Algorithms about final versions of multimodal (haptic, visual, acoustic) scenarios and rendering

Deliverable D2.2

List of Partners:	ETH Zurich, CH	(ETH Zurich)
	Hocoma AG, Volketswil, CH	(HOCOMA)
	University of Ljubljana, SI	(UL)
	Universitat de Barcelona, ES	(UB)
	Neurological Clinic Bad Aibling, DE	(NKBA)

Document Identifier: MIMICS-D2.2-pu.pdf
Version: 6.0
Date: 2010-03-31
Organisation: UB
Deliverable: 2.2
Milestone: 2.2
Work Package: 2
Task: 2.1, 2.2, 2.3, 2.4
Dissemination: public

Authors: Iason Kastanis, Mel Slater, Alexander König, Lukas Zimmerli, Domen Novak, Jaka Ziherl, Andrej Olenšek, Matjaž Mihelj, Marko Munih

Approved by: Matjaž Mihelj, Robert Riener

Project Number: 215 756

Table of Contents

1 Summary

This is the D2.2 Deliverable of the MIMICS project, funded by the European Community's Seventh Framework Programme under Grant Agreement n° 215756. This report describes the latest developments of a multimodal immersive interactive display system. The multimodal system consists of three different rendering modalities, compromising haptic, visual and acoustic cues. Interaction and immersion are achieved by the modeling of engaging scenarios that will motivate the user of the system to perform the selected tasks. The report will present details on the finalization of the elements of the multimodal system.

2 Introduction

After the initial period of research in the area of multimodal scenarios and rendering, new algorithms have been developed for the purposes of the MIMICS project. With the experience gained from this investigation, the algorithms are bringing the project closer to the goal by providing appropriate scenarios and rendering tools.

3 Scenario modeling

3.1 Introduction to the goals of scenario modeling

Two types of scenarios were developed. The first category is modality specific scenarios for the upper extremity using the HapticMaster device and for the lower extremity using the Lokomat. In the second category scenarios that examine general aspects of the project, such as methods of enhancing the connection of the user with his virtual body representation, assistive navigation tasks, as well as the effect that facial expressions have on a user of the system.

3.2 Scenario modeling for the HapticMaster

Scenarios for the HapticMaster must **train reaching, grasping and lifting movement** while keeping the user as **motivated and engaged** as possible. To this end, three scenarios of increasing complexity were designed. All three can make use of the automatic learning systems developed in the WP3 work package.

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 1). 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.

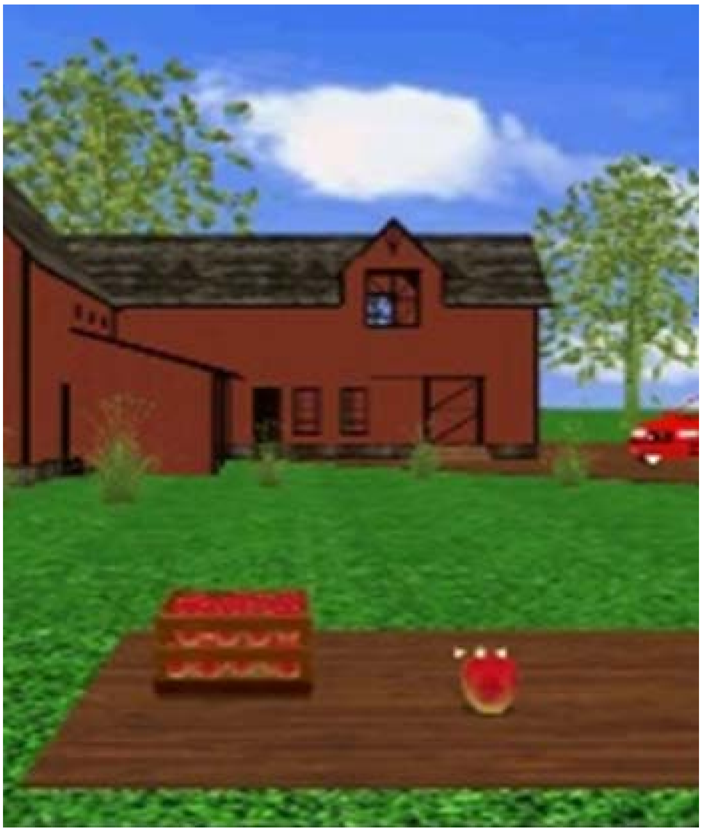

Figure 1 The apple pick-and-place scenario for the HapticMaster, with the apple (lower right) and basket (lower left).

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 2). 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, sizes and weights of the ball.

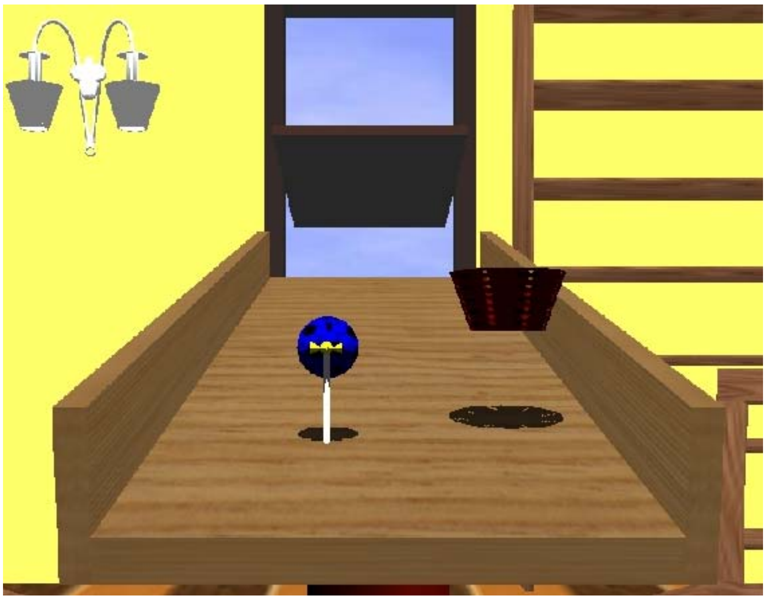

Figure 2 The ball-catching scenario, with the ball (centre, held by virtual end-effector) and basket (centre-right).

Users can choose among **different types of music** (rock, pop, folk music, classical, instrumental) depending on their **preferences** and **mood**. **Environmental sounds** are played for a more realistic experience.

3.2.3 River scenario: For internal dissemination only

3.3 Scenario modeling for the Lokomat

For the driven gait orthosis two multimodal (haptic, visual, acoustic) scenarios were developed and tested. In the following sections the two scenarios are described as well as issues regarding the patient group.

3.3.1 Separation of patient group

A problem of scenario modeling was that the whole patient population had a wide range of different cognitive abilities ranging from almost no impairment to severe cognitive deficits. While some patients have minor cognitive deficits, and are cognitively aware of the virtual scenario, others are severely impaired and might not be able to follow all aspects of the scenario. It would have been possible to selectively switch on additional elements in the virtual scenario such that an increase in difficulty level would be adapted to the patient.

The major problem was identified to be that of neglect. The majority of patients had a neglect syndrome on one side of their visual field, which required that all important action in the virtual environment had to take place in the mid-line of the screen. Patients without neglect could exploit the whole space of the display, allowing them to navigate through a virtual environment with left and right turns. In order to not limit cognitively unimpaired patients to a one dimensional line of action within the game, we decided to build two different scenarios as described below. Both scenarios could be adjusted in difficulty level to fit to the individual patient needs.

3.3.2 Scenario for patients: left and right walking, avoiding objects

If the patient i) does not suffer from neglect syndrome, ii) do not show a too asymmetric gait pattern, iii) are able to change walking direction, and iv) are able to understand the task, then we provide a pick and avoid scenario, where subjects have to navigate in two dimensions within the virtual environment (walking direction and left right. Control of the change in walking direction was performed by computing the difference in weighted force measurements of the left and the right leg. The algorithm was provided by Hocoma Inc.

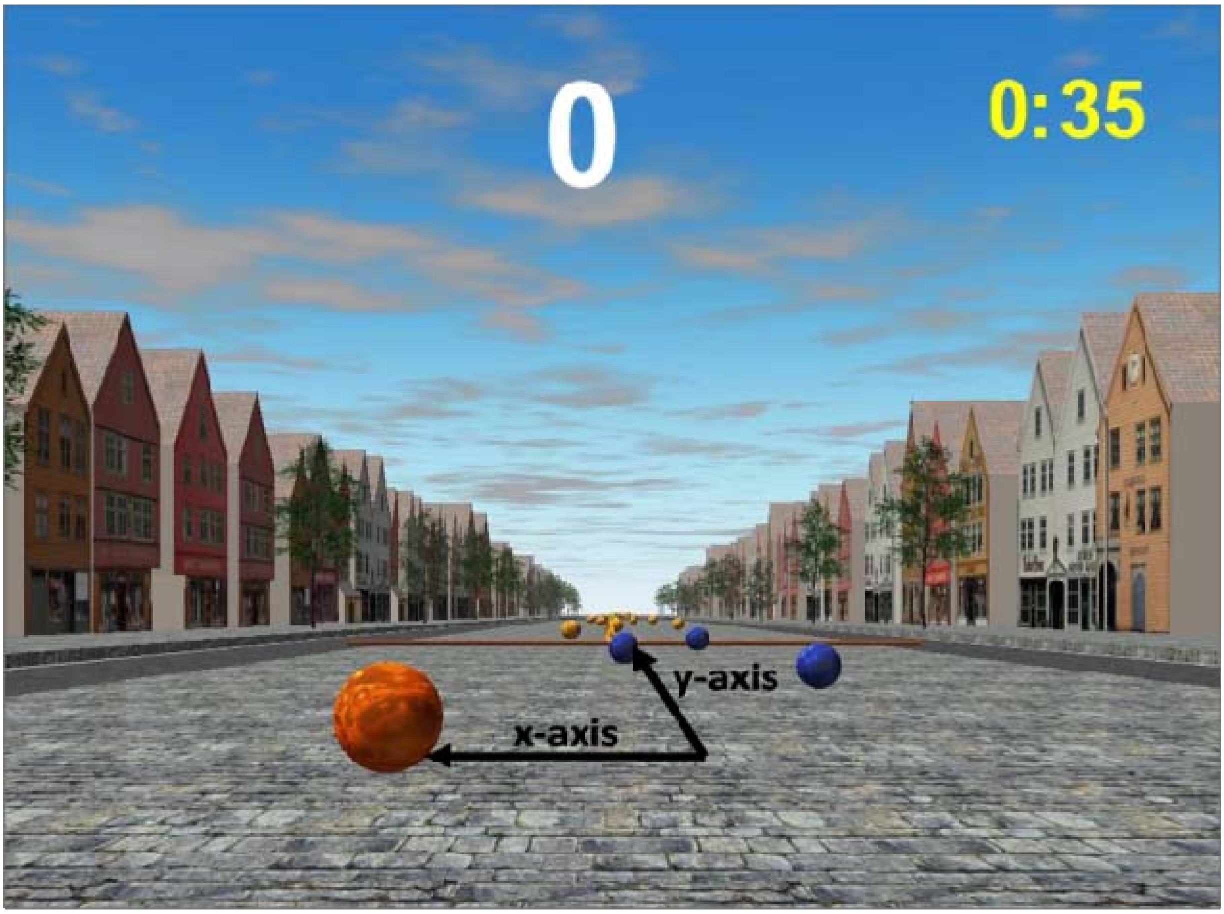

Figure 3 The virtual task for non-neglect patients with the x-axis representing the distance between the middle line and the items and the y-axis representing the distance between the items or the barrels. The x-and y-axis were adjustable to create different difficulty levels.

Adaptation of the difficulty level

The task included two distinct actions at the same time, one biomechanical task and a cognitive task. Subjects had to change walking direction in the virtual environment to collect items by walking into them (biomechanical task). To change the walking direction, subjects had to perform an active push-off in the terminal stance phase. To turn left, the subjects had to increase activity in the right leg during stance. As the required physical effort to change walking direction was set individually, the challenge was to navigate through the virtual environment and collect items. Furthermore, subjects had to jump over barrels which rolled toward them by clicking a computer mouse button (cognitive rather than physical task). Collected items added points to a counter, missed items and non-over jumped barrels subtracted points. To create different task difficulty levels the distance between items were adjustable. Furthermore, the distance between the barrels and their speed was adjustable.

As physical effort influences the psycho-physiological recordings, the VR task was chosen as a combination of coordination (change walking direction) and cognition (jump over the barrels). This allowed creating subject specific task difficulty levels while keeping the physical effort to successfully solve the task as low as possible.

3.3.3 Scenario for more severe patients: all action on the main axis, collect and avoid task

For patients that had a neglect syndrome and/or those that are physically not able to turn or to provide a symmetrical gait pattern, the task feature of changing walking direction was omitted. We programmed a collect and avoid scenario where subjects have only one degree of freedom on the virtual environment, Figure 4. All actions took place in the main axis and changes in walking direction were not possible. Instead, the patient was able to influence his/her walking speed by increased or decreased active participation. Some objects (coins) had to be collected while others had to be avoided. The next available object disappeared after a couple of seconds and could be collected (coins) by approaching it at increased walking speed. It could also be avoided (stones) by decreasing walking speed such that the object would have disappeared before the patient would reach it. To support the impaired visual capabilities of the subjects, the next object on the walking path was marked with blinking arrows.

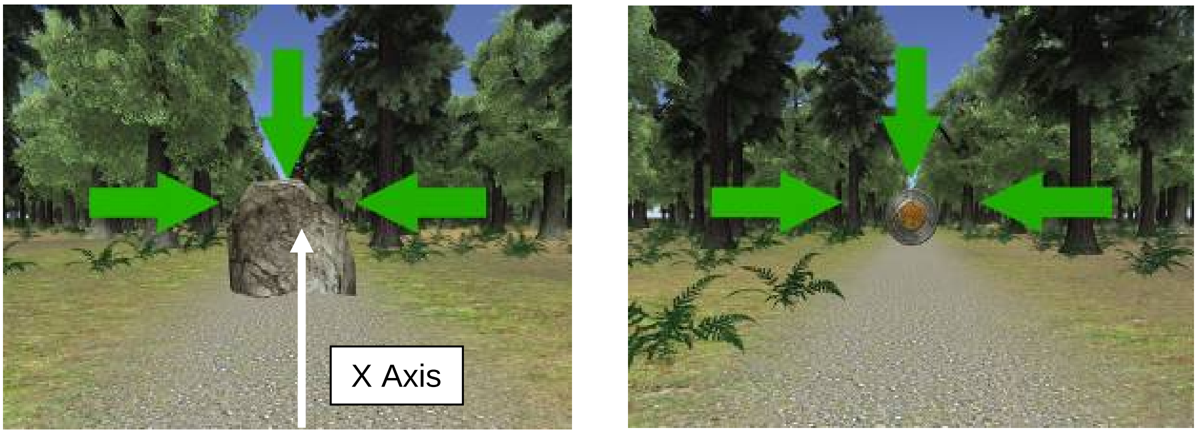

Figure 4 The improved virtual task applied to patients with more severe lesions. All movements happen on the main axis (x axis). Stones (left) have to be avoided, while coins (right) have to be collected. The green arrows indicate objects of interest for better recognition of severely affected subjects.

Adaptation of the difficulty level was possible by changing the distribution of coins and stones, by placing the objects further apart and by decreasing the time until the object would disappear.

3.3.4 Rational how both scenario could be controlled

Control of the walking speed could have been possible with joysticks, voice commands or a joypad. We do not want to decouple the control of the game from the motor control functions that need to be trained (leg force, quality of gait, foot clearance etc). We therefore used Biofeedback [Lunenburger et al 2004] (i.e. more or less active participation) to turn left and right (scenario for non-neglect patients) or to accelerate and decelerate (scenario for neglect patients).

3.4 General purpose scenario modeling

Scenarios have been modelled to validate aspects common to both the HapticMaster and Lokomat systems. These scenarios will examine the interaction of the user with virtual characters. The aim is to build characters that will engage and encourage the user to perform the tasks of a given scenario. In particular, the presented scenarios will examine the extent to which a human user responds to the interaction with an avatar. The first scenario is the starting point for the creation of intelligent avatars that interact with the user according to his/her responses. The second scenario’s scope is to examine the effects of using a physical connection between avatars as well as multisensory correlations that can potentially increase the immersion to the environment particularly for the egocentric viewpoint. The third scenario investigates the physiological effects of facial expressions of a virtual character on a human user.

3.4.1 Scenario 1: Reinforcement learning generates human behavior

One of the goals of MIMICS is to encourage participants to carry out actions that are beneficial to their rehabilitation. For example, ‘walking’ a certain distance. The goal of this research is to assess whether reinforcement learning can be used to create a situation where a virtual character is able to affect the behaviour of participants in this way. In other words the virtual character learns which of its behaviours result in the desired behaviour of the participant. The behavior to be generated in the participant was based on the concept of proxemics. [Hall 1966]. Proxemics deals with the issues of interpersonal distances. Taking advantage of this theory, the goal was to get the participant to move 30 meters backwards. This was achieved indirectly by using RL to control the actions (Figure 5) of a virtual character. This work has been submitted for publication [Kastanis and Slater 2009].

Figure 5 The scenario is an alleyway that contains a avatar seen from the participant's viewpoint: a) the character is quite far away, b) he has walked closer c) calls to the participant to 'come here!' while waving, d) has approached closer, e) is within personal distance, f) is within intimate distance.

Apart from the proof of concept aspect of this experiment, this methodology can be used in assistive navigation tasks. In a planned experiment we are expanding this methodology to navigate a human with the use of an RL controlled avatar within a city environment already developed at UB.

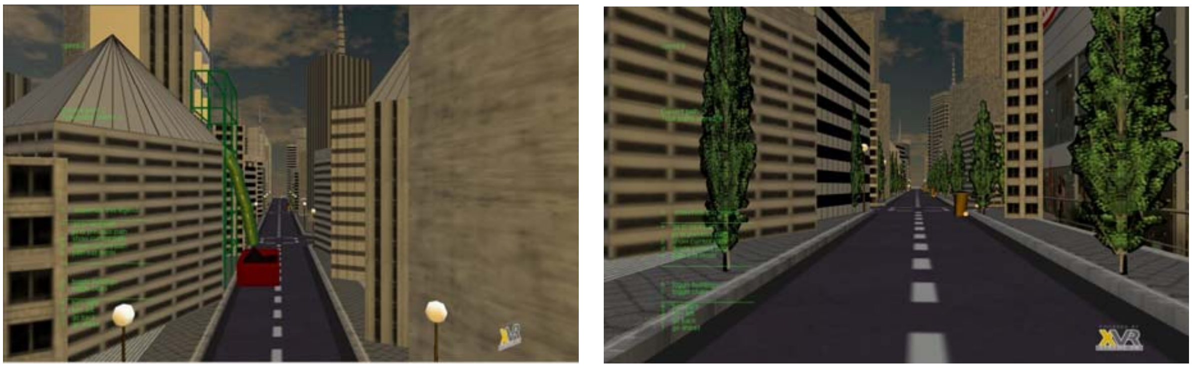

Figure 6 City environment.

3.4.2 Scenario 2: Connection to an avatar

If the participant in a MIMICS scenario is to be represented by a virtual character, an avatar, then our hypothesis is that the more the person identifies with this avatar, the greater the chance that rehabilitation would be successful. For this we draw on the new field of research in cognitive neuroscience concerned with body ownership illusions, based on the rubber hand illusion and other similar paradigms [Botvinick and Cohen 1998], [Ehrsson 2007], [Lenggenhager et al 2007] and their recent exploitation in virtual reality [Slater et al 2009], [Slater et al 2010], [González-Franco et al 2010]. In MIMICS the patient, ultimately will not be wearing a head-mounted display, and therefore their avatar will be displayed on a screen. Using a paradigm similar to [Lenggenhager et al 2007] it is our hypothesis that there will be a stronger identification with the avatar when there is a chord connecting the person to their virtual representation (since we have been unable to reproduce the illusion reported in [Lenggenhager et al 2007] within virtual reality). We have, therefore, designed an experiment with the following components:

What does the user see? Scenario

The subject is placed in a room where they can see their own virtual body, another body in front of them, and a cord connecting both bodies. Both avatars are dressed in the same way. The cord connects the belly of the avatar representing the real subject and the back of the second avatar, Figure 8.

Intent of the experiment

This is an out-of-body experience experiment. The purpose of the cord is just to help the subjects feel as if they somehow were the person they are seeing in front of them. The tapping process is initially aimed to amplify the virtual connection the represented by the chord and finally to help subjects think that the body in front of them could somehow be their own body. Patients in the MIMICS project will not be using an HMD. It is though essential for them to see a virtual body. The question of interest in this experiment is how to maximise the chance that the person will identify with that virtual body. The hypothesis being that people relate more to what happens with that virtual body if they have a sense of ‘ownership’ over it. In this experiment we are expanding on previous work to see if adding the chord between the real and virtual body will enhance the connection.

Haptics

This project uses haptic technology in two different ways. The subject's breathing is used to animate the chord radius at the same pace. Also the subject receives some vibrations depending on his or her actions in the virtual world by means of a vest with an array of vibrators attached to its inner part.

What can the participant do?

The subject is wearing a Head Mounted Display (HMD) with a tracker attached. They can freely move the upper part of their body and arms. In the virtual world these motions are rendered by an inverse kinematics model and displayed in both avatars in sync.

What will the subject experience?

The subject initially looks around to get used to the new environment. After a few minutes a small ball starts a tapping sequence. The tapping is fully automated. The subject feels a small vibration from the haptic vest every time the virtual ball touches his or her virtual body.

Figure 7 What the subject will see

The tapping starts on the subject's chest. The subject sees the tapping going down the belly and then moving along the cord to reach the avatar's back. The haptic feedback corresponding to the virtual tapping stays on the subject's belly until the virtual tapping moves up the back of the second avatar. Then, the haptic vest provides feedback on the subject's back.

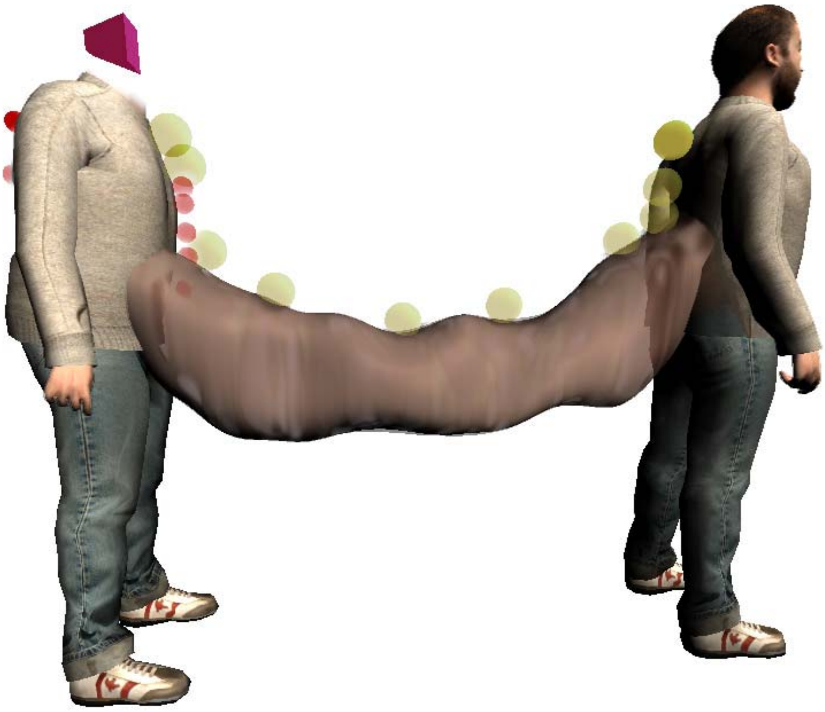

Figure 8 The tapping sequence on the virtual chord.

The tapping runs for about 8 to 10 minutes. When tapping the back of the avatar, being this the last stage of the tapping process, the ground surrounding the avatar in front falls down leaving the avatar standing on a small area by the large vertical drop.

Figure 9 View of the environment

A few seconds later, the second avatar loses his balance for 1 or 2 seconds, recovering it later without falling down.

The experiment runs in two different conditions. One condition shows the cord connecting both bodies. The other condition shows no connection at all. Each one of those conditions is run with synchronous and asynchronous tapping. The no cord and asynchronous conditions are used as control conditions.

What do we measure?

We are measuring the subject's reaction when the avatar loses balance. Our baseline is the same experiment with no cord connecting both virtual bodies.

We use questionnaires to get subjective feedback. Also we measure GSR to get an objective feedback from the experiences.

In the above experiment we only use visual-tactile synchrony to induce the body ownership illusion. However, we have also now completed an experiment where instead we used visual-motor synchrony. In this experiment the subject saw a virtual reflection in a virtual mirror and the upper body moved in synchrony with their real movements or asynchronously. In this experiment we used a novel measurement method, in addition to a questionnaire. In the virtual room a fan descended from the ceiling. We observed whether participants tended to avoid collision with the fan or not. We found that in the synchronous condition there was a significantly greater attempt to avoid collision with the fan that was seen descending in the mirror compared to the asynchronous condition. Additionally the questionnaire responses supported the notion that there was significantly greater body ownership over the mirror reflected body in the synchronous condition. This experiment was reported in [González-Franco et al 2010].

In the above experiment we only use visual-tactile synchrony to induce the body ownership illusion. However, we have also now completed an experiment where instead we used visual-motor synchrony. In this experiment () the subject saw a virtual reflection in a virtual mirror and the upper body moved in synchrony with their real movements or asynchronously. In this experiment we used a novel measurement method, in addition to a questionnaire. In the virtual room a fan descended from the ceiling. We observed whether participants tended to avoid collision with the fan or not. We found that in the synchronous condition there was a significantly greater attempt to avoid collision with the fan that was seen descending in the mirror compared to the asynchronous condition. Additionally the questionnaire responses supported the notion that there was significantly greater body ownership over the mirror reflected body in the synchronous condition. This experiment was reported in [González-Franco et al 2010].

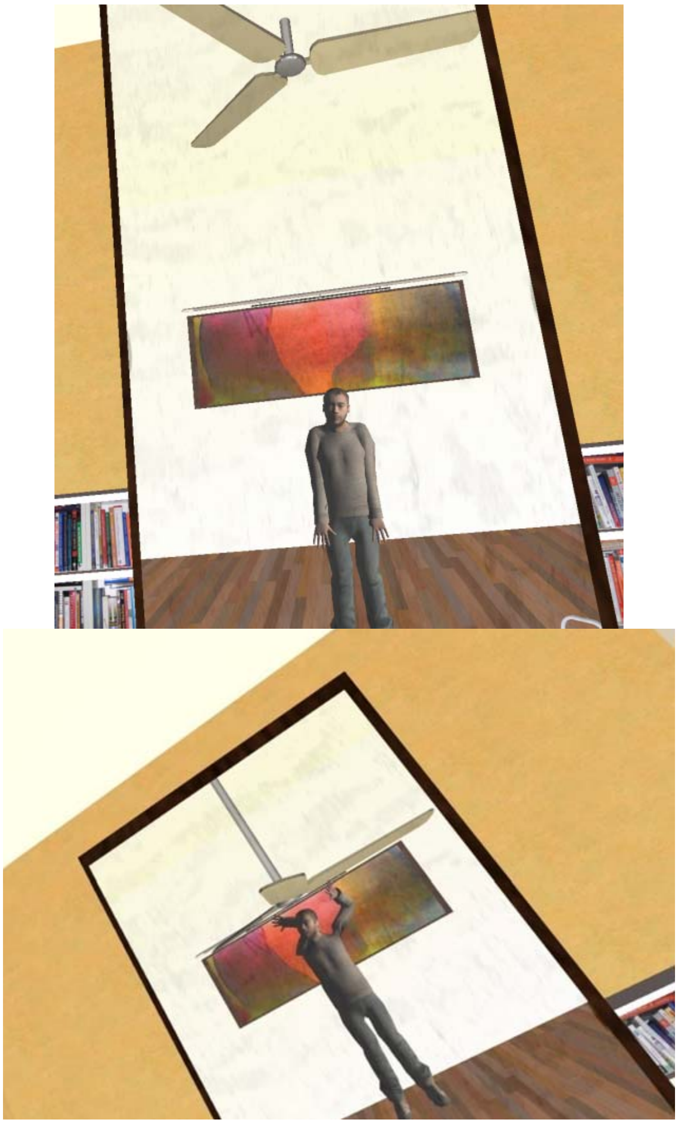

Figure 10 Virtual reflections in a virtual mirror

3.4.3 Scenario 3: Facial expressions in virtual characters

In this experiment we investigate the effect of facial expressions of an avatar on the physiology of the user in the same environment.

Avatars are sitting in a train compartment waiting in the station. The participant is one of the passengers in that train compartment.

Figure 11 Virtual characters in a train compartment.

The aim of this experiment is to test if the human participant has an emotional response to an avatar performing a variety of facial expressions. Facial expressions of avatars are a powerful stimuli to generate physiological responses in a user of the system. We expect the responses of the participant to be different considering the various facial expressions the avatar in front makes. The final goal is to realize a 'closed loop' system, where events in the VE have an affect on the participant, who then responds in some way. This we measure and then affect the displays. Initially we want to gather data and understand the impact of the facial expression on the physiology of the participant (ECG, GSR and respiration) before proceeding to combine it with the machine learning approach to 'close the loop'.

Figure 12 Person in the right will be the one making the different facial expressions.

Apart from that, we record the physiological data of the participant to check if the emotional state of the participant can be reflected on them. We try to find the correlation between the facial expressions of the avatar and the participant's emotional state through this physiological data. The main goal of this experiment is to test if we can find this correlation and understand the emotional state of the subject through the physiological data obtained. Further experiments would try to test if we can induce feelings in the participant through avatars; in other words, we'll try to use the information obtained in the present experiment to make the person achieve a certain emotional state through the right stimuli.

Figure 13 Expressions of the avatar

This is the first step in an application that would use reinforcement learning to manipulate the emotional state of participants depending on the facial expressions of the virtual characters. The goal within MIMICS is to be able to help determine the affective state of participants, to make sure for example, that they are not becoming too stressed in carrying out their tasks.

4 Robotic control and haptic rendering

4.1 Introduction to the goals of robotic control and haptic rendering

Haptic rendering is defined as the process of computing and generating forces in response to user interactions with virtual objects. The process consists of two main steps: collision detection and contact force computation. These forces are fed back to the patient for various reasons. First of all, the haptic sense can increase the degree of realism of the virtual environment. An object can hardly appear real if it cannot be touched. Secondly, haptic force feedback can guide the patient on a given trajectory by bounding the workspace of the robot to desired areas and thereby give the patient a clue on desired behavior.

4.2 Robotic control and haptic rendering for the HapticMaster

Previously, extensive work was done in order to implement the following **robotic control functions** for the HapticMaster:

- interface between xPC Target and Simulink
- computation of the robot's direct and inverse kinematics
- computation of the Jacobian matrix
- PD controllers for robotic control in both joint and world space
- admittance controllers for haptic rendering

Simulink blocks were implemented for several **basic virtual objects**:

- a sphere
- a cube
- a cylinder
- a wall
- collisions between the aforementioned objects

Each of these objects has various definable properties (position, orientation, size, mass, stiffness etc.). **Haptic rendering for complex virtual scenarios can be performed quickly and efficiently by using these basic objects as building blocks.** Thus, all three HapticMaster scenarios were created using the aforementioned functions and objects. Additionally, these functions are used in the haptic support systems and automated learning systems developed in the WP3 work package. Further details regarding these functions are available in the D2.1 Deliverable.

This haptic framework was also transferred to the **ARMEO platform**. An S-function that reads the ARMEO's joint angles from a PCI-DAS card was written in Simulink. Then, the kinematic model of the arm was created and the lengths of the ARMEO's segments as well as the ranges of the different joints were measured. The Simulink file for the scenario was modified so that the external coordinates of the ARMEO are used as input instead of the external coordinates of the HapticMaster. To obtain these external coordinates, signals from the ARMEO's joint sensors are read and converted into external coordinates in a global (x,y,z) system using the following direct kinematics equations:

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_6 \\ q_7 \end{bmatrix} = \begin{bmatrix} 35.4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 35.4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -35.4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 35.4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -35.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 35.4 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \end{bmatrix}$$

$$l_1 = 0.105 \text{ m};$$

$$l_2 = 0.220\ldots0.300 \text{ m};$$

$$l_3 = 0.230\ldots0.360 \text{ m};$$

$$p_{left} = \begin{bmatrix} x_{left} \\ y_{left} \\ z_{left} \end{bmatrix} = \begin{bmatrix} -l_1 \sin(q_1) - l_2 \cos(q_3)\sin(q_1 + q_2) - l_3 \cos(q_5)\sin(q_1 + q_2 - q_4) \\ -l_1 \cos(q_1) - l_2 \cos(q_3)\cos(q_1 + q_2) - l_3 \cos(q_5)\cos(q_1 + q_2 - q_4) \\ l_2 \sin(q_3) + l_3 \sin(q_5) \end{bmatrix}$$

$$p_{right} = \begin{bmatrix} x_{right} \\ y_{right} \\ z_{right} \end{bmatrix} = \begin{bmatrix} -l_1 \sin(q_1) - l_2 \cos(q_3)\sin(q_1 + q_2) - l_3 \cos(q_5)\sin(q_1 + q_2 - q_4) \\ -l_1 \cos(q_1) - l_2 \cos(q_3)\cos(q_1 + q_2) - l_3 \cos(q_5)\cos(q_1 + q_2 - q_4) \\ l_2 \sin(q_3) - l_3 \sin(q_5) \end{bmatrix}$$

$$k_{grip} = 100 \cdot (q_6 - 0.5)$$

$$\varphi_{wrist} = q_7$$

where u_i represent the outputs of the PCI-DAS measurement card, q_i represent the joint angles, l_i represent the lengths of the ARMEO's segments, p_{left} represents the external coordinates of the end-effector in rehabilitation of the left arm, p_{right} represents the external coordinates of the end-effector in rehabilitation of the right arm, k_{grip} represents the strength with which the user is grasping the end-effector, and φ_{wrist} represents the angle of the user's wrist.

Separate algorithms were written for the ARMEO configuration for rehabilitation of the left arm and for the ARMEO configuration for rehabilitation of the right arm. Since the ARMEO does not support active haptics, no haptic feedback can be provided. Apart from that, the three virtual scenarios developed for the HapticMaster function identically on the ARMEO. As an example, Figure 14 shows the Simulink block diagram for the river scenario on the ARMEO. The joint angle measurement and direct kinematics blocks can be found in the central left part of the diagram.

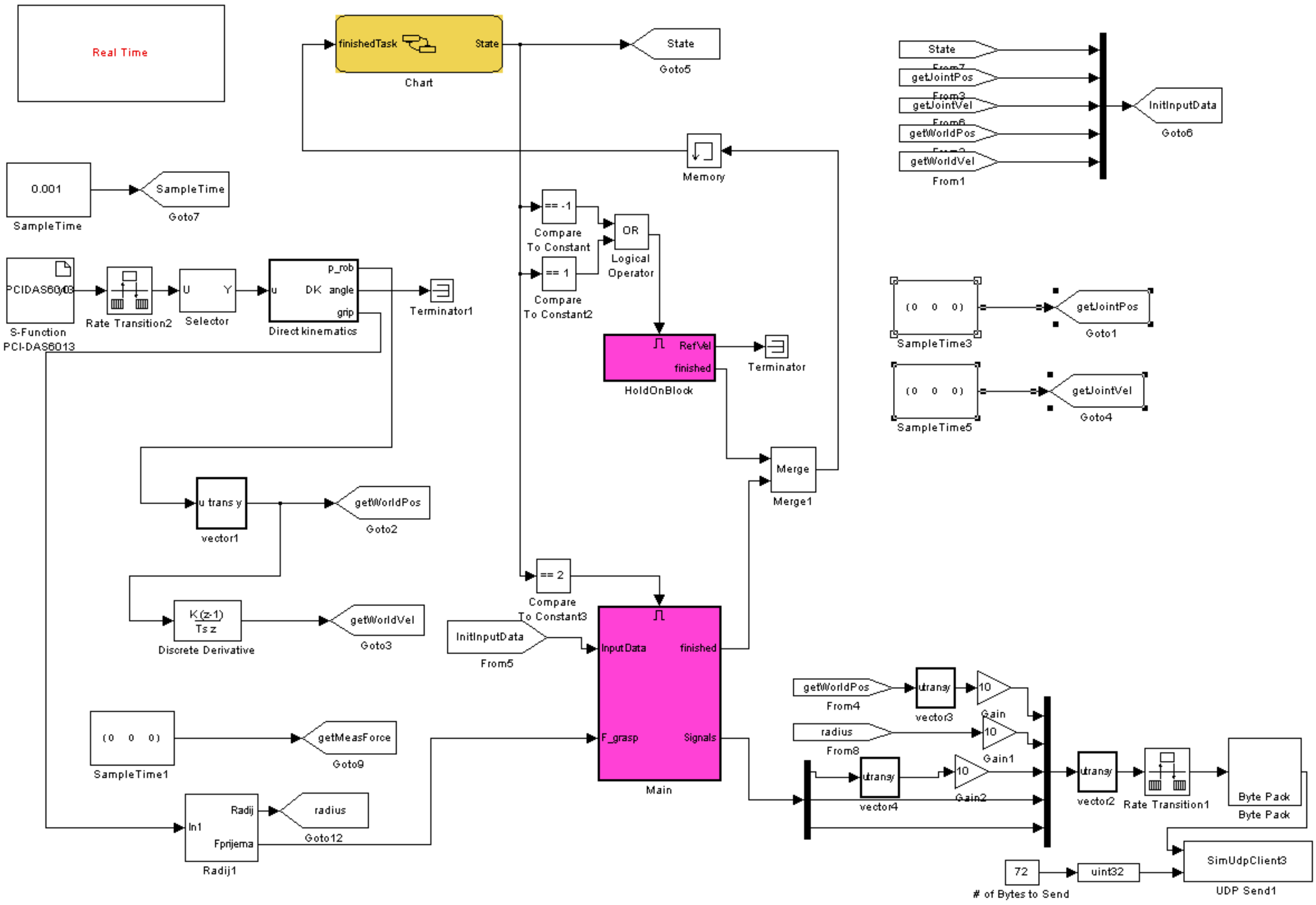

Figure 14 Simulink block diagram for the river scenario.

4.3 Robotic control and haptic rendering for the Lokomat

4.3.1 Robotic Control

We used the standard software of the Lokomat provided by Hocoma Inc. As the highest priority is the safety of the patient, we could rely on the safety features of the standard software.

We extended the standard Hocoma LocoControl Software 5.02 such that we were able to control the virtual environment with it. We left the robotic controller un-altered.

4.3.2 Haptic rendering

Extending the existing impedance control, we also implemented admittance control to be able to display soft objects (impedance) as well as rigid objects (admittance). Details of the implementation are described in the D2.1 Deliverable. We implemented haptic interactions with a soccer ball via impedance control and evaluated the implementation of a hapitc framework that allowed display of poly-edged objects. Despite the possible technical solutions, we decided to not use additional haptics in the final scenario.

Contact with haptic objects during walking could have compromised patient safety and make the patient stumble and fall. We rated the additional benefits of haptic feedback in terms of immersion lower than the positive patient experience of feeling safe.

5 Visual rendering

5.1 Tools for visual renderings

5.1.1 OGRE

OGRE[1] (Object-Oriented Graphics Rendering Engine) is an **object-oriented graphics rendering engine**. It is a flexible 3D object-oriented C++ class library intended for simple hardware-related 3D applications. Even though the tool is merely a rendering engine, the open source and object oriented scheme enables simple plug-in inclusion and therefore considerable modularity. More information about OGRE is available in the D2.1 Deliverable. At UL, Ogre was used for the first two scenarios (apple task chapter 3.2.1, ball catching task chapter 3.2.2), at ETH, Ogre was used for the virtual scenario which included walking left and right (chapter 3.3.2).

5.1.2 Unity

Unity[2] is an integrated authoring tool for creating 3D video games or other interactive content. It makes use of Direct3D (Windows), OpenGL (Mac, Windows) and proprietary APIs (Wii) graphics engines. It provides a very user-friendly game development environment and offers features such as:

- Mono-based game scripting (the open source implementation of the .NET framework)
- hierarchical, visual editing
- detailed property inspectors
- live game preview

While OGRE is a C++-class library that should be integrated with other libraries to allow audio rendering, physics, networking and collisions, Unity's sophisticated framework already incorporates the Ageia PhysX™ Physics Engine, FMOD library-based audio system to play back Ogg-Vorbis compressed audio files and real-time networked multiplayer functionality. Thus, **Unity is much more user-friendly, allowing complex virtual scenarios to be created more quickly than with OGRE**.

Unity also allows users to deploy their application as a Microsoft Windows executable, Mac OS X executable, on the web, as a Wii application and in many other forms. Although many popular 3D modeling applications are supported by Unity, it is most thoroughly integrated with 3ds Max, Maya, Blender, Cinema 4D and Cheetah3D. At UL, Unity was used for the third scenario (river task chapter 3.2.3), at ETH, Unity was used for the virtual scenario for severely affected patients (chapter3.3.3).

---

[1] http://www.ogre3d.org/

[2] http://unity3d.com/

5.1.3 XVR

XVR[3] is a complete system for the development of VR-oriented applications. It consists of a state-of-the-art graphics engine, a scripting language, an integrated development studio and an ActiveX module which can be embedded to various container applications such as web browsers. It offers support for a wide range of VR devices (trackers, motion capture devices and stereo display systems), multimedia including 3D audio and network communications. XVR can be extended using its own scripting language as well as external dynamic link libraries (DLL). While the scripting language offers high-level functionality, OpenGL functions can be used within the script for low-level control. The user of XVR can develop applications on a desktop computer, and with minimum effort transfer them into a full VR system. For more information about XVR refer to [Carrozzino et al 2005]. XVR was used by UB in all scenario rendering.

5.1.4 Hardware Accelerated Library for Character Animation (HALCA)

A library for character animation has been developed to provide an interface to the Cal3D library. It also extends it with GLSL shader support and other additions to the original Cal3D animations system such as morph animations. The library offers support for loading complete character models including textures, skeleton systems and animations. Utilities for motion capture, keyframe animation enable the user to blend and loop different animation sequences. A simple inverse kinematics allows the virtual characters to perform shoulder and elbow rotations. This feature can be used to achieve realistic looking arm movements based on information read from a tracker device. Further to that, GLSL shaders can be used for very efficient skin deformations. Recently features have been added for facial expressions using morph targets, as well bounding cylinders for collision detection. The library has been integrated with crowd simulator. It supports x64 machines, as well as exports from 3DS Max 2009. HALCA is under constant development.

The library has been developed as dynamic link library and it can be embedded to both XVR and OGRE frameworks. Documentation, tutorials and further information are available on the internet[4] and an example application using the character library can be found in [Mortensen et al 2008]. HALCA was used by UB.

5.1.5 Inverse kinematic system

An inverse kinematic (IK) system has been implemented in XVR to work in conjunction with HALCA. The system can be used to perform motions for both the upper and lower limbs, as well as bending the upper body. It overcomes the problems of the OpenGL and non-openGL exported avatars, as well as combining IK for these skeleton parts. The IK system is based on existing work in HALCA using quaternions to describe the rotations. It solves for both out of reach and within reach targets for the limbs. Further to that, the simple solution offered by this IK system is sufficient for most applications.

---

[3] http://www.vrmedia.it/

[4] http://www.lsi.upc.edu/~bspanlang/animation/avatarslib/doc/

5.1.6 Animation blending system

Current status

At present the animation system we use in VR projects can be divided into two groups.

On one side, we can animate avatars by loading precomputed animations. Those animations can be obtained from motion capture data or from an animation package. The HALCA animation mixer and sequencer allow to cycle animations and blend them. It is also possible to cross-fade animations to get smooth transitions and play them on avatars with a specific weight. It is also possible to play animations as morphs to gain control over the animation playback.

On the other side, several IK modules have been developed to add more interactivity to our avatars. These modules are tightly integrated with our tracking systems and allow us to make avatars react to external events in the VR scene. The IK modules currently available are:

- IK for both arms. This IK solver finds appropriate joints rotation values for arms trying to reach a target
- IK for the spine. This solver finds joints rotation values for the spine trying to reach the position of the head
- IK with spring system for head and spine. This IK solver computes rotations for spine joints and head to follow a distant target. This class features independent control over the IK for the head and the spine, just like real humans. The spring system implements user-customizable angle-based constraints. This way the IK solver only computes human-like postures
- IK for both legs. The IK solver computes a solution for each leg when trying to reach a target with the feet

New developments

The animation libraries in HALCA are being extended to provide more flexibility to combine animations (Figure 15).

One of the new modules will provide functionality to blend animations only on some specific parts of the avatars without affecting the other parts. For instance, this is necessary when blending full body animations (e.g. walking) with other animations that only affect the movement of one limb (e.g. waving).

The morphs blending module will allow users to combine and transition between morph animations.

The blending module will be extended to support asynchronous blending between animations. That is necessary to have independent timelines for the animations we want to blend.

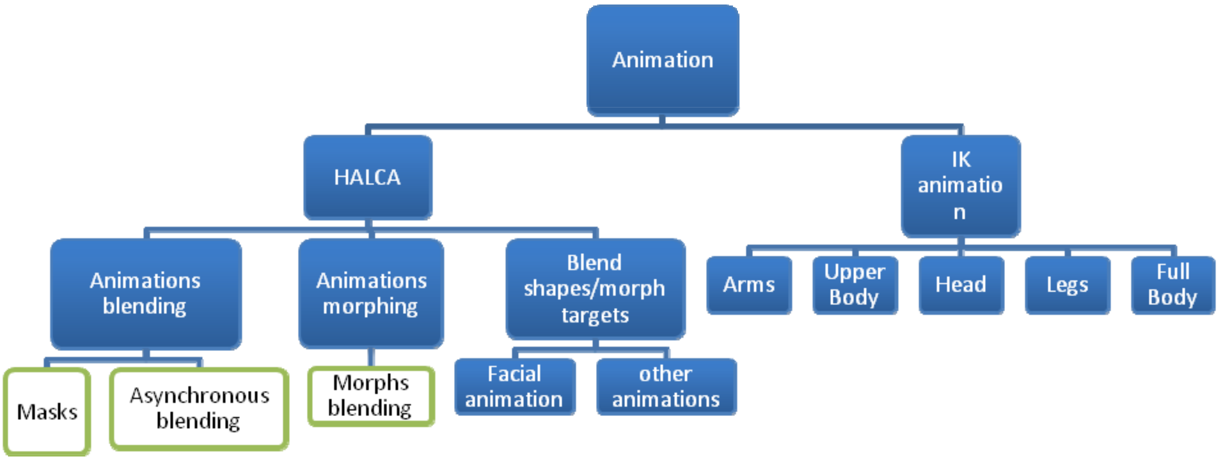

Figure 15 Animation system diagram.

5.1.7 Facial expressions of virtual characters

Apart from the developed facial expressions on a virtual character as presented in section 3.4.3 and the support from the HALCA library. At the UB laboratory there is also a facial expression capture system in place, currently incorporated with the rest of the equipment. The Naturalpoint Face Motion Capture system[5] consists of 6 OptiTrack FLEX:V100R2 cameras. The cameras have been calibrated, but issues related to the detection of the marker and the background viewed by the cameras are currently being solved. This motion capture system will give the ability to capture real facial animations with high complexity such as a person talking and the same time performing facial expressions. This type of animation presents a high level of difficulty and requires a large amount of time and effort to be dedicated by an experienced modeler. Thus, new scenarios will be enriched by these highly realistic facial animations with a minimal amount of resources spent in creating them.

5.1.8 City navigation tools

A city environment has been developed (Figure 6). The city includes various streets as well as points of interest. Various methods for navigating within the city have also been implemented. For the purpose of this, a large scale collision detection algorithm has been devised to test collisions with buildings. The collision algorithm can be used independently of this particular city model. Using these tools, a user can navigate within the city in a realistic manner with the system responding correctly if the user tries to go through a building.

5.2 Visual rendering for the HapticMaster and Lokomat

For the Lokomat two different kinds of scenarios were created. The first scenario used the open source 3D visualization engine Ogre3D. In order to create the second scenario more rapidly, allow faster modifications and increase the graphical authenticity, the 3D game engine Unity3D was employed. Unity3D allows faster

---

[5] http://www.naturalpoint.com/optitrack/products/motion-capture/face-mocap.html

prototyping and deployment compared to Ogre. Apart from the avatars and animals, all elements used in the scenario mainly come together with the engine.

5.3 General purpose visual rendering

The general purpose scenarios have been developed using XVR and the character library described in sections 5.1.3 and 5.1.4 respectively. The scenarios will be run in a Head Mounted Display system. Elements of the environment were exported from Google Warehouse and the characters used were hand-rigged characters from the AXYZ-Design company[6] that are represented by about 5K-10K polygons. The same scenarios can be used with other types of display, such as large screen stereo displays.

6 Auditory rendering

6.1 Introduction to the goals of auditory rendering

The auditory rendering is an important factor to optimize the patient's sense of presence during the rehabilitation training. There are empirical results suggesting that the perceived quality of the visual display can be improved when presented in conjunction with sound. Since hearing is a passive process, we can easily listen while being occupied with other tasks.

Different sound samples will be used to simulated sound as generated from walking steps, music, speech or non-human generated sounds.

6.2 Auditory rendering for the HapticMaster

Since this section contains confidential intellectual property, it has been removed from the public version of the deliverable.

6.3 Auditory rendering for the Lokomat

Cognitive and emotional processes have a strong capability to stimulate emotions like fear and pleasure. Wood et al. [Wood et al 2004] investigated, which characteristics induce a desired for gaming in the first place or are key factors for continuing gaming irrespective of the individual's psychological, physiological or socio-economic status.

Participants took part in an online study answering questions about the importance of sound, graphics, game duration, game dynamics, winning and losing features. Respondents were asked to rate how important they thought each of the features was for their enjoyment of video games. Results showed that realistic sound effects were deemed to be the most important feature by almost two-thirds of participants, whereas speaking characters, background music and narration were seen as less important. Although Wood et al. didn't use any physiological measures and therefore

---

[6] http://www.axyz-design.com/

didn’t assess players’ emotions during gaming. Their study is amongst the first to identify user preferences and their expectations towards successful game development.

In addition to these characteristics, Bradley et al. conducted a study using a set of acoustic stimuli that vary in valence and arousal in order to engage a broad range of emotional responses [Bradley et al. 2000]. Recording physiological signals, subjects were instructed to rate how they felt when listening to each of the sounds. The study showed how different sound effects could be used in video games to rapidly trigger emotional responses. Sound files are accessible for research through the International Affective Digitized Sounds Library (IADS).

6.3.1 Auditory feedback during Lokomat training

Compared to the usage of sound as a method to elicit emotional responses, a study by Wellner et al. [Wellner et al 2008], looked at the effectiveness to use sound as a direct walking feedback-mechanism during an obstacle avoidance task using the Lokomat. They assigned the scenario parameters distance to obstacle and foot clearance to the sound parameters rhythm and pitch respectively. Results indicated that continuous auditory feedback leads to a significantly higher gait speed compared to visual feedback alone. They further concluded that auditory feedback has an effect on task performance and thus should be an integral part of virtual environments for rehabilitation.

6.3.2 Audio integration

The knowledge gained from the studies as discussed above was integrated into the Lokomat walking scenario. Although not all sound effects were applicable, we tried to use as many sounds from the IADS that matched our graphical features. Loud sounds connected to low valence and low arousal were played when the subjects lost points due to missed items. Conversely, correctly avoided objects and collected items were accompanied by pleasant sound features that were identified to elicit.

6.3.3 Audio rendering library

In the first scenario that was rendered using Ogre3D, auditory feedback was provided using the FMOD library. FMOD is a library that allows for the creation and playback of interactive audio and is used by many game studios. In the second scenario for severely affected patients, no separate sound library was necessary, as Unity3D has its own audio library that can directly be used to produce audio renderings.

7 References

Hall, E.T. 1966, *The Hidden Dimension*, Anchor Books

Kastanis, I. and Slater, M. 2009, *Reinforcement Learning Utilizes Proxemics: An Avatar Learns to Manipulate the Position of People in Immersive Virtual Reality*, submitted

Carrozzino, M., Tecchia, F., Bacinelli, S., Cappelletti, C., and Bergamasco, M. 2005. Lowering the development time of multimodal interactive application: the reallife experience of the XVR project. In *Proceedings of the 2005 ACM SIGCHI international Conference on Advances in Computer Entertainment Technology* (Valencia, Spain, June 15 - 17, 2005). ACE '05, vol. 265. ACM, New York, NY, 270-273.

Mortensen, J., Yu I., Khanna P., Tecchia F., Spanlang B., Marino G., Slater M. 2008. Real-Time Global Illumination for Virtual Reality Applications, *to appear in IEEE Computer Graphics and Applications A Special Issue on VR.*

Botvinick, M. and Cohen, J., 1998. Rubber hands 'feel' touch that eyes see. Nature, 391(6669): p. 756-756.

Ehrsson, H.H., 2007. The experimental induction of out-of-body experiences. Science, 317(5841): p. 1048-1048.

Lenggenhager, B., et al., 2007. Video ergo sum: Manipulating bodily self-consciousness. Science, 317(5841): p. 1096-1099.

Slater, M., et al., 2009. Inducing Illusory Ownership of a Virtual Body. Frontiers in Neuroscience, 3(2): p. 214-220.

Slater, M., et al., 2010. First person experience of body transfer in virtual reality. PLos ONE (minor changes),

González-Franco, M., et al., 2010. The Contribution of Real-Time Mirror Reflections of Motor Actions on Virtual Body Ownership in an Immersive Virtual Environment in IEEE VR. 2010: Waltham, MA, US.

Lenggenhager, B., et al., 2007. Video Ergo Sum: Manipulating Bodily Self-Consciousness. Science, 317(5841): p. 1096.

Lunenburger, L., Colombo, G., Riener, R., Dietz, V., 2004, Biofeedback in gait training with the robotic orthosis Lokomat. Conf Proc IEEE Eng Med Biol Soc., nr. 7, pp. 4888-4889

Malone, T., 1980. What makes things fun to learn? A study of intrinsically motivating computer games. Palo Alto, CA: Xerox.

Gomez, P. and Danuser B., 2008. Relationships Between Musical Structure and Psychophysiological Measures of Emotion, Vol. 7, No. 2, 377–387

Lindley C.A., and Sennersten C.C., 2008. Game Play Schemas: From Player Analysis to Adaptive Game Mechanics, Hindawi Publishing Corporation International, Journal of Computer Games Technology, Volume 2008, pp. 1-7

Wood, R.T.A., Griffiths, M.D., Chappell, D., Davies, M.N.O., 2004. The Structural Characteristics of Video Games: A Psycho-Structural Analysis, CyberPsychology & Behavior, Vol 7(1), pp 1-10

Bradley, M.M., Lang, P.J., 2000. Affective reactions to acoustic stimuli, Psychophysiology, Vol 37(2), March 2000 , pp. 204-215(12)

Wellner, M., Schaufelberger, A., v. Zitzewitz, J., Riener, R., Evaluation of visual and auditory feedback in virtual obstacle walking, Presence: Teleoperators and Virtual Environments, Vol 17(5), October 2008, pp 512-524

8 Appendix I

Since this section contains confidential intellectual property, it has been removed from the public version of the deliverable.

9 Appendix II:

Since this section contains confidential intellectual property, it has been removed from the public version of the deliverable.