas ENG and EMG signals, as well as ankle torque have been recorded. The experiments have been started in December 2012 and so far only the first phase of the study has been completed.

The experiment was authorized through the local ethics committee for animal experiment (authorization N° CEEA-LR-12084). The work is supported by INTENSE Project.

6.3. Neuroprostheses and technology

6.3.1. Abstraction and composition for formal design of neuroprotheses

Participants: Hélène Leroux, David Andreu, Karen Godary [LIRMM].

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, 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.

The new formalism has been defined, as well as the model transformation based equivalent PNML generation for using existing analysis tools.

Ongoing work deals with solving state evolution conflicts introducing priorities between transitions, to avoid reaching inconsistent global state while synchronously executing the model.

6.3.2. 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 1 μs time step and 5 μA current step); example of generated stimulations are shown in Figure 12. 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 (Figure 12). 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.

6.3.3. Attitude reconstruction from IMU signals

Participants: Jonathan Peguet [IFMA], Daniel Simon, Christine Azevedo Coste, Roger Pissard-Gibollet [SED Inria Grenoble Rhône-Alpes].

Inertial Measurement Units (IMUs) are currently used by the team for real-time estimation of limbs attitude, e.g. as in section 6.2.2 where the attitude of a leg while walking feeds a agit phase estimator. The IMUs embedded in the FOX nodes (manufactured by HiKob) include 3 gyrometers, 3 accelerometers and 3 magnometers, from which the attitude (e.g. Euler angles) of the node can be computed. The raw measurement signals can be either processed locally in the nodes, or sent on wireless links to be processed on a remote computer.

The raw signals issued from sensors are subject to noise and bias. Additionally, the raw data flow can be corrupted by timing disturbancies induced by communication and computation. Hence, the attitude reconstruction filters must be robust against disturbancies such as noise, bias, jitter and data loss. To evaluate the robustness of attitude reconstruction filters, a software simulation package dedicated to IMUs design and analysis has been customized from the Imusim package (initially developed in Python under GPL at Univ. of Edinburgh, U.K. [44]).

The Imusin modeling features include realistic IMUs models with noise and bias, calibration procedures, radio channels deficiencies and computing timing parameters. Several versions of Extended Kalman Filters and Non-Linear Observers, in particular those previously developed at Inria Grenoble Rhône-Alpes, have been integrated and succesfully tested against measuring noise. The work is supported by Inria SENSBIO ADT.

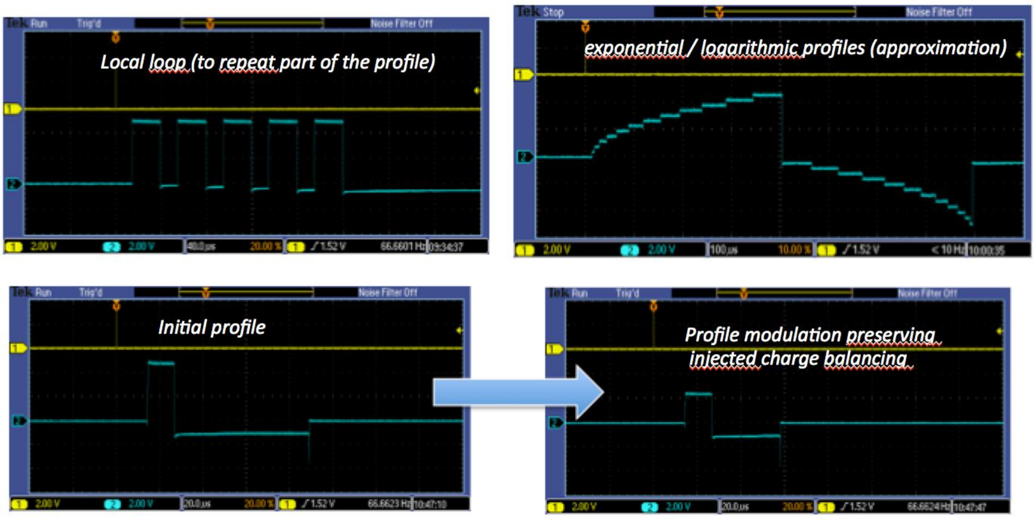

Figure 12. Examples of stimulations (observed at the output of the stimulator)

6.3.4. 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. 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 [17]. 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.

6.3.5. ENG amplifier front-end

Participants: Mariam Abdallah, Fabien Soulier, Serge Bernard, Guy Cathébras.

Electroneurogram acquisition systems are usually based on tripolar cuff electrodes that are known to decrease noise from external sources, such as muscular fibers (EMG) or stimulation artifacts. Thus, we studied a preamplifier associated with this kind of electrode in a true-tripole configuration. It is designed at the transistor level to lower the number of transistors while still rejecting parasitical signals. This kind of integration reduces the size, power consumption and noise of the preamplifier compared to classical true-tripolar structures.

The true-tripole configuration consists of linear combination of signals coming from the three poles

$$V_{out} = A\left(V_{in1} - \frac{V_{in2} + V_{in3}}{2}\right) \tag{1}$$

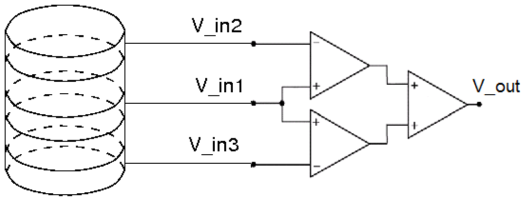

Figure 13. Classical structure of a true-tripolar ENG preamplifier.

This combination is usually realized thanks to several differential amplifiers as shown in the figure 13, whereas the proposed preamplifier is designes as a differential pair whose negative input transistor is split into only two smaller ones. (fig. 14). The circuit is based on a modified ASIC in AMS CMOS $0.35\,\mu$m technology, with 3.3 V supply. The preamplifier provides three functions which are:

- to combine the input signals as shown in the equation (1),
- to barely amplify the neural signal to an acceptable SNR,
- and to present a differential output to a variable-gain amplifier (not presented here, but integrated into the ASIC).

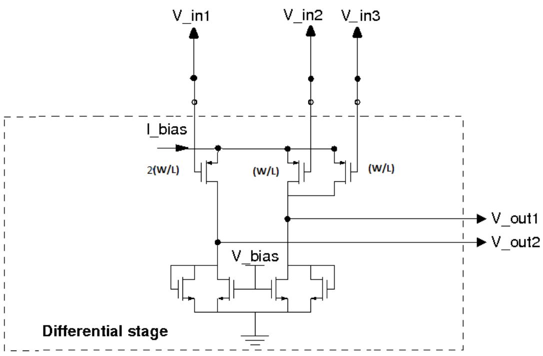

Figure 14. Three input preamplifier schematic.

To characterize the three-input preamplifier, we have to define three orthogonal modes, starting with the main mode expected to be amplified

$$V_{in1} = -2V_{in2} = -2V_{in3}, \tag{2}$$

the common mode, and the differential parasitic mode expected to be as low as possible to achieve a good EMG rejection:

$$V_{in1} = V_{in2} = V_{in3}, \tag{3}$$

$$V_{in1} = 0, \qquad V_{in2} = -V_{in3}. \tag{4}$$

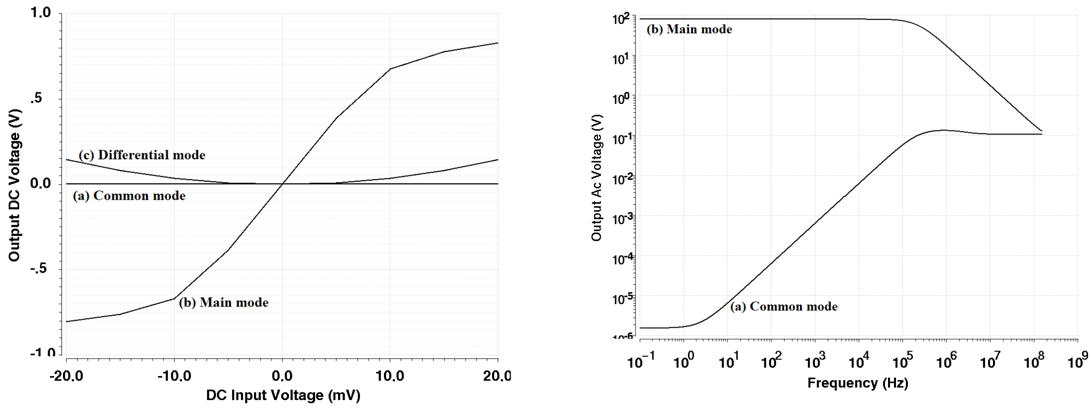

Figure 15. DC (on the left) and AC (on the right) simulation results for main (b), common (a) and differential modes (c). AC differential mode is too low to be simulated using typical values.

DC and AC simulations were performed for these three modes. The results are presented in the figure 15. The main results of these simulations are:

- more than 150 dB rejection ratio for the common and differential modes compared to main one,
- dynamic range of about 5 mV,
- 200 kHz bandwidth (that is far above the needs for ENG acquisition),
- the estimated flicker noise due to input and load transistors is below the μV on the required bandwidth.

This work has been presented to the 18th IFESS Annual Conference [16].

6.3.6. Characterization of the CAFE12 chip

Participants: Jérémie Salles, Fabien Soulier, Serge Bernard, Guy Cathébras.

The circuit CAFE12 (Cool Analog Front End, 12 poles) used in StimND, which was designed in 2006, exploit the bases of a DEMAR patent. A characterization of a circuit (1st version, manufactured in 2006-2007) showed limitations to its capabilities. Thus a 2nd version was designed and manufactured in 2012 to improve the circuit linearity and consumption. CAFE12 is an ASIC generating 12 current outputs. This ASIC was developed in high voltage CMOS technology (H35, Austria Mikro Systems). Each output is able to deliver/absorb a current as high as 5mA.

The measurements presented below were carried on 3 CAFE12_V2 prototypes (C8002 & C8003). Some comparisons with 2 CAFE12_V1 (T1201 & nD09) prototypes are also shown.

- Integral non linearity (INL) Figure 16 highlights the INL improvement of the anodic generators. This significant decrease is due to a wiring modification on a specific operational amplifier (OPA). No improvement on the cathodic side was expected.

- Differential non linearity (DNL) The noticed improvement on the INL is also noticeable on the differential non linearity on both anodic and cathodic sides (Figure 17 and Figure 18).

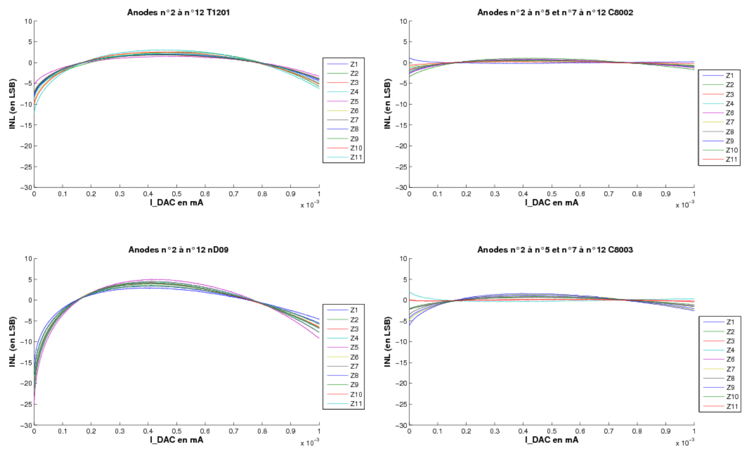

Figure 16. INL comparison, anodic generators (CAFE12_V1 & CAFE12_V2)

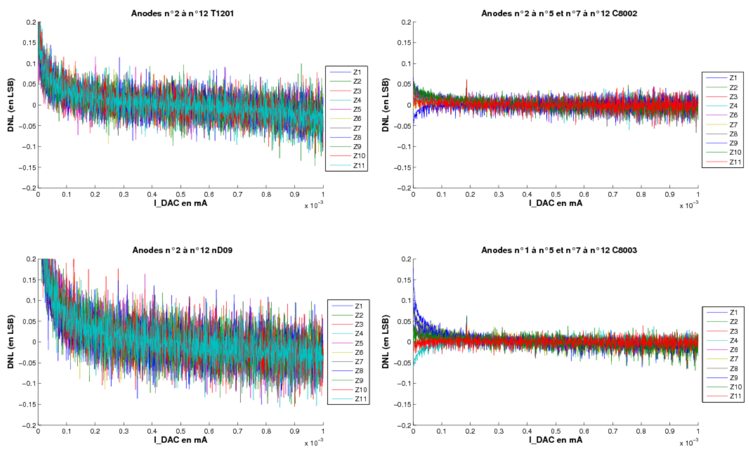

Figure 17. DNL comparison, anodic side (CAFE12_V1 & CAFE12_V2)

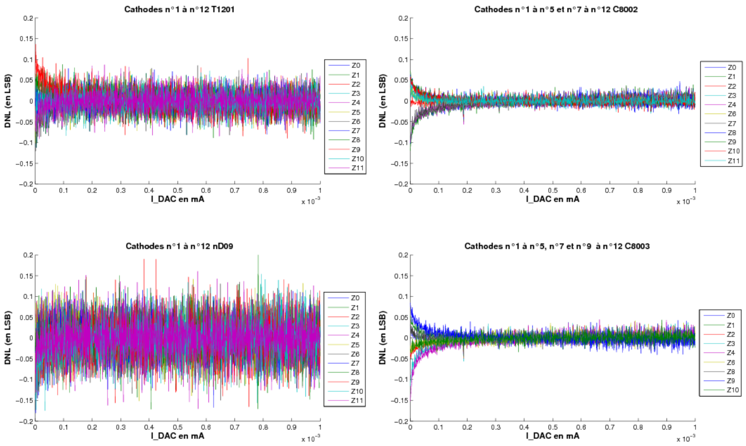

Figure 18. DNL comparison, cathodic side (CAFE12_V1 & CAFE12_V2)

The following table 1 sums up the characterization results. The main achievements are better anodic generators (linearity and gain) and a reduced static consumption.

Table 1.

	INL (LSB)		DNL (LSB)		Gain accuracy $(\%)$		Power (mW)
	Anode	Cathode	Anode	Cathode	Anode	Cathode	Total
CAFE12_V1	-26 to 4	±5	±0.02	±0.015	±13.43	±6.19	50
CAFE12_V2	-6 to 2	-4 to 6	±0.01	±0.01	±6.53	±5.90	38

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

7.1.1. IFP Energies Nouvelles

Accompanying PhD contract with IFPEN, in the framework of the PhD grant of A. Ben Khaled. The thesis explores new architectures and flexible scheduling methods to enhance the trade-off between the integration accuracy and the simulation speed of distributed real-time (hardware-in-the-loop) simulators, in particular in the framework of automotive power-trains.

7.1.2. MXM/CIFRE

CIFRE contract to fund the PhD thesis of Wafa Tigra. The purpose of this project is to develop a method to provide a limited set of commands to an upper extremity neuroprosthesis based on either intuitive motion using a limited number of commands to execute a set of important daily activities that require coordination.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. Appel d'Offre Interne (AOI) CGS Merri (CHU Montpellier)

Development and evaluation of a freezing detection system for people subject to the Parkinson disease : CHU Montpellier - UM1 M2H (Montpellier) - DEMAR

8.1.2. Labex NUMEV

Optimization of the sitting to stand-up transfer under FES for paraplegic people : preliminary study.

8.1.3. Running CPP protocols (Comité de Protection des Personnes)

- Optimisation du transfert assis-debout sous électro myostimulation fonctionnelle du patient paraplégique : Etude préliminaire, PROPARA, Montpellier. CPP Sud Méditerranée III - ID RCB : 2010-A00808-31 + Amendement.
- Détection et quantification du freezing chez le sujet parkinsonien CHU Montpellier, A. Balmes. CPP Sud Méditerranée 4 - étude qualifiée "soins courants".
- Observation du cycle de marche chez des patients hémiplégiques dans le but d'améliorer le déclenchement de la stimulation électrique fonctionnelle CHU Nîmes, Grau du Roi. CPP Sud Méditerranée III
- Mise au point d'une stratégie pour le stimulation sélective chez le lapin. Laboratoire de recherches chirurgicales Institut de Biologie, Université Montpellier I. Comité d'Ethique pour l'Expérimentation Animale Languedoc-Roussillon

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, Daniel Simon.

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 DANTE], 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.

(2008-2013). 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).

http://www.project-time.eu/

8.3.2. FP7 European project EPIONE

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

(2013-2017) "*Natural sensory feedback for phantom limb pain modulation and therapy*,

Partners: AAU (Aalborg, Denmark), 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)

http://project-epione.eu/

8.4. International Initiatives

8.4.1. Participation In other International Programs

8.4.1.1. 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. Dante Elias (Professor, Pontificia Universidad Católica del Perú) visited and presented his work on "Characteristics of a walking simulator with parallel manipulators" (7th, Nov 2013).

8.5.1.1. Internships

David Andreu supervised Milan Demarcq on "Mesure et Optimisation de la consommation de systèmes numériques implantables", Engineer final internship, from March. 2013 to Sep. 2013.

David Guiraud supervised Charles Juillet on «Transmission d'énergie et de données à un implant via un câble bifilaire », Engineer final internship, from March. 2013 to Sep. 2013.

David Andreu supervised Arthur Hiairrassary on "Architecture logicielle temps-réel d'un contrôleur de SEF implantable", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2013 to Feb. 2014.

David Andreu supervised Joannick Azama on "Implémentation d'un protocole application multi-charge pour réseau de SEF sans-fil", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2013 to Feb. 2014.

David Andreu supervised Chams Jied on "Architecture logicielle d'un contrôleur temps-réel de stimulation électrique fonctionnelle", Projet Industriel de Fin d'Etudes (engineer final year project), from Sep. 2013 to Feb. 2014.

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).

Daniel Simon supervised Jonathan Peguet on "Attitude Reconstruction of an Inertial Measurement Unit using IMUSim Software", IFMA (Clermont-Ferrand) engineer final year project, from Apr. to Sep. 2013.

Mitsuhiro Hayashibe supervised Sourav Chandra on "Dynamic modeling of fatigue induced hand tremor", PhD internship, Svaagata.eu: experience Europe as an Indian Erasmus Mundus, Indian Institute of Technology Madras, India, from Sep. 2013 to Feb. 2014.

8.5.2. Visits to International Teams

- Mitsuhiro Hayashibe visited Pontificia Universidad Católica del Perú for STIC Amsud - CARAT project and made a seminer on "Modeling and Control for Neuroprosthetic Systems and Rehabilitation" (15th May 2013 -25th May 2013).
- Mitsuhiro Hayashibe was Visiting Researcher at RIKEN BSI-TOYOYA research institute and worked on "Tacit Motor learning for rehabilitation" (Jul.-Aug. 2013).

9. Dissemination

9.1. Scientific Animation

- David Guiraud D. Guiraud is Member of the Editorial Board of Journal of Neural Eng., Associate Editor of EMBC conferences "track rehabilitation, theme 6" 2010-2013, Member of the organizing committee of IEEE NER 2013 (more than 550 registrations for the 2013 edition), member of the steering committee of "Institut des Technologies pour la Santé", Chair of the Labex Numev "Aide à la personne malade et déficiente" specific action. D. Guiraud was reviewer for the 2013 ERC consolidator program panel PE7. specific action.
- C. Azevedo-Coste is Board member of IFESS society (international functional electrical stimulation society) and Associate Editor of Paladyn Behavioral Robotics Journal.
- M. Hayashibe is member of the Editorial Board of the International Journal of Advanced Robotic Systems, Rehabilitation Robotics, and Guest Associate Editor, Frontiers in Neuroprosthetics, Biosignal processing and computational methods to enhance sensory motor neuroprosthetics.
- François Bonnetblanc is reviewer for several journals : Journal of Neuroscience (2011), IEEE Transactions on Neural Systems & Rehabilitation Engineering (2012), Neurosurgery, Journal of Neurology, Research in Developmental Disabilities (2012), Neurocase, Experimental Brain Research, Neuroscience Letters et Journal of Biomechanics.
- Daniel Simon was member of the RTNS'13 (Real Time Networks and Systems) and ETFA'13 (Emerging Technologies and Factory Automation int. conference program commitees and of the IFAC Joint Conference (Grenoble, february 2013) organization committees. Peer reviewer for the IEEE Trans. on Industrial Informatics and the Simulation: Transactions of the Society for Modeling and Simulation International journals, and for the ECC'13, SysTol'13, ECC'14 and ACC'14 int. conferences.
- D. Andreu is co-organizer of the french working group on Control Architectures of Robots of the french GdR Robotique and assistant manager of the Robotic Department (LIRMM).
- F. Soulier was Local coordinator of the Belem (BioElectronics for Medical Engineering) intensive program for the University of Montpellier 2 (Erasmus program).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master : D. Guiraud, basics of neurophysiology and neuroprosthetics, 10h, niveau (M1, M2), Institut Telecom / Mines specialisation "Tic santé" UE "medical robotics", France;

Master : D. Guiraud, muscle function, modeling and the basics for the control through FES and neuroprosthesis, 20h, , master 1 & 2 "Tic et santé" and master 2 Human Movement Sciences UE "neuroprotheses", 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, Neuroprotheses II, Neurophysiology, 6h, Master STIC pour la Santé , Univ. Montpellier 2, France;

Master : Christine Azevedo-Coste, Neuroprotheses I, Neurophysiology, 4.5h, Master STIC pour la Santé , Univ. Montpellier 2, France;

Master : Mitsuhiro Hayashibe, Neuroprotheses II,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 : Fabien Soulier, electronics and signal processing, 200h, Polytech' Montpellier, France;

Master : François Bonnetblanc, neurophysiology of movement and cerebral plasticity, 65h, University of Bourgogne, France;

Master : Paweł Maciejasz, Neuroprotheses I, Electrical stimulation of nerve fibers – Computer simulation and data processing, 4.5h (TP), Master STIC pour la Santé , Univ. Montpellier 2, France;

Master : Paweł Maciejasz, Neuroprotheses II, Electrical stimulation of nerve fibers and recording of neurophysiological signals, 4.5h (TP), Master STIC pour la Santé , Univ. Montpellier 2, France;

9.2.2. Supervision

HdR : François Bonnetblanc, "Prédictions et traitement des erreurs dans les comportements visuomanuels : de la flexibilité à la plasticité" , Université de Bourgogne, 23 Sept.

PhD : Maud Pasquier, "Segmentation de la locomotion humaine dans le domaine du sport et de la déficience à partir de capteurs embarqués", Université Montpellier 2, Sep. 16, Ch. Azevedo-Coste and B. Espiau

PhD in progress : Hélène Leroux, "Abstraction et composition pour la conception formelle de neuroprothèses", 09/2011 , D. Andreu

PhD in progress : Yacine Berranen, Modélisation volumique du muscle avec représentation des fonctions physiologiques, 10/2011, D. Guiraud, M. Hayashibe and B. Gilles

PhD in progress : Alejandro Gonzalez de Alba, Whole body control framework for lower limb stability in computational rehabilitation, 09/2011, P. Fraisse and M. Hayashibe

PhD in progress :Zhan Li , Réhabilitation fonctionnelle computationnelle et modélisation physiologique neuromusculaire, 10/2011, D. Guiraud and M. Hayashibe

PhD in progress : Mariam Abdallah, Système d'acquisition de signaux bioélectriques multicanal, programmable et implantable, 09/2012, G. Cathebras, F. Soulier and S. Bernard

PhD in progress : Marion Vincent, "Effets de la stimulation électrique directe (SED): intérêts pour la cartographie fonctionnelle en chirurgie éveillée" , 12/2013, F. Bonnetblanc

PhD in progress : Wafa Tigra, "Vers la commande intuitive d'une neuroprothèse dédiée à la préhension chez le tétraplégique" , 11/2013, Christine Azevedo-Coste, Guillaume Souquet (MXM), David Guiraud, Charles Fattal (Propara)

PhD in progress : Thomas Guiho, "Stimulation electrique medullaire en vue de la restauration des fonctions urinaires, intestinales et sexuelles chez le sujet lese medullaire" , 11/2013, David Guiraud, Luc Bauchet (CHU Montpellier), Christine Azevedo-Coste

PhD in progress : Abir Ben Khaled (IFPEN), "Distributed real-time simulation of numerical models : application to powertrains", 01/2010, D. Simon and M. Ben Gaid (IFPEN)

9.2.3. Juries

D. Guiraud was member of F. Bonnetblanc HDR defense jury, Univ. de Bourgogne, Sep. 23;

Ch. Azevedo Coste was member of M. Pasquier PhD defense, UM2 Montpellier, Sep. 16.

10. Bibliography

Publications of the year

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[3] 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, http://hal.inria.fr/lirmm-00922705

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