Publishable Summary

MIMICS

Multimodal Immersive Motion rehabilitation with Interactive Cognitive Systems
www.mimics.ethz.ch

1 Project goals and objectives

The main hypothesis of this project is that movement training for neurorehabilitation can be substantially improved through immersive and multimodal sensory feedback. The approach is real-time acquisition of behavioural and physiological data from patients and the use of this to adaptively and dynamically change the displays of an immersive virtual reality system, with the goal of maximising patient motivation.

The overall objective of MIMICS is to significantly enhance existing robot-assisted rehabilitation methods with multi-sensorial acquisitions, multimodal displays and technical cognition so that the patient's motivation can be improved leading to a more intensive training and to an improved therapeutic outcome. Following objectives were in the focus of the reporting period (1^{st} project year):

- Development of a "maximal configuration" rehabilitation system for upper and lower extremities with a rich choice of sensors and displays (including haptic, visual, acoustic).
- Development of multi-sensorial data acquisition methods based on recording of sensory-motor actions and physiological measurements.
- Development of first algorithms about multi-modal (haptic, visual, acoustic) scenarios & rendering.
- Derivation of a first downscaled configuration systems for upper and lower extremities based on first experimental evaluations.

2 Work and results so far

2.1 WP1: System specification and hardware set up

General requirements were defined together with all partners. Main user need is an improved recovery after stroke resulting from higher intensity of training and a patient-adjusted and engaging training scenario. A special need is that the patient should exercise with maximal effort and involvement, while the system automatically adjusts to the demands and abilities of the patients.

According to these needs a maximal configuration hardware setup was developed for the upper and lower extremities (see Figure 1). The main system components for the rehabilitation of upper extremities are the HapticMaster robot, with additional axes for arm gravity compensation and training of grasping, 3D projection system, surround sound system and a system for measuring psycho-physiological signals. The complete system for therapy of the lower extremities consists of the robotic device Lokomat, a body weight support system, an automatic treadmill, a 3D projection system, a surround sound system and a system for measuring psycho-physiological signals.

For the first online detection and assessment trials of psycho-physiological activities during arm and gait training we set up maximum configuration systems, which were comprised by the following recording functions: skin conductance, skin temperature, electrocardiogram (for recording of heart rate and heart rate variability), blood pressure, breathing frequency, joint angles, and joint torques. Facial electromyography (EMG) measurements were tested in an early phase, but were later assessed as unsuitable. For the gait application also Electroencephaologram and ergospirometry was tested. Due to movement artefacts and too cumbersome preparations, blood pressure, EEG and also ergospirometric measurements were omitted in the downscaled hardware setup applied later on.

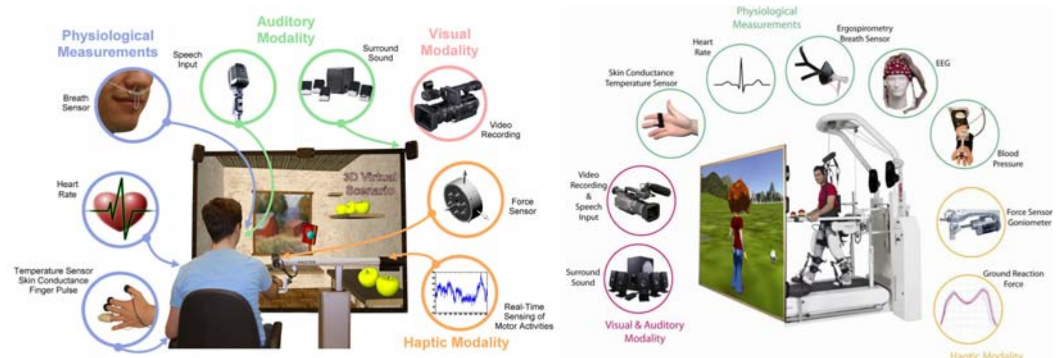

Figure 1 The maximum configuration setups for the upper and lower extremity training systems

2.2 WP2: Multimodal immersive interactive display environments

Audiovisually rendered scenarios have been developed for both upper and lower extremities at ETH Zurich, HOCOMA and UL with challenging tasks for the participants (Figure 2). In the lower extremity setup an avatar of the patient walks on a parcour, where he or she has to solve different motor and cognitive tasks. Three different scenarios have been developed, 1) where the patient walks along a street and cars passing on each side, 2) where the patient has to cross a narrow bridge (beam) over a canyon, and 3) where the patient has to kick a soccer ball placed on the parcour. The level of arousal can be changed, e.g. by changing the kind and noise of cars passing the avatar or the height or width of the bridge. In the upper extremity scenario a virtual character (virtual therapist) is placed in a comfortable room to provide assistance to the patient when performing a task via haptic feedback as well as to provide a social component to the scenario. In this respect the virtual character gives instructions on how to successfully complete a specific task as well as to motivate the patient by providing encouraging words. If the patient has difficulties to perform the task, the virtual character may provide assistance via haptic feedback. In a second scenario a static tunnel is placed in an empty space, where the patient has to move a ball along this tunnel. In the third scenario the patient has to pick and place virtual objects. Haptic feedback methods have been implemented to render the interaction with virtual objects (soccer ball, pick and place objects) and display the collision with virtual obstacles.

General purpose scenarios addressing presence issues and the automatic learning system have been developed at UPC. The ability to change various parameters, such as lighting conditions and elements of the environment, of the scenarios have been developed. Real time rendering of scenes as well as virtual humans has been included in the scenarios. Methodologies for the rapid construction of scenarios are progressing with the aim of simplifying this process.

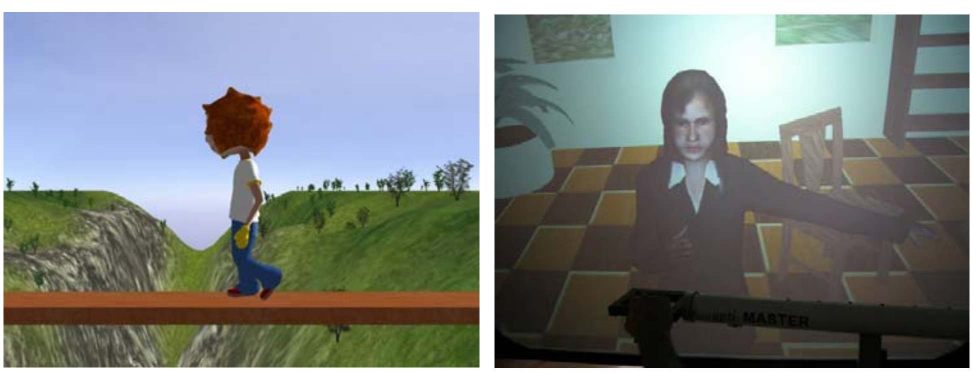

Figure 2 Virtual scenarios for the lower and upper extremity training setups.

2.3 WP3: Multi-sensorial data processing and decision making

All algorithms for acquisition and processing of physiological and motor data have been developed and tested. Basic connections have been established between physiological data and psychological states. Efforts are currently underway to develop an advanced presence and emotion recognition system as well as an automated learning system.

Sensors on board the Lokomat (ETH Zurich) and the HapticMaster (UL) have been successfully configured for acquisition of static and dynamic information about motor actions including forces, torques, positions, derivatives of position, and EMG. Algorithms have been developed by ETH Zurich and UL that can filter this data as well as calculate parameters connected with task performance. Sensors have also been set up to record and store audio streams.

A number of physiological responses were examined in connection with estimation of psychophysiological state. Four principal physiological responses were chosen for further use, including ECG, skin conductance (i.e. electrodermal activity), respiratory rate, and peripheral skin temperature. Algorithms for real-time acquisition and processing of physiological data have been jointly developed by UL, ETH Zurich and UPC. All physiological recordings are synchronized with recordings of audio streams and motor actions. Large differences in baseline values of several physiological parameters were found among subjects. For this reason, NKBA designed a study to analyze the distribution of measured baseline parameters in patients. A special emphasis was placed on the effects of medication, which can drastically affect physiological responses.

Preliminary studies were carried out at ETH Zurich and UL to confirm the basic hypothesis that changes in psychological state are reflected in physiological responses. The study at ETH Zurich investigated exerted forces and physiological changes while walking in the Lokomat in the presence or absence of different virtual environments. It was observed that mental activities influenced skin conductance responses and heart rate, whereas physical efforts influenced heart rate, respiration rate, EMG signals and recorded forces and torques. Independently of the study at ETH Zurich, UL carried out a study that investigated physiological responses to two tasks. The first task was a mental arithmetic task that required no physical activity. The second was a hand-eye coordination task that was performed with a Phantom Premium haptic interface and required mild physical activity. Additionally, subjects had to perform both tasks at once. Large increases in the frequency of skin conductance responses were observed in response to mental activity, whereas skin temperature and respiratory rate decreased during the tasks. The preliminary studies confirmed that physiological responses were associated with changes in psychological state, but highlighted the need for a detailed model of psychophysiological state. Therefore, two independent studies were conducted at UL and ETH Zurich that could determine the feasibility of such a model.

Development of a learning algorithm began at UPC in autumn 2008. The algorithm is based on the reinforcement learning methodology. This methodology divides the system into the actor (the part performing the actions), and the environment (everything else that is not part of the actor). The algorithm aims to maximise the long-term reward by choosing appropriate actions. The developed algorithm can be trained before being used in experiments in order to reduce the initial learning phase. The learning can continue while the experiment is progressing, adjusting the algorithm according to each individual participant. This capability of the algorithm can respond to changes in the behaviour of the user. The decision making system has been developed as an independent library that can be added to a large variety of virtual reality software tools. The functionality of the library does not require extensive knowledge of the underlying algorithm. The algorithm has been designed and developed in order to work in real-time and not to add a large computational cost to the system.

2.4 WP4: Experimental evaluation

In the first reporting period, the partners at ETH Zurich (at Balgrist) and Hocoma evaluated several sensors for recording of physiological signals. Different communication network architectures (both in hardware and software) were tested to enable two-way communication between the hardware control PC, the measurement computer and the audiovisual display system. In first clinical trials with healthy subjects (Figure 3), the labs at ETH Zurich and Balgrist examined the influence of Lokomat training, cognitive tasks and fear on the following physiological signals: blood pressure, EMG, skin temperature, skin conductance, ECG, respiration and joint forces. Based upon these experiments, the downscaled version for the clinical partners was implemented. It included the physiological signals ECG, skin temperature, skin conductance, respiration and joint forces.

At UPC, a scenario has been prepared with the purposes of examining the validity of the automatic learning approach. This initial scenario will be using the location of the participant as a signal to be controlled. Further scenarios will address the more complex physiological signals.

At NKBA, the design for the final clinical evaluation of the system was defined. Ethics approvals were submitted to the according authorities. First trials regarding the effect of the virtual scenarios on biomechanical data gathered from the Lokomat training at NKBA demonstrated no conclusive effect on the recorded parameters. During the course of these primary evaluations, a measurement setup and procedure was implemented at NKBA and key therapists were trained in the use of the measurement equipment. First results support the hypothesis that additional feedback information enhances patient participation. However, this effect depends on significant cognitive ability of the patient at the current type of feedback.

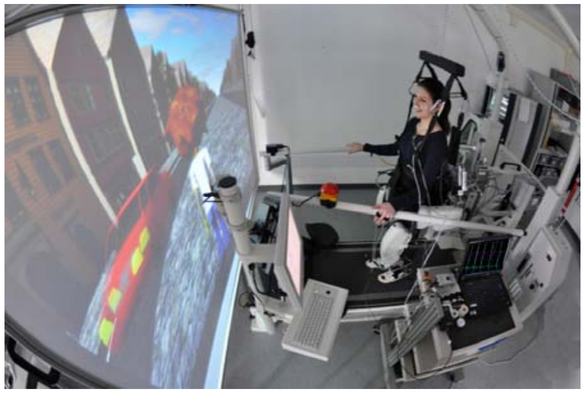

Figure 3 Setup used for technical evaluations at ETH Zurich

2.5 Dissemination, exploitation and management

A public web site of the project (www.mimics.ethz.ch) was implemented at the very beginning of the project. A project flyer and project poster was created. A project logo was selected in the frame of an internal contest and distributed among the partners and project collaborators (see header). A scientific symposium was organised together with Hocoma (www.inrs2009.com). More than 350 attendees participated and the general feedback of the symposium was tremendously good. All deliverables and achievements of milestones have been on time. Only the D.6.1 Quality Assurance Plan was late due to the fact that the project manager could not start before March 08. Two internal newsletters were distributed to the consortium. A large number of peer-reviewed publications and media reports in newspapers and on television as been published so far.

3 Potential impact and use

We performed a targeted research effort to select optimal acquisition and display modalities for the rehabilitation training. The novel systems developed in MIMICS autonomously assess the actual psycho-physiological state and motor actions of the user. This will be the basis to increase the patient's sense of presence, engagement and motivation. This should finally lead to an enhanced rehabilitation outcome.

The project will propose significant advances in the field of human-machine interaction and coordination based on implicit communication from human to machine. Implicit communication is defined as a communication where physiological measures are sensed and the psycho-physiological state of the person is automatically interpreted by the machine in real-time. This will lead to more intuitive, natural, efficient, and motivating interactions. The capability of the machine to alter its behaviour based on human physical interaction and emotional state will be a hallmark of a successful patient-centred robotic rehabilitation system that can be transferred to other areas of human-robot and human-computer interactions, e.g., to applications, where the machine interacting with a human operator could change the level of its autonomy based on the user's psycho-physiological state.

Besides those scientific and technological outcomes, MIMICS will produce a large portion of novel clinical expertise and scientific results in the area of robot-assisted rehabilitation. Gait training in stroke patients is the most important task to enable the patients return to their home self-dependence. Current treatment relies heavily on manual assistance by therapists. Improvements of therapeutic outcome of rehabilitation training might be achieved by increasing the sense of self-control and effort by the patient through awareness and challenge in the training process. The proposed project analyses the contributions of this additional variables to the process of relearning gait. Unique is the approach of combining leaders in technology and neurorehabilitation medicine. Therefore, the scientific basis of locomotor training should be broadened through a combined view.

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