OctaVis: A Virtual Reality System for Clinical Studies and Rehabilitation

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Figure 1: *Two photographs and a simplified illustration of our* OctaVis *virtual reality (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. Its orientation determines the movement direction. A "throttle joystick" in the armrest controls the movement speed. Easy and natural interaction with objects is enabled through a simple touch screen interface. Biosensors and surveillance cameras permit permanent patient observation by clinical staff.*

Abstract

Brain function disorders, resulting for instance from stroke, epilepsy, or other incidents can be partially recovered by rehabilitation training. Performing neuro-rehabilitation in virtual reality systems allows for training scenarios close to daily tasks, is easily adaptable to the patients' needs, is fully controllable by clinical staff, and guarantees patient safety at all times. In this paper, we describe the OctaVis *system, a novel virtual reality platform developed primary for clinical studies with and rehabilitation training of patients with brain function disorders. To meet the special requirements for clinical use, our system has been designed with ease of use, ease of maintenance, patient safety, space and cost efficiency in mind. Our system has been successfully deployed to four hospitals, where it is used for rehabilitation training and clinical studies. We report first results of these studies, demonstrating that our system is immersive, easy to use, and supportive for rehabilitation purposes.*

1. Introduction

Every year about 270.000 people in Germany suffer stroke. Half of them remain disabled, which makes stroke the most frequent reason for becoming disabled as an adult. Apart from stroke, brain function disorders can also result from cerebral traumata caused by accidents, as well as from psychiatric or neurological diseases (e.g., epilepsy).

Neuro-rehabilitation training can help to (at least partially) recover the lost cognitive abilities. Unfortunately it is well known that the improvement gained in standard paper-and-pencil tests cannot sufficiently be transferred to real-life scenarios. This is mainly because these standard tests (1) train certain cognitive functions in isolation and (2) are rather abstract and far from the problems in daily routine.

VR technology helps to design more realistic training scenarios in highly immersive setups (see, e.g., [RBR05]). In addition, VR training has the benefit that it can easily be adjusted to the specific needs or capabilities of the patient and can perfectly be controlled by clinical staff.

In this paper, we describe the VR system OCTAVIS , which was developed during the interdisciplinary ERDF[†] project *CITmed: Cognitive Interaction Technology for Medical Applications*[‡]. Its main purpose is the diagnosis and rehabilitation of the above mentioned brain function disorders. In particular, it has been designed to train memory, spatial orientation and navigation, as well as higher order executive functions like path planing. The first 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 shopping items, have to navigate through the supermarket in order to find and buy each item, and should improve their path through the supermarket over multiple training sessions.

Currently, the OCTAVIS system is being evaluated in four hospitals, where it achieves high acceptance by both staff and patients and was shown to be supportive for rehabilitation purposes. The high acceptance rates by experts and non-experts, old and young, and disabled and non-disabled people reflects well our effort to develop the OCTAVIS system as a general VR training platform.

2. The OCTAVIS System

A VR system for rehabilitation training has to satisfy several (partially conflicting) requirements. For example, the VR should on the one hand be highly immersive, but on the other hand has to be reasonably cheap and with a small spatial footprint. The navigation should be intuitive and natural, but also feasible for handicapped people. Therefore, we followed the advice of Bowman and McMahan [BM07], who argue that rather than trying to increase each parameter responsible for immersion, it is more important to concentrate on the parameters mostly involved for the task.

2.1. Hardware Setup

Although there exists a variety of VR systems, most of them are not suitable for our purposes. VR training on standard desktop PCs does not offer a sufficient degree of immersion. CAVE or MiniCAVE systems are highly immersive, but far too complex, space consuming, and costly to be used in a clinical environment. Head-mounted displays (HMDs) lack of self-perception in the virtual environment, which makes interaction (e.g., buying items) less intuitive.

Our OCTAVIS system (cf. Figure 1) consists of eight 26" LCDs that are arranged in a circle (an octagon) around the patient, who is sitting in the center on a rotating office chair. The eight screens therefore provide an immersive 360° horizontal view of the virtual environment. The screens are mounted on aluminum segments, two of which are assembled as doors and provide an easy and safe entrance and exit for patients. In contrast to many multi-screen VR systems that build on a distributed rendering solution with one render client per view, our OCTAVIS is driven by a single PC with three consumer-level graphics cards. Each card provides three display ports, such that in addition to the eight OCTAVIS screens one external operator display can be connected. Our custom-tailored rendering framework (Section 2.2) guarantees sufficient rendering performance by fully exploiting CPU and GPU parallelism.

For the navigation in VR natural metaphors like real-walking, walking in place, or within a rotating sphere are the most immersive, but are not suitable for disabled people. Navigation devices like game pads, keyboard and mouse are not suitable for novice VR users, because they introduce an additional abstraction layer. In our OCTAVIS system, we have chosen a 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 throttle joystick in the armrest. Easy and intuitive interaction with objects in the VR is enabled through touch screen displays. This design choice significantly simplifies user interaction, but comes at the price of bigger frames around the displays. However, this was shown not to influence performance in VR systems in [MPS11], which we could confirm in our studies [DSPB12].

To account for medical requirements, some additional devices have been integrated (Figure 1, right). An optional footrest allows even patients with hemiparesis to operate our system. Biosensors attached to the fingers track the heart rate and the skin conductance of the patient. Two surveillance cameras give the operator a detailed overview about the patient's action. Finally, a galvanic separation 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.

The resulting system, described in detail in [DZK*12], is reasonably cheap (< 20k Euro), spatially compact (diameter < 120cm), easy to maintain (just one Windows PC), and—most importantly—easy to operate for patients: In our studies *all* participants (elderly people, no VR experience, healthy or stroke/epilepsy patients) succeeded in the virtual shopping experiment, whereas in the CAVE-based study of Renner et al. [RDS*10] most (young, healthy) novice users failed to perform a very similar task in a virtual supermarket.

† European Regional Development Fund, HighTech.NRW

‡ http://citmed.uni-bielefeld.de

2.2. Software Framework

Besides the hardware setup, the software framework is also crucial for a successful VR system, in particular since our rendering solution has to run on a single PC. Commercial VR frameworks, such as, e.g., Virtools or Vizard, as well as modified game engines, disqualify because of their price and/or insufficient multi-GPU support. We therefore developed a slim, custom-tailored VR architecture, with a focus on simple extensibility to new hardware devices, new experiment setups, and new virtual environments.

Our highly optimized 3D rendering pipeline fully exploits the parallelism offered by our multi-core CPU and multi-GPU workstation. The highly realistic supermarket model used in our studies (Figure 1) consist of more than 4M triangles, which are rendered on eight screens at a rate of 70 fps, which is more than 2 billion triangles per second. Note that a frame-rate of at least 60 fps is crucial for avoiding cybersickness problems, in particular with non-VR-experts.

This is accomplished by a combination of low-level and high-level optimizations for CPUs and GPUs: To feed the eight screens, each GPU renders the scene up to three times, distributed to a dedicated CPU thread per view. Low-level optimizations prevent GPUs from interfering with each other, thereby guaranteeing the scalability of the whole system. All data is stored on the GPU and re-ordered for cache efficiency. Higher-level optimization like geometry instancing and view-frustum culling further increase performance. The whole rendering framework as well as the individual optimizations are described in more detail in [DSPB12].

3. Results of Clinical Studies

The OCTAVIS systems have been deployed to our collaborating medical partners about 1.5 years ago, where they are evaluated since then. These institutions are: a stroke unit in a clinic for neurology, an epilepsy center, a clinic for psychiatry and psychotherapy, and a neuro-rehabilitation clinic. The feedback from the different hospitals attests that our system is accepted and appreciated by staff and patients, not only for its simplicity, but also for its suitability in their respective patient context.

First studies proved the OCTAVIS system to be immersive and easy to use [DZK*12] as well as supportive for learning real-life cognitive abilities [GKF*12]. Here we want to present results for training visuospatial cognition from two different patient groups: First, 13 people with focal epilepsy, being 19–51 years old (mean=32.3, sd=10.0) and second, 11 stroke patients within the age range of 34–76 (mean=61.0, sd=15.2). In addition, we present results for 13 healthy senior people of age 61–94 (mean=71.4, sd=10.8).

All groups performed the following training: On eight consecutive days they had to buy a list of 20 items in a grocery shopping task. On days 1–6 the same shopping list (*List A*) was presented, memorized, and bought. On day 7 a completely different distractive list (*List B*) was used. To test how stable the learning of List A was, the participants had to buy List A *without* presenting it again (*free recall*): once immediately after the distractive trial on day 7 and once more on day 8. 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) and the Verbal Learning and Memory Test (VLMT).

Figure 2 shows the number of correctly bought items per trial. In general, one can observe that the numbers increase during days 1–6, and that the distractive trial on day 7 has only a very small effect on the two subsequent trails with free recall of List A. The negligible influence of the distractive list is in contrast to standard verbal learning tests and proves the efficacy and stability of our multi-modal learning. A repeated measures ANOVA proves statistical significance of these improvements for seniors ($p=0.003$), stroke patients ($p=0.024$) and epilepsy patients ($p<0.001$). Similarly to the improvement in product score, the length of the walked trajectory and required time decreased during the eight days (by about 30% and 40%, respectively), which shows an improvement of spatial orientation, map learning, and executive functions like path planning.

To analyze the improvement of general visuospatial performance, we compared the visuospatial abilities before and after the training, using the comparable Rey Figure test (before) and Taylor Figure test (after). Concerning the visuoconstructive ability to assemble a figure from its components, all groups improved in average (seniors: 3.7%; stroke: 13.3%; epilepsy: 3.6%), but due to Wilcoxon calculus only the patients showed statistical significance (stroke: $z=-2.052$, $p=0.040$; epilepsy: $z=-2.455$, $p=0.014$). For the visuospatial memory, participants had to remember and draw the figure after 30 minutes. Again each group improved (seniors: 2.0%; stroke: 18.8%; epilepsy: 15.7%), but only the patients did so significantly (stroke: $z=-1.956$, $p=0.050$; epilepsy: $z=-2.276$, $p=0.023$). It is plausible that the senior people did not improve significantly, since they had no brain injuries to recover from. These results clearly show that our system contributes to a *general* improvement in visuospatial cognition.

Finally, a questionnaire concerning the perceived efficacy of the training were performed after the day 8 (Figure 2, right). On a 0–6 scale (0=not al all, 3=average, 6=very much), participants rated whether the OCTAVIS training was interesting, motivating, and useful. All groups rate these items very high, which is an important result, since it is well known that internal motivation is crucial for treatment success. Participants then rated whether they think they improved on memory, orientation, and their grocery shopping performance. While both patient groups rate all learning areas above average, the senior people do so only for the memory gain. This is again plausible, since the healthy seniors did not need help with orientation or shopping.

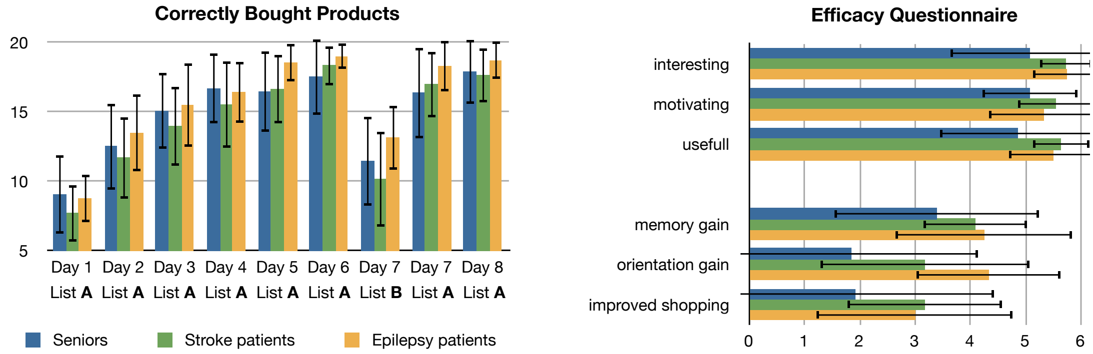

Figure 2: *Results of* OCTAVIS *training for healthy seniors, stroke and epilepsy patients.* Left: *Number of correctly bought items for each trial.* Right: *Ratings of training efficacy, concerning general appreciation (top) and perceived learning effects (bottom).*

4. Conclusion

From the beginning the OCTAVIS system was designed and developed in a highly interdisciplinary effort by a team of computer scientists, psychologists, and medical scientists. As such, and in contrast to most other VR platforms, it meets the following crucial criteria for clinical use:

Ease of use: Our typical users are elderly patients, many of them suffering from stroke, and without any PC or VR experience. Still, thanks to its intuitive use even a 94 years old participant managed to operate our system right away.

Maintenance: Since we employ a single PC, instead of a rendering cluster, our system can be operated by clinical staff without technical experience.

Cost efficiency: With costs of less than 20k Euro our system is cheaper than most multi-view VR systems and therefore affordable for most neuro-rehabilitation clinics.

Space efficiency: With a diameter of about 120 cm the OCTAVIS system fits easily into a typical hospital room.

Medical requirements: By using a robust chair with footrest, usability and safety are given even for patients with hemiparesis. Clinical staff can monitor the experiments and intervene at any moment. The system is a CE-certified Class I medical device in Germany.

Flexibility: While first clinical studies focused on the virtual supermarket, the system is easily extensible. More specific studies (maze/city navigation, Morris water navigation) have been implemented and will be started soon.

These properties make our system a valuable platform for multi-modal cognitive training in neuro-rehabilitation. The first results of our clinical studies (shown in [DSPB12, GKF*12] and this paper) confirm a high acceptance by both medical staff and patients, and demonstrate our OCTAVIS platform to be supportive in the rehabilitation of cognitive disabilities resulting from stroke or epilepsy. Motivated by these results the consequent next step will be professional distribution of the OCTAVIS system.

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References

[BM07] BOWMAN D. A., MCMAHAN R. P.: Virtual reality: How much immersion is enough? *Computer 40*, 7 (July 2007), 36–43. 2

[DSPB12] DYCK E., SCHMIDT H., PIEFKE M., BOTSCH M.: OCTAVIS: Optimization techniques for multi-GPU multi-view rendering. *Journal of Virtual Reality and Broadcasting 9*, 6 (2012). 2, 3, 4

[DZK*12] DYCK E., ZELL E., KOHSIK A., GREWE P., WINTER Y., PIEFKE M., BOTSCH M.: OCTAVIS: An easy-to-use VR-system for clinical studies. In *Proceedings of Virtual Reality Interaction and Physical Simulation (VRIPHYS)* (2012), pp. 127–136. 2, 3

[GKF*12] GREWE P., KOHSIK A., FLENTGE D., DYCK E., BIEN C., WINTER Y., BOTSCH M., MARKOWITSCH H. J., PIEFKE M.: Learning real-life cognitive abilities in a novel 360°-virtual reality supermarket: A neuropsychological study of healthy participants and patients with epilepsy. *Journal of NeuroEngineering and Rehabilitation* (2012). to appear. 3, 4

[MPS11] MCNAMARA A., PARKE F., SANFORD M.: Evaluating performance in tiled displays: navigation and wayfinding. In *Proceedings of the 10th International Conference on Virtual Reality Continuum and Its Applications in Industry* (2011), ACM, pp. 483–490. 2

[RBR05] ROSE F. D., BROOKS B. M., RIZZO A. A.: Virtual reality in brain damage rehabilitation: Review. *CyberPsychology and Behavior 8*, 3 (2005), 241–262. 2

[RDS*10] RENNER P., DANKERT T., SCHNEIDER D., MATTAR N., PFEIFFER T.: Navigating and selecting in the virtual supermarket: Review and update of classic interaction techniques. In *Virtuelle und Erweiterte Realität: 7. Workshop der GI-Fachgruppe VR/AR* (2010), pp. 71–82. 2