3 Publishable summary

3.1 MINDWALKER in a nutshell

A lack of mobility often leads to limited participation in social life. The purpose of MINDWALKER (https://mindwalker-project.eu/) is to conceive a system empowering lower limbs disabled people with walking abilities that let them perform their usual daily activities in the most autonomous and natural manner.

The project addresses 3 main different fields of expertise:

- BNCI technologies
- Virtual Reality
- Exoskeleton Mechatronics and Control

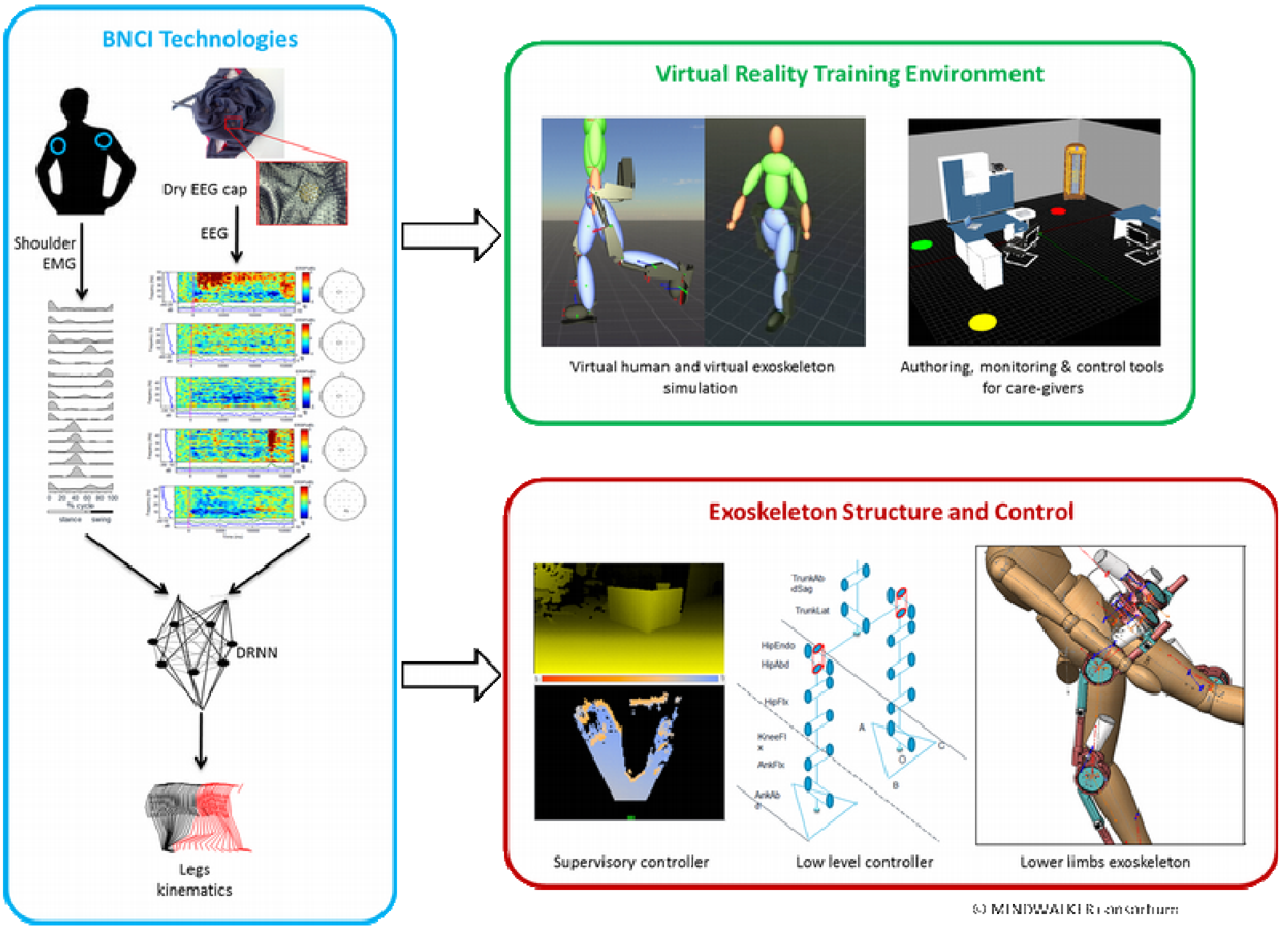

Figure 1: MINDWALKER 3 main research areas

The project top level objective is to combine these expertises to develop an integrated MINDWALKER system. In addition the system shall undergo a clinical evaluation process.

3.1.1 Approach and expected results

- New smart dry EEG bio-sensors will be applied to enable lightweight wearable EEG caps for everyday use. (WP4)
- Novel approaches to non-invasive BNCI will be experimented in order to control a purpose-designed lower limbs orthosis enabling different types of gaits. Complementary research on EMG processing will strengthen the approach. The main BCI approach relies on Dynamic Recurrent Neural Network (DRNN) technology. (WP5)
- A Virtual Reality (VR) training environment will assist the patients in generating the correct brain control signals and in properly using the orthosis. The VR training environment will comprise both a set of components for the progressive patient training in a safe and controlled medical environment, and a lightweight portable set using immersive VR solutions for self-training at home. (WP6)
- Novel exoskeleton orthosis will be designed to support the weight of an adult, to address the dynamic stability of a body-exoskeleton combined system, and to enable different walking modalities. (WP2, WP3)

3.1.2 Evaluation

The developed technologies will be assessed and validated with the support of a clinical evaluation procedure (WP8). This will allow measuring the strengths and weaknesses of the chosen approach and to identify improvements required to build a future commercial system. In addition the resulting system is expected to be progressively tested in everyday life environments and situations, ranging from simple activities at home to ultimately shopping and interacting with people in the street.

3.2 Activities and work done since the beginning of the project

YEAR 1

The 6 first months (M1 to M6) of the project essentially consisted in setting up a solid collaboration ground and performing initial activities related to user requirements elicitation, system architecture definition and system requirements specification.

One of the essential activities during the six first months of the project has been the early system specification phase (WP1), dealing with (i) the collection of user & system requirements, (ii) the preliminary technical specification of the MINDWALKER system, and (iii) the preliminary specification of the interfaces between major subsystems. These activities resulted in a set of deliverables supporting the overall system specification at an early stage. Iteration has then been carried out in the next 6 months, in order to further refine and detail the overall specification.

Besides this essential specification phase, review of the state of the art has been performed in a number of MINDWALKER major scientific areas, resulting in state of the art surveys deliverables (WP2, WP4, WP5, WP6).

Additionally, as a central concern during for the MINDWALKER project, WP5 partners investigated and defined the baseline approaches and experimental protocols required for the BNCI side

(WP5), in order to validate the “ideation” concept (i.e. the ability to link the EEG signals obtained from a subject imagining walking, to the legs kinematics). Work has been done to identify the promising setups for a proper parameterization of the DRNN processing chain, that may prove to be reliable enough for generating a walking gait signal.

Ethical considerations have been tackled by WP8, with activities aiming at setting up and maintaining a release of an “ethical package”, that shall support the preparation of an ethical review after 2 years, that will then allow the clinical evaluation with Spinal Cords Injured patients.

Dissemination material, including the MINDWALKER website and a MINDWALKER leaflet, has been prepared in the frame of WP9. Initial dissemination and exploitation plan have been worked out and reported.

Finally, contacts have been established and interactions occurred within the Future-BNCI cluster, and project partners attended a couple of specific Future-BNCI cluster round-table discussions during 2010 (in particular at the TOBI workshop). Potential collaboration modalities between Future-BNCI projects have been investigated. Initiative for BNCI technologies standardisation has been supported by project’s partners.

The second half of the year (M7 to M12) has been critical in confirming work hypothesis and methodology, strengthening the collaboration between partners, and ensuring the convergence of partners’ vision for the whole project. The following activities, in particular, have been carried out in this timeframe:

- BNCI experimentations to address fundamental research questions (WP5).
- Subsystems technology trade-offs analysis (WP2, WP3, WP4, WP5, WP6).
- Review, refinement and consolidation of initiated system technical specification and interfaces definition (WP1).
- Development of V0 preliminary versions of each subsystems, (WP3, WP4, WP5, WP6)
- Step 0 integration preparation (integration dry-run), Step 0 integration sessions performance, debriefing with end-users (WP7).
- Producing Year 1 due deliverables.

An important activity in this period has been to investigate, and figure out if (and in which extent) the BNCI “ideation” concept feasibility could be confirmed. Experiments carried out in this timeframe helped better understanding the related stakes and issues, though did not allow giving a definite answer to the complex question.

Due to the rather fundamental characteristics of the related research, the consortium approach is to develop solutions that do not only rely on the success of the “ideation” approach: though the consortium aims at providing the MINDWALKER system with such an ideation capable BNCI (which is a major research objective of the project), multiple complementary means are being investigated in parallel, that could improve, complement and/or substitute to the baseline approach, should it reveal unfeasible or ineffective in the project time frame. This complementary means are for instance: EMG-supported BNCI with measures of arm’s EMG (FSL performed a number of experiments with this approach), and gait pattern generators (CPG) to mix BNCI signals with well formed gait pattern signals. Additionally, back-up control approaches based on voice, joystick / buttons, etc. are also scrutinized (will anyway be used for subsystem level testing of e.g. the lower limbs exoskeleton).

An important milestone has been the Step 0 integration that gave partners an opportunity to setup a V0 version of the different subsystems, and allowed partners facing actual integration issues for the first time. It helped ensuring that data formalisms and communication protocols were making sense. The development of a common communication library dramatically eased the integration process, reducing the burden, and allowing the partners to focus their efforts on understanding the subsystems connection architectures, testing various data types transfer, and testing various failure cases (e.g. manually un-plugging/re-plugging communication cables and ensuring overall robustness).

A number of publications have already been submitted and for some of them accepted to different types of peer reviewed symposium (both workshops and conferences).

YEAR 2

Year 2 has been an intense and crucial period of the project. Partners worked out early version V1 of the different subsystems, and prepared experimentations for integration Step 1 with several options including back-up ones, with the aim of diminishing identified risks. With this approach in mind, Step 1 integration collocations' focus shifted from tests addressing EEG based approaches testing, to backup solution validation, with experiment performed with shoulder EMG based control approach. This allowed ensuring feasibility of shoulder EMG based control approach, performed with the LOPES setup of Twente University. VRTE (WP6) early version was introduced, with preliminary tests of upper torso tracking. Low level controller (EXOC-LOW) early version

In WP2, actuation concept has been refined and first prototyping has been scheduled. Delays however occurred in the finalization of the concept, with a novel actuation approach addressing MINDWALKER needs and constraints, but requiring complex design, assembly and concepts validation.

In WP5, latest experiments and status regarding EEG "ideation" approach as of June (M18) could not confirm the feasibility of the approach for proper exploitation in MINDWALKER, although the approach was still considered scientifically interesting and beyond the state of the art.

WP2 and WP5 status led the consortium to agree on provisioning some more time until the integration Step 2 (initially scheduled at M24), in order to further mature some of the most challenging (high risk / high reward) aspects of the project. Integration Step 2 therefore shifted to M26, which has been confirmed by FSL to impact only in a minor extent the clinical evaluation agenda (WP8 - with overall clinical evaluation phase reduced from 9 to 7 months, accordingly).

For the sake of ensuring proper integration of results (WP7) despite the shift of the integration Step 2, an intermediary integration step (namely Step 1.5) has been introduced. It took place in November 2011 (i.e. M23), and allowed checking the latest status of subsystems development, and evaluating remaining challenges.

During Step 1.5, EEG based approach based on SSVEP was tested and allowed to control a gait pattern generator component of the BNCI chain. The VRTE (WP6) setup allowed demonstrating improved upper body tracking based on a kinect camera, and modelling and rendering of a virtual human and virtual exoskeleton. Interaction through physics engine was partially implemented, with virtual human's pelvis fixed along one dimension in the simulation environment.

As a bottom line of Step 1.5 integration and plenary progress meeting, EEG "ideation" was considered unlikely to be developed to an exploitable level in the timeframe of the MINDWALKER project. It was however agreed to maintain research activities in background for this approach, considering its high scientific value and the magnitude of the challenge, while focusing efforts on BNCI control approaches that can be implemented and tested with the developed exoskeleton.

Although not connected to the BNCI chain in the integration trials, eemagine delivered a first prototype of dry EEG cap with fabric-embedded electrodes to ULB, along with enhanced electronics and amplifier, for testing and evaluation purpose (ongoing activity).

Over the last quarter of the year, additional delays took place in WP2 due to manufacturing issues, increasing the delay for the exoskeleton prototyping delivery to about 6 months. At the end of 2011, mitigation strategies to handle these delays were under study by the consortium. Possibilities include stepped clinical evaluation, starting with the VRTE in due time (M30) and postponing by a few months the beginning of the real exoskeleton clinical evaluation (so that it can be fully tested prior its delivery to FSL, for the sake of safety).

Despite delays and challenges met, consortium keeps focused on the development of a consistent and usable MINDWALKER prototype solution, with the activation of provisioned backup options where necessary.

3.3 Main results and achievements since the beginning of the project

Noticeable results after **Year 1** include:

- The development of a common understanding of the project's challenges by all partners through the specification phase (WP1) to which all partners contributed, and going toward a common vision of the approach, identification of potential (sometimes unforeseen) problems to solve, and possible strategies to overcome these problems.
- Technologies trade-offs have been performed, with early technologies tested in different areas, such as the electrodes concept testing for the SWEEBS (WP4), and the VRTE visual feedback and human body tracking technologies (with e.g. head-mounted displays, 3D screens, kinect based tracking, etc.).
- An important milestone has been the Step 0 integration that gave partners an opportunity to setup the V0 version of the different subsystems, and allowed them to face the actual integration issues for the first time. It helped ensuring that data formalisms and communication protocols were making sense. The development of a common communication library dramatically eased the integration process, reducing the burden, and allowing the partners to focus their efforts on understanding the subsystems connection architectures, testing various data types transfer, and testing various failure cases (e.g. manually un-plugging/re-plugging communication cables and ensuring overall robustness).

- As far as ethical issues are concerned, both FSL and ULB obtained the agreement from their respective ethical board committee (EBC) to carry out BNCI related experimental protocols in the frame of WP5.
- Attendance to a number of dissemination events (including e.g. the EU ICT event in September 2010), and preliminary publications of early results in peer-reviewed symposium proceedings.

Noticeable results after **Year 2** include:

- Consolidated exoskeleton structure and actuators design, manufacturing orders passed (WP2).
- Low level model predictive controller (PMC) preliminary version tested with UT LOPES system, now further improved performance-wise to allow concrete use with the MINDWALKER exoskeleton (WP3).
- Supervisory controller hardware setup preliminary version tested for digital elevation map building and obstacles identification (WP3).
- Dry EEG cap and acquisition electronics (including amplification stage) prototype worked out, and delivered to ULB for testing and evaluation (WP4).
- Range of experimentations carried out, targeting EEG ideation primary approach, and alternative EEG approach (based on SSVEP in particular) and shoulder EMG approach (tight collaboration between ULB and FSL). Shoulder EMG feasibility validated with the LOPES setup. (WP5)
- VRTE core components with virtual exoskeleton and virtual human modelling, physics engine instantiation, and user upper body tracking system have been implemented (WP6).
- An important amount of papers and journals (20) have been published, a major part of them under WP5.

Year 2 required as expected all the consortium energy for experimenting different approaches, and to design, implement and integrate many of the needed MINDWALKER components. The main milestone and objective for year 3 is therefore to get a MINDWALKER system prototype ready with sufficient time left, despite anticipated delays, to properly undergo clinical evaluation at FSL.