Advanced downscaled Lokomat and HapticMaster platforms ready for clinical trials and ARMEO prototype with new features as an example of a “minimal configuration”.

Deliverable D4.4

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1 Summary

The goal of the MIMICS project is to enhance existing robot-assisted rehabilitation methods with multi-sensorial acquisitions, multimodal displays and technical cognition. The Lokomat is the main component of the robotic system for the lower extremity and the HapticMaster for the upper extremity.

The next two sections give a specific overview of the downscaled system used at the site of the clinical partners for the patient studies. Section 2 details the lower extremity (Lokomat) setup used at NKBA. Section 3 describes the upper extremity systems (HapticMaster and Armeo). Finally in section 4 we present conclusions on the future work in the MIMICS project.

2 Lokomat

The maximal configuration setup (cf. Deliverables D1.2 and D3.1) was reduced to the first downscaled platform based on the evaluation of all possible psycho-physiological measurement sensors in Deliverable D4.1. This system was transferred to NKBA in May 2009 after necessary structural changes at NKBA had been completed, Figure 1.

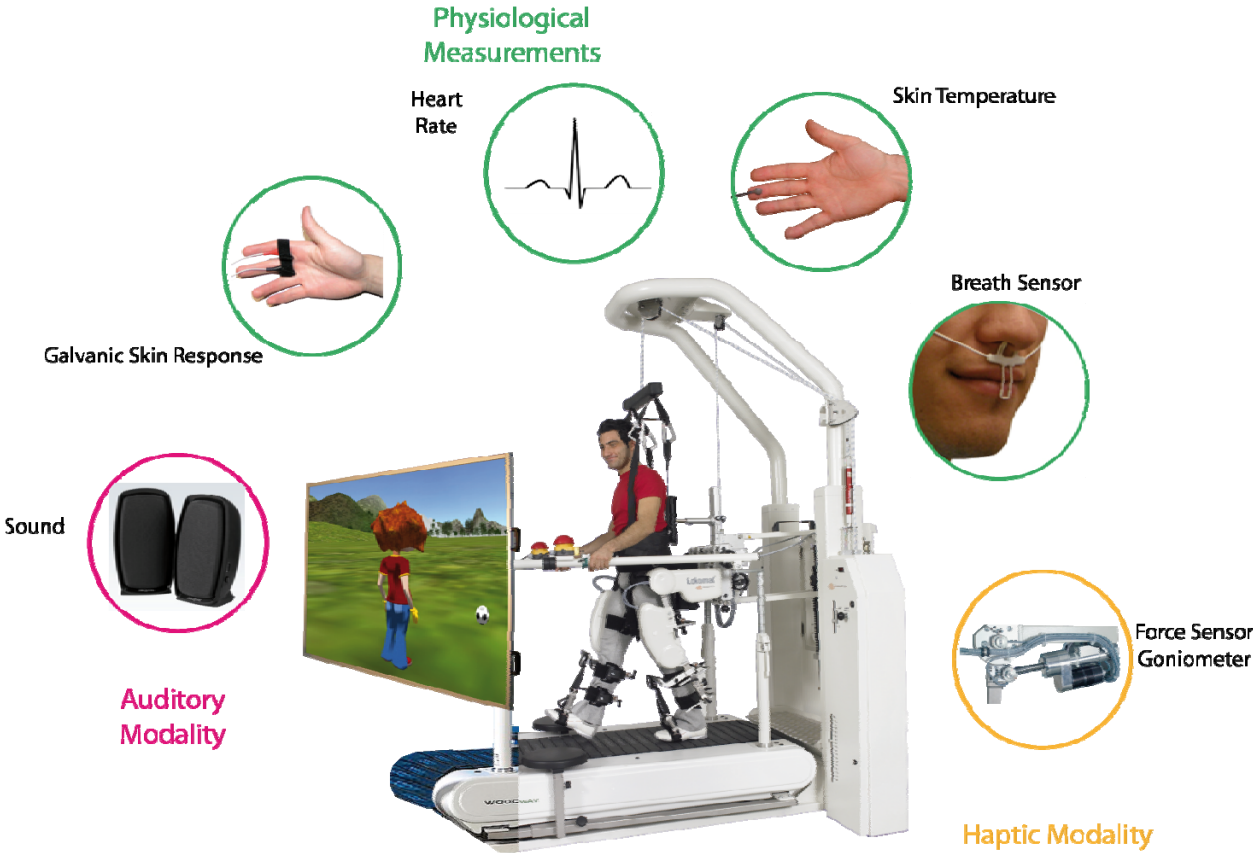

Figure 1 Downscaled configuration set-up for the lower extremity (Lokomat).

2.1 Lokomat system

The robotic component of the lower extremity system at NKBA is a Lokomat® Pro V4.0 system (Hocoma AG, Volketswil, CH) with Augmented Feedback Module and Woodway treadmill. The Augmented Feedback Module consists of a large flat-screen monitor, an additional computer and data connections. A 42" LCD flat screen monitor is placed on a monitor stand in front of the patient at approximately eye level. The visible diagonal is approximately 34° visual angle. The additional computer receives command and movement data from the user interface computer and the real-time controller of the Lokomat system respectively.

The screen size was reduced compared to the initial configuration because no evidence or publication had been found that large screen size amplifies the motivation of the subjects. The known relevance of large field visual stimuli on postural reflexes was not considered important enough for specific lower extremity

movement training in the Lokomat compared to the complication of a large back-projection system that has to be fit into spatially limited hospital space.

Several virtual environments (exercises) have been developed by Hocoma for the MIMICS project These virtual environments are used to present tasks related to specific movements of the patient in the Lokomat system, used by a therapist to induce specific functional exercises.

2.2 Audiovisual displays

Audio hardware consists of the stereo output in the flat screen monitor as there is currently insufficient evidence for necessity or benefits of surround sound. The visual hardware used is described above.

The audiovisual display is used for the presentation of several scenarios. The first scenario depicts a city. In one variant of this scenario, the patient walks through a city street lined with two rows of houses. On both sides of the walkway, cars are passing by (moving stimulus). Within the scenario, the experimenter (and later the therapist) can adjust different parameters of the scenario, including width of the walkway, time of day, sunny or rainy weather, camera elevation angle, ambient light and the background sound (scary, relaxing).

The second scenario depicts a path through a forest, Figure 2. The speed of the avatar's movement along this path correlates to the biofeedback values (as described by Banz et al 2009[*]), measured through the force sensors of the Lokomat device. The therapist can select the gait phases and joints used for the calculation of the virtual speed. No directional control (left/right) is implemented.
Along the path, the patient's representation (avatar) can encounter two kinds of objects: Coins that have to be collected and Rocks that have to be avoided. The distance between the objects and the frequency of occurrence can be adjusted by the therapist.
Each object is only presented for a time span defined by the therapist, after which it slowly fades out and disappears completely. In order to draw the patients' attention towards the objects, green arrows point out the next object on the avatar's path. The green colour changes via yellow to red over time corresponding to the fading of the object.

[*] Banz R, Bolliger M, Muller S, Santelli C, Riener R. (2009) A method of estimating the degree of active participation during stepping in a driven gait orthosis based on actuator force profile matching. IEEE Trans Neural Syst Rehabil Eng. 2009 Feb;17(1):15-22.

The patients' task in this scenario is to continually adapt his walking speed in order to collect as many coins as possible (by increasing participation and thereby increasing walking speed) whilst avoiding the rocks (by decreasing walking speed). Each coin collected by the avatar increases a total score by 5 points, each rock hit by the avatar decreases the total score by 5 points. The difficulty of the task is adjusted by the distance between the objects and the fading-out times of rocks and coins in order to attain the 3-state classification (under-, over- and adequately challenged).
Separate controls allow the therapist to adjust properties of the environment such as lighting, weather, animals encountered along the forest path and ambient sounds.

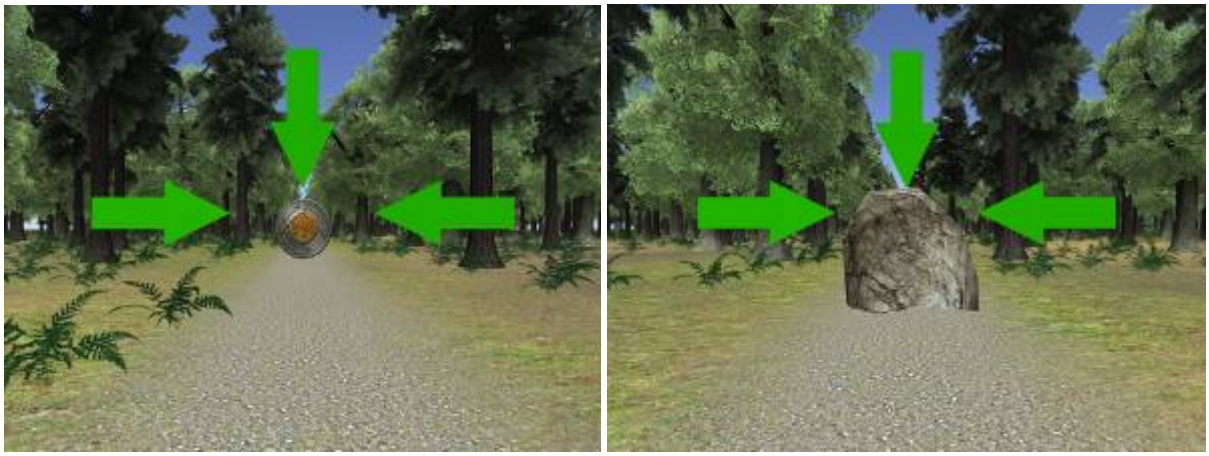

Figure 2 Collect-avoid scenario: subjects had to collect coins (left side) and avoid stones (right side) by increasing or reducing their physical activity, respectively. If they fulfilled the task their performance score increased.

2.3 Physiological measurements systems

In the downscaled lower extremity system uses for the clinical studies, the following psycho-physiological measurement sensors are implemented:

- Electrocardiogram (ECG)
- Galvanic skin response (GSR): g.GSRsensor (Guger Technologies, Graz, Austria)
- Skin temperature: g.TEMPsensor (Guger Technologies, Graz, Austria)
- Breathing frequency (BF): g.FLOWsensor (S.L.P. Inc., IL, USA)

Signals obtained from the sensors are amplified and converted to digital form using the g.USBamp biosignal amplifier (Guger Technologies, Graz, Austria). Additionally biomechanical signals from the Lokomat (joint torques and angles) are recorded to assess the activity from subjects walking in the Lokomat.

2.4 First results from open loop measurements

First clinical trials showed that the virtual environments worked well with healthy subjects as well as with subjects with both central and peripheral gait disorders due to neurological syndromes such as stroke, spinal cord injury, Guillain-Barré Syndrome and Critical Illness Polyneuropathy. Both groups were able to control the avatar in the virtual environment and could successfully perform the presented task. We found that the data from the physiological recordings were sufficient to identify the current level of task difficulty and to differentiate between the three presented conditions: task too difficult, task difficult and challenging, task too easy.
Based on these open loop measurements, a closed loop controller for task difficulty is being developed.

3 HapticMaster

3.1 Hardware modifications

As specified in Deliverable D4.1, the downscaled HapticMaster platform was transferred to IR-RS at the end of 2008. The first clinical study was performed in 2009 and described in Deliverable D4.2. Using the knowledge obtained during this study, a small number of modifications were made to the hardware. Most importantly, absolute position sensors were added to the HapticMaster since the original relative position sensors had noticeable drift and always required the HapticMaster to be started from the same position, which proved very inconvenient in clinical use. Additional safety features were also implemented so that the therapist or supervisor can more quickly stop the HapticMaster if any problems occur. A few minor ergonomic changes were made to the grasping device, and minor modifications were made to the existing control software.

The audiovisual and psychophysiological hardware were not modified from the downscaled platform described in D4.1. In the first clinical study, a two-dimensional display was found to be sufficient for patients. The heart rate, skin conductance, and temperature sensors provided useful data from patients. While the usefulness of the respiration sensor in the first clinical study is uncertain, useful psychophysiological data has been obtained from the respiration sensor in non-clinical HapticMaster studies (D4.2), so the respiration sensor will be used in further clinical studies.

3.2 Virtual scenarios

Three different multimodal virtual scenarios have been developed for the upper extremity systems.

3.2.1 Apple pick-and-place scenario

The first scenario is a simple pick-and-place task in which apples fall from a tree onto the ground (Figure 3). The subject needs to pick up the apples and place them into a crate. The task involves no time limitations; the subjects can proceed as quickly or as slowly as they desire.

The scenario offers all of the previously developed active haptic support options (reaching assistance, grasping assistance, haptic tunnels, and lifting assistance).

Figure 3 The apple pick-and-place scenario, with the apple (lower right) and basket (lower left).

3.2.2 Ball catching scenario

The second scenario is a more intensive task that adds a time constraint and a competitive element: a ball rolls down a slope, and the subject must catch it before it reaches the bottom (Figure 4). Once the subject grasps the ball, he or she must place it into a basket above the slope. Several task difficulty levels were implemented, with different speeds and sizes of the ball. The haptic and auditory feedback loop described in section 3.3 was also implemented, providing adaptive haptic feedback for the patient.

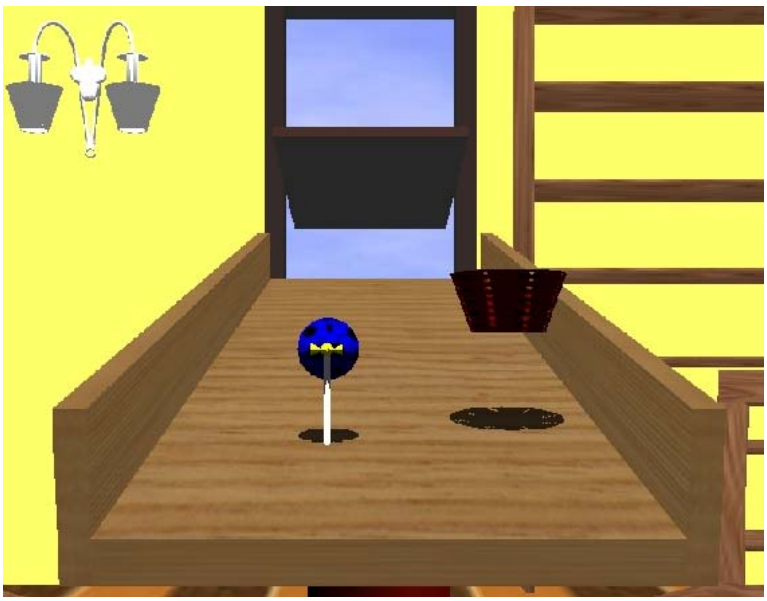

Figure 4 The ball-catching scenario, with the ball (centre, held by virtual end-effector) and basket (centre-right).

The scenario offers all of the previously developed active haptic support options (reaching assistance, grasping assistance, haptic tunnels, and lifting assistance).

Different haptic difficulty levels are possible:

- Table inclination reflecting in ball speed (slower balls are easier to catch).
- Ball size (larger balls are easier to catch).
- Ball weight (heavier balls require larger lifting force).

Alternatively, difficulty levels can be chosen by a **haptic and/or psychophysiological feedback loop**. For instance, if the user finds the task too demanding, the ball becomes slower, larger and lighter. This mode was used in reinforcement learning and other psychophysiological feedback tests.

The newly developed **haptic and auditory feedback loop** applying an adaptive force field support that is observing subject physical performance within the same trial and among various subsequent trials is available. Performance is also reflected in pre-recorded verbal encouragements and instructions. Description is in Section 3.3.

The users can choose among **different types of music** (rock, pop, folk music, classical, instrumental), depending on their **preferences** and **mood**.

The **environment sounds** are played for realistic environmental sense.

3.2.3 River scenario

Based on feedback received from patient trials with the above scenarios, a third scenario was developed, which is an advanced, augmented and better designed version of the Ball catching scenario.

Screenshot of the scenario is shown in Figure 5. More details about the scenario will be available in the forthcoming publications.

Figure 5 The river scenario, with the bottle (centre) and the circle-with-squares representing the user's current position (above and to the left of bottle). The two baskets wait on the far left and right for the user to pick up the bottle.

3.3 ARMEO platform

On December 1st, the ARMEO® (Hocoma AG, Volketwil, CH) was delivered to UL. It has been assembled and set up at the Faculty of Electrical Engineering, and the commercial ARMEO applications have been successfully tested. The river scenario developed by UL has been transferred to the ARMEO successfully and will be thoroughly tested at the Faculty of Electrical Engineering before the ARMEO platform is moved to the Institute for Rehabilitation in the beginning of 2010. A photo of a subject testing the river scenario with the ARMEO in early December 2009 is shown in Figure 6.

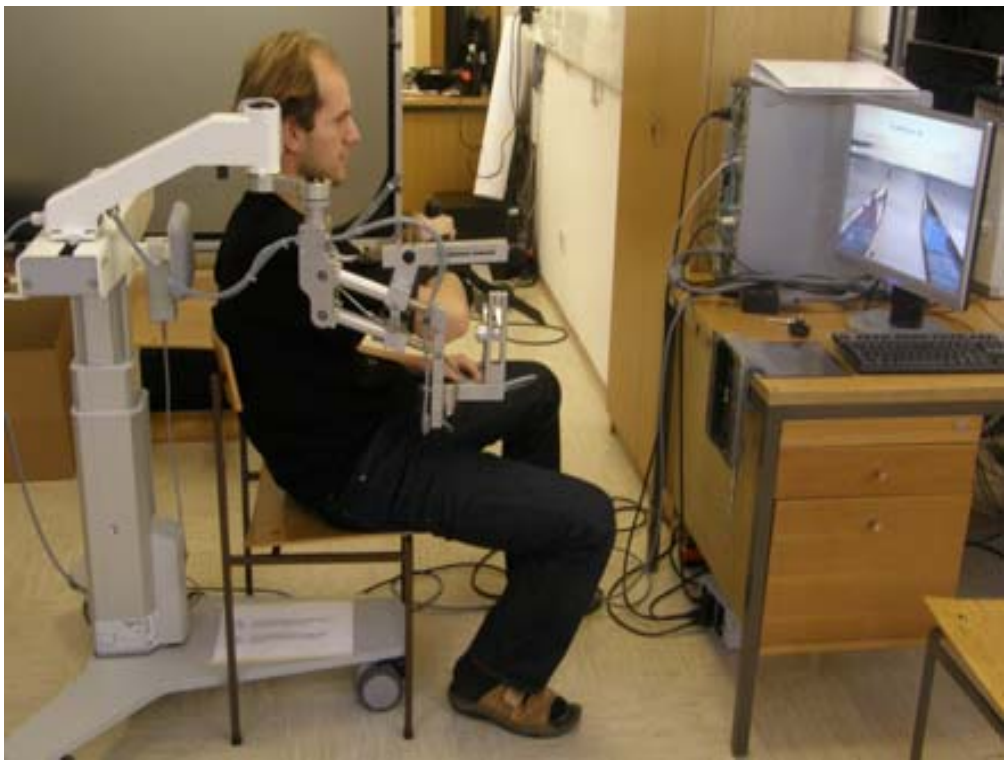

Figure 6 A subject testing the river scenario with the ARMEO at UL.

Since the ARMEO does not support active haptics, no haptic feedback can be provided. Apart from that all options in River scenario are available, same as in HapticMaster version.

3.4 ARMEO testing

A methodology has been jointly proposed by NKBA and UL for the ARMEO tests required by Task 4.3. A limited number of patients will perform the river task on both the HapticMaster and the ARMEO at IR-RS in Ljubljana. After these initial sessions, additional patients will perform the river task with the HapticMaster only (UL) and with the ARMEO only (NKBA). In addition to the stroke patients, both UL and NKBA will also perform the experiment with a group of healthy subjects, as these are more easily available and have less variation in cognitive/motor ability than patients. While the number of subjects needed to obtain reliable results is not certain in advance, an initial target of 10 patients on the ARMEO, 10 patients on the HapticMaster, and 10 healthy subjects has been set.

The goal of the tests will be to establish whether different machines with different haptic feedback (HapticMaster offers active force feedback while ARMEO only offers passive feedback) produce differences in performance, motivation and physiological responses. The methodology and patient group characteristics will be as closely matched as possible in order to avoid differences due to location and therapist/supervisor behavior.

4 Conclusion and Outlook

During the second reporting period, substantial progress towards clinically useable systems has been made both in the upper and lower extremity devices:

Several models of augmented feedback have been tested in the clinical environment on the Lokomat. Virtual environment 1 included calculations to simulate turning in the virtual environment. This was useable for patients with various symmetrical muscular disabilities, e.g. spinal cord lesions or polyradiculitis. However, patients with hemiplegia were usually unable to maintain (the adjustable) balance between both sides to control the avatar. Therefore virtual environment 2 was designed using only one-dimensional control by the patient to accelerate or decelerate the avatar by the patient's effort as measured by the force sensors. Preliminary observations show an increase in patient's motivation and endurance especially in young hemiplegic patients by this simpler model. The system for the second generation "Forest" scenario is implemented at NKBA and has already been used to measure patients.

For the HapticMaster, several scenarios with both haptic and auditory feedback loops have been implemented, using a simple pick-and-place task and a more diverse ball-catching task. Based on the clinical experience with these scenarios, the next generation "River" scenario was developed to maximize motivation and combine both physical and cognitive tasks with haptic, auditory (both spoken and ambient) and visual feedback. This scenario is already implemented for the HapticMaster at UL and has been transferred to the Armeo at UL. Both devices have been transferred to the IRRS by UL.

In conclusion, the consortium has succeeded in the timely implementation of advanced downscaled prototypes for clinical use both for upper and lower extremity rehabilitation. These prototypes have been delivered to the respective clinical partners. Testing methodologies and target variables for measuring the stipulated increase in motivation have been developed, and testing of subjects has begun.

We therefore deem the Deliverable fully achieved as envisioned by the Quality Assurance Plan as significant progress has been made in all subtasks targeted by this Deliverable and transfer to the clinical partners for experiments with patients has been initiated.