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The SMILING system: a comprehensive approach to the perturbation of walking

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Abstract—**The SMILING system has been developed to supply a complete system for walking perturbation in free conditions. The system is built on a motorized pair of shoes able to modify shoe sole height and inclination during the swing phase of walking to supply to the subject wearing the shoe a different "ground" each time he/she hits the soil. The basic apparatus is completed by a dedicated user unit to manage the perturbations administration and an external "operator unit" to deal with the generation and tailoring of perturbations. To add the system measurement capabilities to allow a fast and reliable assessment of perturbation effects on the walking features a dedicated system for gait analysis has been setup. Precise protocols have been developed to manage the working of the system as a device for training of walking.**

I. Introduction

THE SMILING system is a complete system for walking assessment and perturbation consisting of four main modules: i) a motorized pair of shoes, ii) a user friendly portable control unit, iii) a set of PC based algorithms for ad hoc perturbation generation, iv) a full apparatus for walking assessment.

The rationale of the system design lays in new spreading approaches in neuro-motor rehabilitation suggesting exercise programs characterised by sensory, cognitive, and motor tasks highly challenging brain functions to naturally recover and improve neural plasticity [1-2]. This approach requires an extensive training schedule; a desired skill must be practiced over multiple cycles to ensure motor learning is developed and transferred to everyday live activities.

The SMILING project aimed at applying these new training trends to counteract falls in elderly persons. It has been widely demonstrated the important role of physical-activity-based interventions in improving function in older people, both with and without age-related pathology [3-5].

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Walking features modify with ageing and flexibility and stability in the performance of the gesture decrease. Flexibility is a key factor in adapting to the unexpected changes of the environment, such as an uneven terrain, while stability allows to overcome any external perturbation [3-5].

Within this frame, the basic idea, leading to the design and developing of the here described SMILING system, was to setup a system specifically dedicated to the training of walking by means of administration of sensorial and proprioceptive perturbations by managing "alterations" of the ground not supported by any additional sight clue.

This paper describes the overall functional structure with a particular focus on perturbations tailoring and administration.

II. The Components of the System

According to the rationale previously described, the key specification for the SMILING system was the development of a pair of shoes able to perturb walking by presenting a different "sole configuration" each time the foot hits the ground during normal free walking.

Functional specifications, elaborated to guarantee the safety of the subject undergoing the training, set a maximum inclination of ±4.5 degrees both in plantar- dorsi flexion and pronation-supination of the foot.

Because of the specific application to walking, the SMILING shoes were commanded to be able to "change" their configuration during the swing phase of the gait cycle that means a working time window of 280 msec.

Furthermore the "shoes" had to be designed to manage different foot sizes and body weight constraints to allow a wide functional evaluations with volunteering elderly subjects.

The mechanical challenges related to the functional specifications above are deeply analysed in [9]. The shoe structure comprises separate heel and forefoot units, which are assembled as independent units and fitted to a support structure (fig.1, fig.2).

Each shoe is equipped with dedicated electronics (micro-controller, sensors and wireless communication capabilities) to allow different functions.

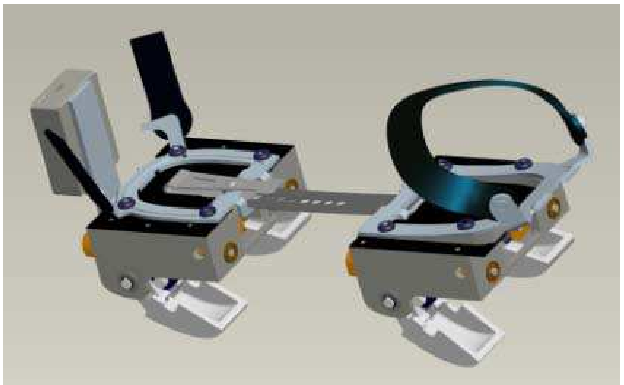

Fig.1 : The mechanical structure of the motorised SMILING shoe

Fig.2 : The manufacturing results

The need to manage the change of configuration of the shoe only during the swing phase of gait to allow motors to work with no heavy load due to the body weight, present also some challenging issues from the control point of view.

Each shoe is equipped with a 3D gyroscope and a 3D accelerometer to allow identification of toe off to initiate motors activation [10]. The sensors are part of a wireless unit (S-Sense), placed on the back of the shoe transmitting data about the foot position to the MCU that controls the motors (fig.3). Dedicated software has been designed to speed up the event recognition and start motors.

Features and capabilities of the shoe's embedded control unit are detailed in [11].

High level control function of the shoes is managed by means of a devoted user control unit (UCU) worn by the subject performing the walking trials [12].

Ad hoc tailored perturbation patterns are downloaded to the shoe before starting any training section to drive the motors to provide the expected functional perturbation.

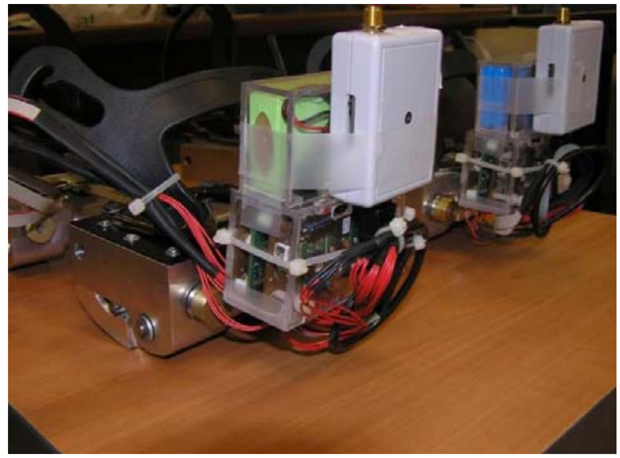

Fig.3 : The SMILING shoe electronics

The UCU communicate wirelessly with the electronics on board the shoe (fig.4) . The communication with the shoe is bi-directional. The unit is capable to start and stop training and to download foreseen perturbation patterns to the shoes but also to collect data from the shoe sensors to evaluate walking features.

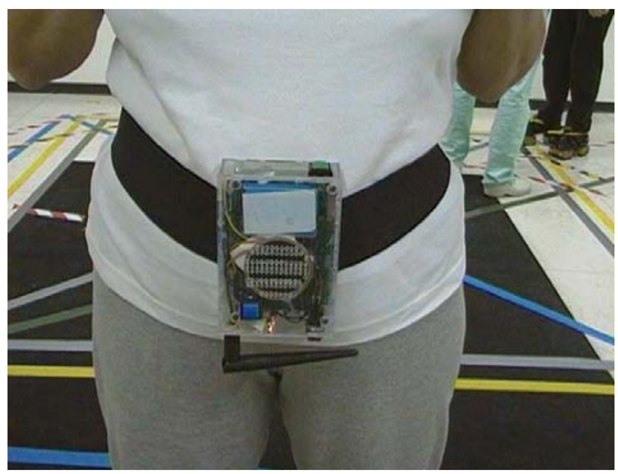

Fig.4: The SMILING User Control Unit

During the walking the user wears the shoes and the UCU (fig.5, fig.6). He/she activates autonomously the perturbation session. For each foreseen walking task, the control unit supplies the main instructions and monitors the user's performance.

At the end of the complete walking session, the UCU evaluate acquired walking data and supplied a performance indication.

The walking tasks and the perturbation amount needs to be tailored to the single subject keeping in account his/her walking capabilities and his/her walking anthropometric parameters. This preparation phase is managed by an other control unit, the Operator Control Unit (OCU), that is normally installed on an external PC.

Fig.5: Wearing the SMILING system

Fig.6: Using the SMILING system

III. THE ARCHITECTURE

The harmonised working of the different components of the system previously described is allowed by a dedicated architecture joining various communication channels and protocols (fig.7).

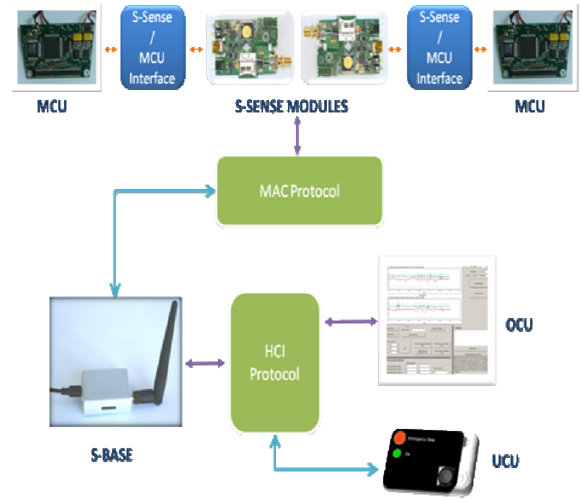

Fig.7: SMILING communication architecture

Within the shoe, there is an interface between the MCU and the S-Sense. The communication between the two modules is bi-directional and manages the exchange of information on the swing period start (from the sensors to the MCU) and from the MCU to the "external world" by allowing the transmission of error and warning messages by means of the wireless component of the S-Sense module.

The S-Sense transmission unit is able to set a bi-directional communication both towards the User Control Unit (UCU) and the Operator Control Unit (OCU) with several aims. On the UCU side the communication allows i) to start the calibration of the shoes motors, ii) to download the perturbation patterns, iii) to start/stop the perturbations administration, iv) to send to the UCU complete information on gait features (by the 3D gyroscope and accelerometer) for further walking investigation. On the OCU side the communication allows to start and stop an independent gait analysis session without motors activation. Raw gait data are transmitted on line to the OCU for real time displaying and additional off line processing.

Additionally, there is also an off-line communication link between the UCU and the OCU to set up and manage oeprations including the transferring of perturbations data to the OCU and vice versa the transmission of gait data back to the OCU for further investigation of data acquired during the perturbed walking.

Interfacing with end users is allowed both by the UCU and OCU components.

The UCU is directly managed by people undergoing training. Because of the initial test application with elderly people, attention was paid to a simple interface characterised by only two buttons easily identifiable thanks to colour code and position and played audio messages available in multiple languages.

The OCU is envisaged for high level setup . It is managed by the operator, a clinician or a therapist in the current evaluation trials, to perform gait analysis tests and to prepare ad hoc training sessions to be administered to the single patients. In this case the interfacing is managed by the PC screen and the process is driven via a wizard approach.

IV. THE PERTURBATIONS TAILORING

Because of the various walking capabilities and anthropometric features, the SMILING perturbations need to be tailored for each subject (fig.8).

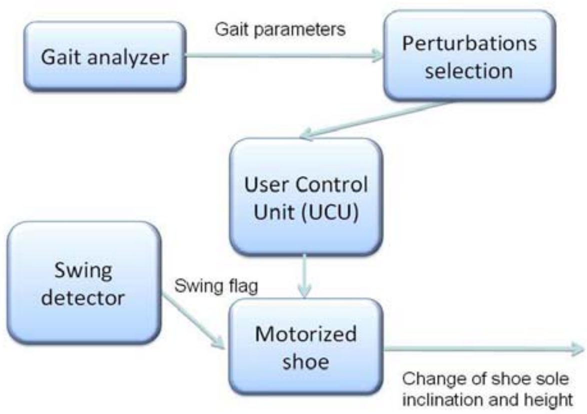

Fig.8: Perturbations administration

The walking capabilities of the subject that have to undergo the training , drive the first phase of the setup procedure. According to the SMILING shoe design, perturbations may be any sequence of foot inclinations (both in the frontal and sagittal plane). Because of different theoretical approaches it is possible to use deterministic, random or chaotic sessions. Chaotic perturbations generation is detailed in [11].

For each kind of perturbation, limits are set by the maximum perturbation amplitude (up to ±4.5 degrees both in flexion extension and internal external rotation) and the frequency of perturbing that may be set to each step or any multiple. At the end of this setup phase, there exist perturbation patterns in degrees with predefined constraints on maximum excursions.

The following step is the conversion from degrees to motor rotations taking in account manufacturing data and anthropometric data (foot length) of the subject.

Geometrical parameters of the shoe (lateral distance between the actuators, relationship between motor rotations and height change, …) are fixed by manufacturing constraints while the shoe length may be varied according to the subject and need to be measured for each subject undergoing training.

The reciprocal position of the four actuators (two in the rear and two in the front of the shoe) is computed allowing the implementation of trigonometric computations to know the required excursion for each motor to get the desired sole inclination. Once the height to be reached by each actuator is needed, it is transformed in number of motor rotations to be able to drive the motors correctly by means of the shoe MCU.

The final perturbations are then transmitted to the UCU and are ready to be downloaded to the SMILING shoes for the training performing.

V. THE GAIT ASSESMENT

Gait analysis is a key add on to the SMILING system. The assessment of any modification in the walking features of the subject both wearing ad not wearing the SMILING shoes is a must to tailor perturbations session and complete training programs.

To perform gait analysis without the SMILING shoes, the user wears, on the back of his/her shoes a self powered S-Sense unit. Data from the sensors are acquired in real time and sent to the Operator Control Unit – OCU for on line checking and off line dedicated processing. The SMILING user is asked to walk according to a well defined analysis protocol [13] to allow both a linear and non linear analysis of his/her walking features.

The computed gait parameters are used by the operator in charge of the SMILING system setup to select the most suitable training exercises for the specific user.

VI. FUTURE DEVELOPMENTS

In initial functional testing and users trials, the SMILING system showed to be extremely versatile, making possible its application in multiple research and training area.

Sensorial and proprioceptive perturbation of walking is normally obtained by means of moving and/or tilting platform and it is not normally performed in free walking conditions as the ones offered by the SMILING system. Applications in the area of Virtual Reality (VR) are under investigation, to couple the SMILING system with audio and visual clues.

Interesting application fields are in the basic motor and neuro- physiological sciences to investigate human reactions to different kind of perturbations during movement but also, as described in the introductory section of this paper, in training and rehabilitation areas where ad hoc motor challenges may help in motor learning and recovery.

The current architecture of the system is quite flexible and modular to allow different applications without main changes to its structure.

Acknowledgments

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