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OctaVis: An Easy-to-Use VR-System for Clinical Studies

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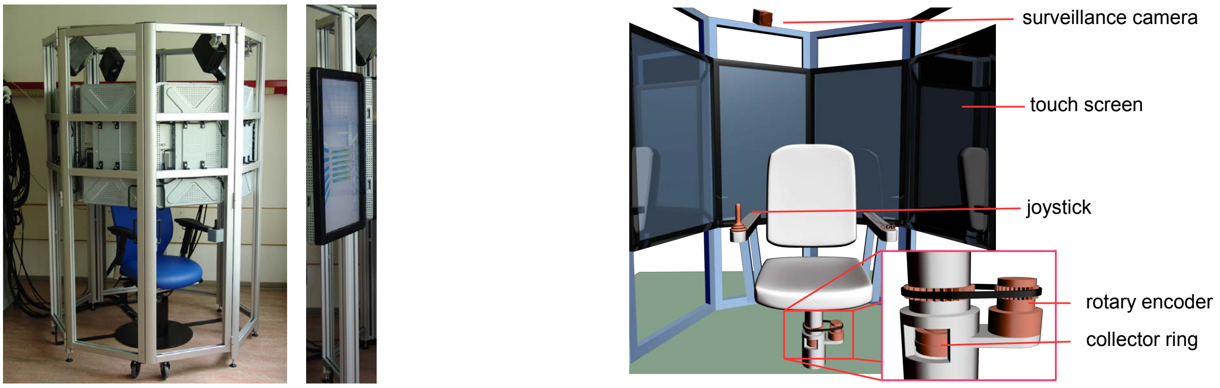

Figure 1: *Two photographs (left) and a simplified illustration of our* OctaVis *VR-system. Eight screens, arranged in an octagon, provide a* 360° *panorama visualization of the virtual environment. Two door segments can be opened. Navigation in the VR is performed through a modified office chair, whose orientation determines the movement direction, and a "throttle joystick" in the armrest. Easy and natural interaction with objects is enabled through a simple touch screen interface.*

Abstract

We present the OctaVis *system, a novel virtual reality platform developed for rehabilitation and training of patients with brain function disorders. To meet the special requirements of clinical studies, our system has been designed with ease of use, patient safety, ease of maintenance, space and cost efficiency in mind. Patients are sitting on a rotating office chair in the center of eight touch screen displays arranged in octagon around them, thereby providing a* 360° *horizontal panorama view. Navigation is intuitively controlled through chair rotation and a joystick in the armrest. A touch interface enables easy object selection. The* OctaVis *system has been successfully deployed to four hospitals. We report first results of clinical studies conducted with patients and control groups, demonstrating that our system is immersive, easy to use, and supportive for rehabilitation purposes.*

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1. Introduction

During the last decades we have witnessed a steady increase in computational resources and a growing knowledge about the principles of immersion, which developed virtual reality (VR) systems into valuable tools for a large variety of applications, such as automotive design, architectural previews, computer games, or medical applications, to name just a few.

In the medical context one is often facing the problem that patients should undergo a training on tasks that are as close as possible to their daily real-life routines, but due to labor costs and safety reasons such individualized training often cannot be realized. VR technology helps us to realize these trainings in a highly realistic and immersive *virtual* reality, which was shown to considerably improve the transfer of training success to real-life situations (see, e.g., [RBR05]).

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In this paper we present the VR platform OCTAVIS that was developed in the highly interdisciplinary medical project *CITmed: Cognitive Interaction Technologies for Medical Applications*. Its major goal is the diagnosis and rehabilitation of patients with brain function disorders, as they might result from stroke, cerebral traumata caused by accidents, neurological or psychiatric diseases. In particular if higher cognitive brain functions are affected, patients have to relearn several abilities, such as memory, spatial orientation and navigation, as well as executive functions like path planning. The VR scenario we have chosen for training these cognitive abilities in daily tasks is grocery shopping in a virtual supermarket: Patients have to memorize a list of items, have to navigate through the supermarket in order to find and buy them, and should improve their path through the supermarket over multiple training sessions.

Although many VR systems provide a sufficient level of immersion for this kind of rehabilitation training, they do not qualify for clinical studies like ours since they do not meet the following crucial requirements:

Ease of use: Most existing VR systems are used by VR experts in academic or industrial research labs only. In contrast, our system has to be used by patients, typically being elderly people suffering from a stroke and without any prior computer or VR experience.

Maintenance: Since our system has to be operated by clinical staff, which typically does not have a strong technical background, it should be as easy as possible to operate and maintain. This is in strong contrast to complex VR systems like CAVE installations, which are typically driven by a high performance network of distributed render clusters and therefore require experienced specialists.

Cost efficiency: To perform clinical studies in several hospitals or to provide the VR system to rehabilitation clinics, the system has to be reasonably cost efficient.

Space efficiency: Similar to financial budgets, space or rooms are typically also limited, requiring a VR system with an as compact as possible spatial footprint.

Medical requirements: Patient safety is the highest goal in any clinical study. Since many stroke patients also suffer from hemiparesis to a certain degree, they cannot be expected to stand or walk without support. Consequently, robust and save chairs must be employed. Moreover, the clinical staff must be able to monitor and supervise the experiments, as well as to intervene at any moment.

In this paper we describe our OCTAVIS system, which meets the above requirements and is successfully being used in clinical studies. While previous papers describe our multi-GPU rendering solution [DSPB12] and demonstrate first clinical results on patients' training success [GKF*12], the contribution of this paper is the description of the whole OCTAVIS system (Section 3) as well as an evaluation of its level of immersion and ease of use (Section 4).

2. Related Work

In this section we discuss related work on VR systems, both in terms of hardware and software architectures. A high level of immersion is the major goal of any VR platform. As a consequence many studies have been conducted in order to determine the factors contributing to the feeling of immersion, aiming to minimize the gap between real reality (RR) and virtual reality (VR).

Although there are concurrent theories about the very nature and the measurements of presence in VR [SUS94, WS98, WHB*07, SB11], this line of research agrees upon the two major causalities: (1) the *presentation* of the VR to the user and (2) the scope and quality of *interaction* in the VR. The presentation is perceived more realistic as more senses are stimulated in a consistent manner as RR does (e.g., unlimited field of view, high resolution, surround sound, sufficiently detailed models and realistic rendering). User interaction is perceived as natural if variety and physical movements mimic RR without abstraction layers like controllers (e.g., real walking, turning, gestures, touching).

However, Bowman and McMahan [BM07] raise objections against the permanent run for increased realism in both presentation and interaction. They argue that depending on the application it is not necessary to care about every single parameter responsible for generating immersion. Instead it is sufficient to focus on those parameters that are mainly involved in the task the user is supposed to perform in the virtual environment. This insight allows us to find compromises between as realistic as possible presentation and interaction on the one hand and ease of use and patient safety on the other hand.

In the following sections we first discuss existing hardware architectures that provide an omnidirectional field of view, before looking at navigation and interaction interfaces suitable for our virtual supermarket scenario. We finish this section with an overview of related software packages for driving VR systems.

2.1. VR Presentation

In order to optimally trick the visual sense in VR, the presentation device has to provide a high resolution omnidirectional view of the virtual environment. Many VR systems employ head-mounted displays (HMDs), since they provide a seamless horizontal and vertical 360° view, but they lack of visual self perception since body limbs remain occluded. It is possible to counteract such occlusions, for instance by adding a virtual avatar, but such setups require expensive motion capturing hardware.

CAVE installations [CNSD*92] are known for providing a very high level of immersion, especially due to their large field of view, but they disqualify for our project because of high cost, occupied space, and maintenance effort. To improve space and cost efficiency, several MiniCAVE systems have been proposed [WSV*99, Sch08], which basically are CAVE-like systems with smaller projection areas and less space consumption. However, the space requirements of these systems is still too large for clinical facilities.

Microsoft's MiniDome [BW10] avoids the typical sharp edges and corners of a CAVE system by employing a hemispherical projection. However, the projectors are placed inside the dome and therefore cast shadows as soon as the user moves between them and the dome surface. While in their project this was a desired interaction pattern, it is not suitable for our project. Taking the dome idea one step further, cybersphere systems [FRE03, Bar12] project the virtual environment on a seamless sphere. This is ideal in terms of field of view, but does not fulfill our requirements on cost and space efficiency as well as maintenance, because these systems rely on custom-tailored projection surfaces. This is also true for circular systems like [HJHL08].

Google's Liquid Galaxy project [Liq12] presents the Google Earth data on eight flat screens arranged in a circle around the user. The use of displays (instead of back-projections) allows for a smaller spatial footprint. Their display circle is not closed in order to have an open entrance, such that the horizontal surround view is broken. Using ClusterGL [NHM11], each of their displays is driven by a dedicated render client, which increases costs and maintenance efforts.

In our OCTAVIS system we also use flat screens, but these are arranged in a closed circle (octagon) centered around the user in order to provide a full 360° horizontal panorama view of the virtual environment (see Figure 1). In contrast to the Liquid Galaxy approach, our system is driven by a single PC, which effectively reduces costs and maintenance effort, as described in Section 3.1.

2.2. VR Navigation and Interaction

Besides the presentation of the VR, interaction with the virtual environment is the other critical factor for immersion. In our project interaction means navigating through the virtual supermarket and selecting/buying products.

Interestingly, a very similar VR supermarket scenario was analyzed by Renner et al. [RDS*10], who conducted a series of experiments investigating different navigation metaphors (path-drawing, lean-based velocity, walking-in-place, world-in-miniature, scene-in-hand) and interaction techniques (ray-casting, image plane) in a CAVE installation. They found that *novice users failed* to complete the given tasks in reasonable time and therefore had to evaluate their techniques with participants having sufficient VR experience. We, in contrast, cannot expect any VR experience from patients in our studies, who typically are elderly people with cognitive disabilities, e.g., due to a stroke. Hence, we have to find simpler and more intuitive methods for navigating in and interacting with the VR.

Small-movement navigation metaphors like mouse, keyboard, game-pad, or wand are not suitable for novice VR users, because they introduce an additional abstraction layer for navigation, complicating the VR task to be performed and not being immersive.

The most natural way to navigate in a VR obviously is walking. The different metaphors like real-walking [RL09], walking-in-place [SUS95] or within a rotating sphere [FRE03, MFW08] are known to feed both the vestibular and the proprioceptive queues generating high immersion. Unfortunately, these systems contradict the requirement for a small footprint. Moreover, patients with hemiparesis might not be able to walk or even stand without support.

Allowing users to sit, ChairIO [BBH05] is a navigation idea similar to ours. Sitting on a sweeper chair one navigates through the VR by rotating the chair (controlling orientation) and leaning forward/backward (controlling translation). In contrast to our system, the VR presentation was done only for a single frontal view, such that the virtual world had to be rotated around the user, thereby failing to stimulate the vestibular and proprioceptive queues in a natural way. Apart from the neat concept, the flexible spring balance attached to the sitting platform causes safety problems with patients.

In our OCTAVIS system we therefore employ a robust rotating office chair equipped with a throttle joystick in the armrest (Section 3.2). The walking direction is intuitively controlled by rotating the chair into the desired direction and the joystick controls forward/backward movement.

While for object selection several interaction metaphors exist, e.g. using a wand, joystick, game-pad, or pointing through finger tracking [RDS*10], they are typically either not easy to use or not immersive. Since in our system the user is surrounded by flat screens anyway, we decided to use touch screens, such that object selection can be performed very easily by simply touching them on the screen.

2.3. Software

Virtual reality software as a middle layer shields application developers from hardware and rendering details. At least it handles a variety of input devices (wands, gloves, steering wheels) and different output devices (HMD, CAVE, power-walls, projection systems). Often packages also provide scripting, (stereo) rendering, cluster support, editors, art pipeline, tracking, and configuration systems to ease application development and add flexibility. Virtools [Das12], Vizard [Wor12], and Instant Reality [Fra12] all represent such extensive frameworks, but disqualify for our project due to their commercial license and price.

Since the visual stimulus is of great importance, VR software often relies on third-party scene graph libraries. Instant

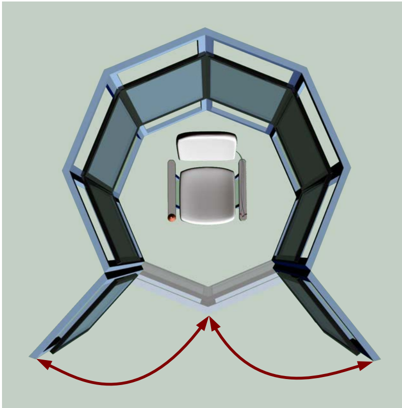


Figure 2: *The OctaVis viewed from top. Two displays ı as door segments and allow to easily enter the system.*

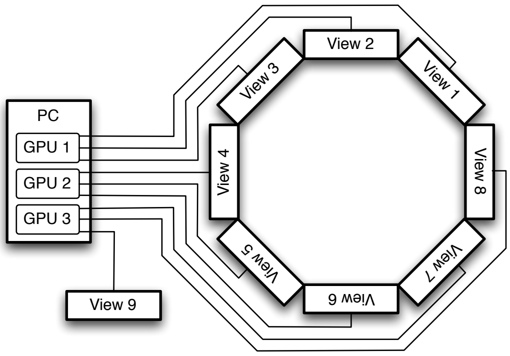


Figure 3: *Schematic view of the hardware setup. One PC, equipped with three GPUs, drives the eight VR displays and an operator display.*

Reality, for example, is built on top of OpenSG, Vizarc top of OpenSceneGraph. Using such a scene graph libı however, was not possible for our project, since most e› ing libraries are neither designed nor optimized for sin PC multi-GPU rendering systems like ours [DSPB12].

Favoring rendering quality, another approach is to ext existing game engines [JL05, JSB10, imi12]. Unfortunat being designed and optimized for single screen applicati game engines also lack multi-GPU support and existing tensions target distributed rendering setups only.

VR Juggler [BJH*01] is an open source VR package supporting standard VR tasks while allowing for custom graphics programming interfaces. In particular it supports OpenGL, OpenGL Performer, OpenSG, and OpenSceneGraph. VR Juggler itself allows multi-pipe setups but handles just the window management. Since in our experiments [DSPB12] the window management and the low-level rendering turned out to be strongly interconnected for multi-pipe optimizations, we dismiss this package.

Instead we custom-tailor a slim, simply extensible, and multi-pipe optimized VR architecture, which offers a simple user interface that allows non-technical hospital staff to operate experiments of clinical studies (Section 3.4).

3. The OctaVis VR-System

The discussions of the previous section showed that existing VR systems do not meet the requirements for our clinical studies listed in the introduction. Navigation and interaction in the VR must be intuitive, but also feasible for patients of different age and disability level. Additionally, set-up times should be short and the VR-training has to be save for the patient at any moment. Since the studies are supervised mainly by medical staff, the system should be easy to operate and maintain even without technical background.

Our OctaVis system has been designed with these special requirements in mind. Similar in structure to the related work discussion, we first describe our presentation of the VR, then the navigation and interaction, and finally discuss some aspects of the software architecture.

3.1. VR Presentation

In order to appropriately stimulate the visual sense our OctaVis system consists of eight standard displays arranged upright in an octagon around the patient. This setup provides a full 360° horizontal view of the virtual environment. Each screen is mounted on an aluminum profile segment about an arm-length away from the patient, who is sitting on a rotating office chair in the center of the octagon. Two of the octagon segments are assembled as doors, providing an easy and safe entrance and exit for patients. See Figures 1 and 2.

In order to enable easy selection of objects in the VR, we employ touch screen displays (*EloTouch 2639L* 26"). The eight touch modules are connected via USB (see Figure 10) and trigger standard mouse events, hence are easy to integrate into our VR framework. While the touch option considerably simplifies user interaction, it comes at the price of bigger frames around the displays. However, it has been recently shown that seams between adjacent views do not influence performance in virtual reality systems [MPS11], which was confirmed by our user studies [DSPB12].

In contrast to most other VR systems, which typically follow a distributed rendering approach using one render client per view/screen, our OctaVis is driven by a single PC. This workstation is equipped with three graphics cards, each of which is connected to three screens, resulting in nine screens in total: eight for VR presentation and one operator display (Figure 3). This single-PC multi-GPU approach considerably reduces hardware costs and maintenance effort. It also simplifies implementation of graphics-related functionality

Figure 4: *The eight views of the virtual supermarket (about 4M triangles), corresponding to an "unfolded octagon".*

and reduces latency, since no network synchronization is required, like it would be for distributed rendering. Finally, since the system is just one (powerful) PC, it can be operated easily, requiring no special technical background.

In terms of graphics hardware, we employ ATI consumer-level graphics cards (*ATI HD Radeon 5850*). In comparison, an NVIDIA solution turned out to be either much more expensive (professional QuadroPlex systems) or to be considerably slower, because the consumer-level cards do not allow for efficient multi-view multi-GPU rendering. To exploit this efficiency and visualize complex scenes in real time, we had to develop a custom-tailored rendering architecture. Due to driver limitations of some devices we are bound to Microsoft Windows 7, which requires certain low-level optimizations to fully exploit the parallel performance of our multi-GPU system, as described in detail in [DSPB12]. In our scene graph architecture every GPU reserves an OpenGL context for storing geometry, textures, and shaders, which is shared between the three views connected to this GPU, thereby reducing memory cost. A combination of low-level and high-level performance optimizations (VBOs, geometry instancing, frustum culling, GPU load balancing) finally enables real-time rendering (70 fps) of our detailed supermarket model (4M triangles, Figure 4) on the eight OCTAVIS displays.

Besides the visual sense, the auditory stimulus is another important factor to trigger presence at the sensory scale. Therefore four loudspeakers are installed above the display arrangement to increase sensory richness and fidelity.

3.2. VR Navigation and Interaction

Many intuitive navigation metaphors, like walking-in-place or ChairIO, are not suitable for physically handicapped people, who might not be capable of sitting on a tilting chair or walking without additional help. Hence our navigation and interaction techniques must be custom-tailored towards people sitting on a robust chair placed in the center of the OCTAVIS system.

For the navigation we used an interaction metaphor similar to an electronic wheelchair: The movement direction is intuitively controlled by rotating the chair into the desired walking direction. Movement speed (forward/backward) is controlled through a joystick in the armrest. When standing in front of a shelf, left/right movement of the joystick translates to sideward movement along that shelf.

Figure 5: *Photograph of a user navigating in the virtual supermarket and buying items via touch interface.*

An advantage of our system is that rotating oneself on the chair—instead of rotating the virtual world around oneself using a joystick—matches the physical motion to the virtual action. This correctly stimulates the proprioceptive and vestibular queues, which has been shown to improve immersion and to better support learning of spatial configurations [KLB*98]. For the translatory movement no physical stimulation is triggered. However, in our context with partially handicapped people sitting on a chair, only the rotation can be handled in a physically consistent manner.

We measure the chair orientation using a rotary encoder (*Heidenhain ERN120*) that is placed around the shaft of the chair and connected to the PC through an Arduino board. The encoder has an accuracy of 0.35° at a sampling frequency of 300 kHz. The chair rotation should not be limited by any cables, thus a collector ring (*A-Drive Technology SRH50120*) is integrated into the chair and the outgoing cable remains hidden from the user under a metal plate.

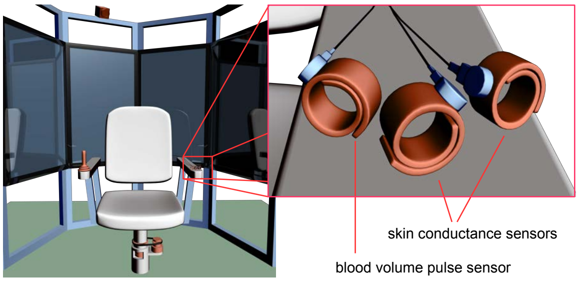


Figure 6: *Illustration of our* OCTAVIS *system with a close-up of the skin conductance and blood volume pulse sensors used for patient monitoring.*

The throttle joystick is a *Metallux MJ-3K MTP* mounted in the armrests. It is connected via a USB hub attached to the chair, which itself is connected to the PC through the collector ring (see Figure 10). The joystick is an analog device, allowing the user to continuously control the movement speed up to a maximum speed, which we determined empirically to minimize cybersickness.

Regarding interaction in the VR, objects are selected/bought by touching them on the screens, i.e., by natural and intuitive arm movements (Figure 5). Accidental selections of objects are avoided due to the constraint that objects have to be within reach of the user in order to be bought. Combining the touch interface with the rotating chair metaphor an intuitive whole-body involvement is achieved for interacting with the virtual environment.

3.3. Clinical Requirements

Further requirements that have to be fulfilled for the use of VR systems in medical experiments are the recording of patients' physiological reaction and the supervision of the experiment.

In order to measure the heart rate and stress level of the patient two bio-sensors (*ProComp Infiniti*) are incorporated into the chair's armrest (Figure 6), and are connected to the PC via the USB hub in the chair. The experiment is operated and controlled by medical staff through an operator display (view 9 in Figure 3). Two surveillance video cameras, mounted at the top of the OCTAVIS system, give the operator detailed information about the patient's action in the OCTAVIS system. Finally a galvanic separation (*Noratel IMEDe 2000*, Figure 10) is incorporated in order to secure patients from potential electric shocks.

After fulfilling these special medical requirements our system has been successfully CE-certified as a Class 1 medical device in Germany, which allows us to conduct clinical studies with patients.

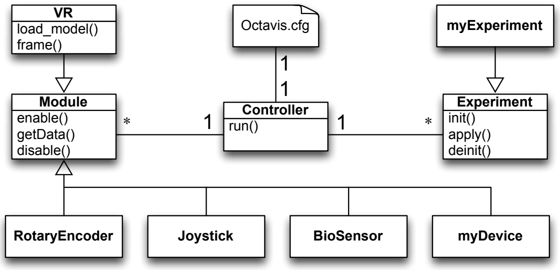


Figure 7: *UML diagram of the main software architecture.*

3.4. Software Architecture

Flexibility was and is a major goal of our software design, for instance in order to be able to connect different input devices or to perform different types of experiments. These experiments range from shopping tasks in a detailed virtual supermarket to orientation tasks in abstract virtual environments (e.g., Morris water navigation task). Because of that, each experiment is encapsulated in a separate class and derived from the abstract class *Experiment*, thereby providing a persistent interface for the main application. A similar method has been applied to all attached devices, which derive from a common parent class *Module*. Figure 7 depicts this software architecture principle.

This class hierarchy turned out to be flexible and beneficial during the development stage. It provides a simple way for the integration of different devices for navigation (gamepad, joystick, mouse, and keyboard) or different variations of a certain device. Even the VR representation and visualization is implemented as such a module, allowing to read arbitrary COLLADA scene descriptions. Optional features such as different experiments or different input devices or sensors can be controlled either via simple configuration files or via a graphical user interface.

4. Evaluation

The OCTAVIS system was developed in a highly interdisciplinary effort by a team of computer scientists, technicians, psychologists, and medical researchers. From the criteria listed in the introduction it meets the space requirements (<150cm in diameter, see Figure 1). Thanks to the single PC architecture the system is easy to operate and maintain even without technical background, and is well accepted by the hospital staff. Since only standard consumer-level hardware components are used, the system is affordable (<20k Euro material costs). Our OCTAVIS system has been CE-certified as a Class I medical device and currently is in use in four different hospitals: a stroke unit in a clinic for neurology, an epilepsy center, and a clinic for psychiatry and psychotherapy, and a neuro-rehabilitation clinic. In all hospitals VR-training is already being performed with admitted patients.

Philips	productscore	sd	epi_prod_score	epi_sd
Day 1	13.5	3.13	8.6	1.8
Day 2	17.0	2.82	12	2.3
Day 3	18.17	1.89	13.4	2.9
Day 4	15.33	2.77	14.6	1.8
Day 5	17.56	2.20	17.4	1.3
Day 6			18.4	1.1
Day 7			11.8	1.8
Day 8			17.8	1.3

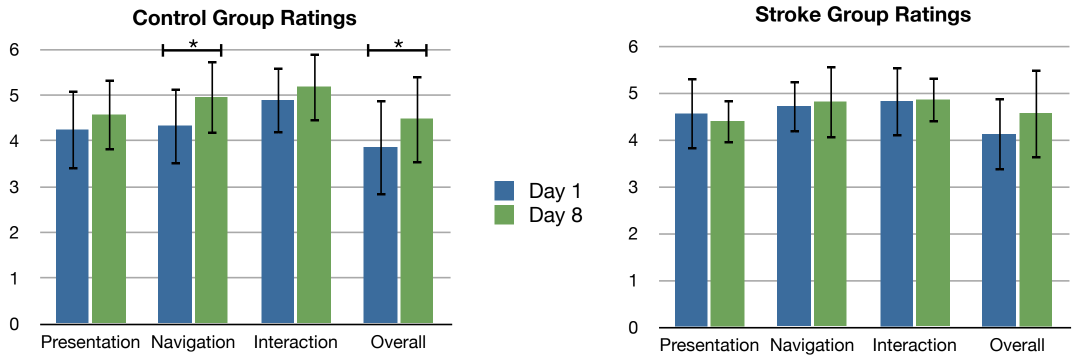


Figure 8: *Questionnaire results for healthy elderly people (left) and stroke patients (right), showing scores above average on every scale. Stars mark significances. Error bars depict standard deviation.*

Below we report first evaluations of the system in terms of immersion, ease of use, and its actual benefit for the training of real-life cognitive abilities.

4.1. Immersion & Ease of Use

We first evaluate the level of immersion and the resulting sense of presence in a user study with 19 healthy elderly participants (4 male, 15 female) within the age range of 32–94 (mean 65.42, standard deviation 15.57). This group acts as a control group for a study with 10 stroke patients (7 male, 3 female) being 34–79 years old (m=59.4, sd=17.09).

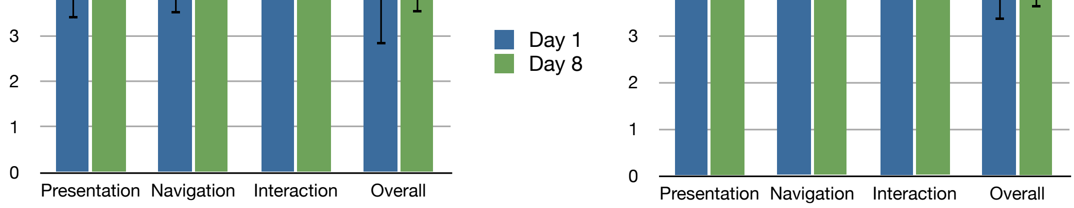
In the experiments participants were first introduced to the system and performed a simple training course in a virtual office in order to become familiar with the OCTAVIS system. On each of the following eight days participants performed a grocery shopping task in the virtual supermarket, for which they had to memorize a shopping list of 20 products that were to be bought in the supermarket. On every day the same 20 items had to be bought, except for the seventh day that introduced a different, distractive list. On the last day, the initial product list had to be bought again, but this time without any new presentation of this list. This training paradigm is based on the rationale of classic neuropsychological tests of verbal learning and memory, such as the California Verbal Learning Test (CVLT) [NSTOW08] and the Verbal Learning and Memory Test (VLMT) [HLL01].

After finishing the training on the first and eighth day, a questionnaire inspired by Witmer and Singer [WS98] was filled out, which investigates the quality of the VR in terms of *presentation*, *navigation*, and *interaction* as responsible factors to mediate immersion. Also the *overall* impression of the VR system was asked. In total the questionnaire consists of 31 items on a 0–6 scale (0: very bad, 6: very good). In order to analyze and test the data for significance we calculate descriptive statistics and perform the non-parametric Wilcoxon test ($\alpha = .05$) to compare results of day 1 to day 8.

Figure 8 depicts the results for the control group and stroke group. The individual evaluations are discussed below.

- The *presentation* scale yields six questions examining different aspects of model quality, rendering quality, and the contribution of the display system to the sense of diving into a different place. Compared to the other scales, the ratings for the presentation component are lower but still significantly above average.
- We asked nine questions about realism and intuition of the control paradigm and the perceived movement to evaluate the *navigation* metaphor. Also system response and eventual difficulties were rated. The results are high above average. For the control group the navigation score even improves significantly (z=-3.127, p=.002) over time.
- Five questions make up the *interaction* scale, which measures the perceived realism, intuition, and the system's response to touch-actions. From both groups on both days this metaphor gets high scores above 75% .
- The last scale represents the *overall* impression and coherence of the OCTAVIS experience. Here six questions directly ask for the perceived presence, the ability to focus on the task, and how convincing the general feeling is. A significantly (z=-2.665, p=.008) higher score is found for the control group on day 8 compared to day 1.

In total, the results of all scales clearly demonstrate our OCTAVIS system to be a very immersive setup causing a real sense of presence in the virtual scene. The most noticeable facts of the questionnaire are (1) the increased rating over time by the control group and (2) the high initial scores for all scales by the stroke patients. Both statements prove that in our system users do not loose appreciation after the initial excitement phase, which VR systems often suffer from. Furthermore, all participants (being non-experts!) succeeded in the virtual shopping experiment, whereas in the CAVE-based study of Renner et al. [RDS*10] novice users failed to perform a very similar task.



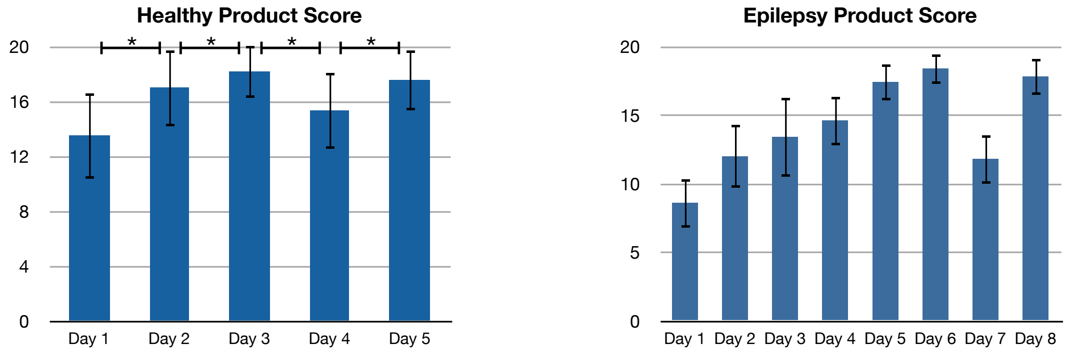


Figure 9: *Product scores for training in a virtual supermarket. Stars mark significances. Error bars depict standard deviation. Left: Healthy university students with five days of training. On day four a distractive shopping list was presented. Right: Epilepsy patients with eight days of training. On day eight a distractive shopping list was presented.*

In addition to the positive questionnaire evaluation, participants often asked for the location of the exit door in the display arrangement after finishing the experiment. This is another indicator that the participants lost their orientation in real-reality and primarily located themselves in the virtual supermarket, again hinting at a high level of presence generated by our OCTAVIS system.

4.2. Training Cognitive Abilities

After having demonstrated that the OCTAVIS system generates a sufficient level of immersion, we now analyze the effects of our VR-training on spatial orientation and learning. While the clinical study of the previous section has not been finished yet and we therefore cannot present training results, we can report first results of a very similar study recently published in [GKF*12].

In that study, we investigated and measured training aspects for 19 healthy university students (5 male, 14 female) of age 19–28 years (m=23, sd=3.45), and a small group of epilepsy patients (4 male, 1 female) of age 25–47 (m=35.04, sd=8.08). The task setup was exactly the same as for the previous study, but for the healthy students limited to a five day training, where on the fourth day the distractive list was presented. In case of the healthy participants the study revealed a stable learning effect for the number of correctly bought products (WL $= .157$, F $= 18.82$, $p < .001$, $\eta^2 = .843$), where the distractive list on day 4 has almost no influence on the performance on day 5 (Figure 9, left). For the epilepsy group, which performed the 8-day training, the results are qualitatively very similar, but for a quantitative evaluation more patients are needed (Figure 9, right). These early results indicate that VR-training results in more stable visual-spatial learning compared to mere verbal memorization—as done in typical paper-and-pencil rehabilitation trainings.

5. Conclusions

In this paper we presented the novel OCTAVIS VR-system, where users are sitting on a rotating chair in the center of eight displays arranged around them. The eight displays provide a 360° horizontal full-panorama view of the virtual world, through which the user can easily navigate via chair rotation and a throttle joystick. Object selection is naturally performed through an intuitive touch-screen interface.

Using just a single PC to drive the eight VR-displays, the OCTAVIS system is easy to maintain, cost efficient (<20k Euro hardware cost), and has a small spatial footprint (<150cm in diameter). The system was designed for use in clinical studies, with patient safety and patient abilities in mind. It has been deployed to four hospitals, where it is successfully used for clinical studies. First experimental studies confirm that the OCTAVIS system is easy to use even for elderly people without any VR experience, that it generates a high level of subjective immersion, and that it helps rehabilitation of patients with cognitive disabilities.

The display seams can be considered a current limitation of our system. Although they have been shown not to have a distracting effect for most users [MPS11, DSPB12], they might certainly have for some individuals. An interesting direction for future work is to incorporate head- and eye-tracking, which would allow a more precise diagnosis and better individualized training for patients suffering hemi-neglect or hemi-anopsia.

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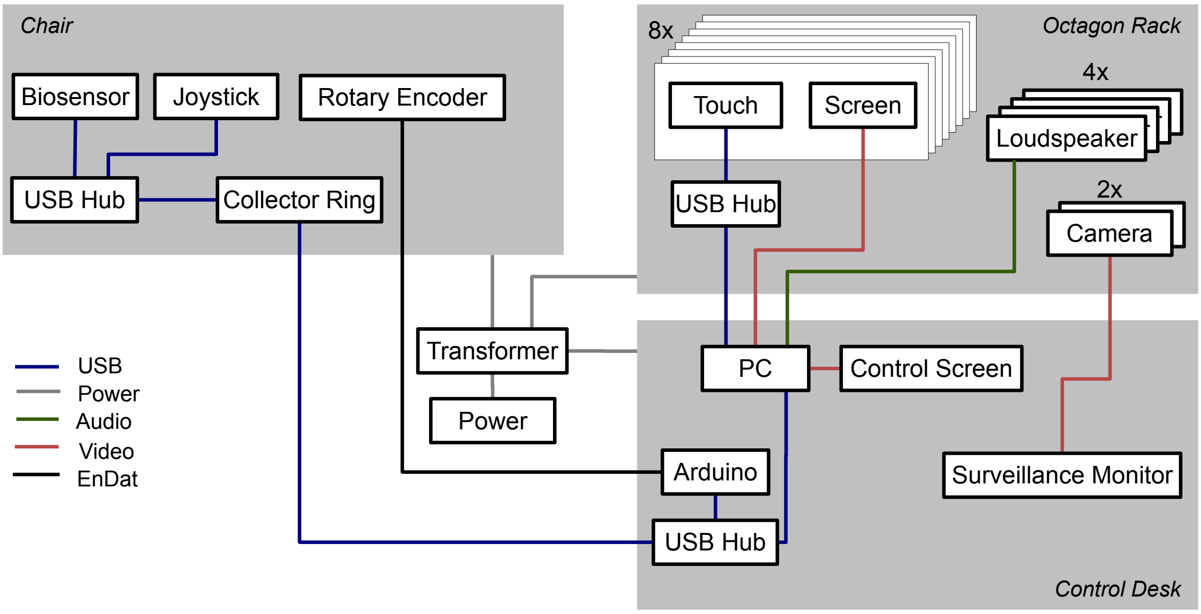

Figure 10: *Hardware wiring plan showing interconnections of the different modules. (1) The Chair module, containing the bio-sensors, the joystick, and the rotary encoder. (2) The OctaVis Rack module, containing eight screens and four loudspeakers for presenting the VR. Also two surveillance cameras for patient monitoring are mounted here. (3) The Control Desk module, containing the PC, the operator display for controlling the application, and a surveillance monitor showing the video signals of the surveillance cameras.*

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