An Open-Source Virtual Reality Platform for Clinical and Research Applications

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Abstract. In recent years, there has been an increasing interest in clinical and research applications of virtual reality (VR). However, the adoption of this approach is still limited by the high costs of software development, lack of technical expertise among end-users, and the difficulty of adapting the contents of the virtual environments (VEs). To address these needs, we have designed and developed NeuroVR, (http://www.neurovr.org), a cost-free virtual reality platform based on open-source software components. NeuroVR allows non-expert users to easily customize a VE by using a set of pre-designed virtual scenes, and to run them in an immersive or non-immersive modality. In this paper, we provide a description of the key functional features of the platform.

Keywords: virtual reality, 3D modeling, psychotherapy, neuroscience, open-source software.

1 Introduction

Virtual reality is a technology that allows a user to interact in real-time with a simulated three-dimensional space, the virtual environment (VE). A typical VR system consists of a relatively powerful PC for processing data, a fast 3D accelerator graphic card, a set of input devices to allow control of the viewpoint and objects, and a viewing device. VR systems generally fall into two main categories, depending on the technology components that they use. In non-immersive systems, the VE is usually viewed through a standard monitor, and interaction occurs by conventional means such as keyboards and mice. In immersive systems, on the other hand, the user wears an head-mounted display and is provided with tracking systems that allows the views to be changed dynamically according to the movements he makes. The interaction with the virtual scene occurs via a joystick or a glove, and the configuration can include haptic devices that provide the user with force-feedback and can be used to convey a sense of touch, weight, or resistance.

Despite the initial promises, VR has remained for several years an expensive niche application used only in high-end fields such as military, automotive industry,

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medicine and academic research projects. In the last few years, reduction of computer and storage costs has made VR more affordable. However, the wide adoption of this technology requires not only a further fall in the prices of hardware components, but also that software development tools become less expensive and easier to use.

To address this problem, researchers at several universities are developing open-source and low-cost VR platforms for various applications of this technology. Here, we describe of the NeuroVR project, a cost-free software platform based on open-source elements that has been designed to customize and run virtual environments for clinic and research applications.

2 VR in Therapy, Research and Education

In recent years, a number of studies have suggested the efficacy of VR in the diagnosis and treatment of various psychological and neurological disorders.

In the field of psychotherapy, most studies have addressed specific phobias, in particular fear of flying, acrophobia, fear of driving, claustrophobia and fear of spiders. In addition, several studies have been published on the use of this approach in eating disorders, social anxiety disorders, sexual disorders, post-traumatic stress disorder and panic disorder with or without agoraphobia [1-4].

Traditional cognitive-behavioral approaches to exposure therapy include *in vivo* exposure and *imaginal* exposure. In the first procedure, patients approach a feared situation step-by-step, supported by therapist's encouragement and skilled advice.

Imaginal exposure consists in having the patient relax, then imagine the stimulus, gradually progressing from the least fearful to the most fearful.

In VR exposure, the patient is immersed in a VE containing the feared stimulus. This procedure has been showed to be at least as effective as these traditional techniques in reducing phobic symptoms [1]. The added-value of this approach consists in the practical advantages offered by the use of VR technology. As stimuli are generated by the computer, the therapist has full control over their intensity and the risk of unpredictable effects is significantly lower than in *in vivo* exposure.

Further, virtual exposure allows to present the patient with realistic three-dimensional visualization of the feared situation. This feature can be very useful when the patient is unable to recreate the scenarios because of pathological avoidance of problematic memories, as it is often the case in post-traumatic stress disorder [3].

Another field where VR has been successfully integrated is physical and neurological rehabilitation [5-9]. The main aim of rehabilitation is to help the disabled person to acquire knowledge and skills in order to gain autonomy, self-reliance, self-worth, and integrate into the community. This process can be broken down in three key areas: a) approaches that decrease disability; b) approaches designed to maximise activity through the acquisition of novel skills and strategies; and c) approaches designed to modify the psycho-social environment, in order to reduce the disadaptive consequences of a specific disability. Research so far conducted suggests that VR-based interventions can improve all these areas. In particular, most clinical rehabilitation studies have addressed the potential role of this technology in improving functional recovery in post-stroke patients [8-9]. In a typical approach, a patient is presented with a virtual task that he/she has to complete by using the dysfunctional arm or leg. The virtual exercise can be performed with the help of a glove that detects finger, wrist and arm motions to manipulate on-screen images, and in some systems haptic/tactile feedback cues are provided. As motor performance improves, the level of difficulty of the exercise can be increased by changing the parameters of the virtual task, and this loop can have beneficial effects on patient's motivation and compliance. In addition, this approach provides the opportunity for ecological validity (as the virtual task can be designed for reproducing real-life situations, i.e. grasping an object), independent practice, and stimulus and response modifications that are contingent on a user's physical abilities.

Another area in which VR has been fruitfully integrated is neuropsychological assessment. Here, the advantage of VR on traditional pen-paper approaches is provided by three key features of this technology: the capacity to deliver interactive 3D stimuli within an immersive environment in a variety of forms and sensory modalities; the possibility of designing of safe testing and training environments, and the provision of "cueing" stimuli or visualization strategies designed to help guide successful performance to support an error-free learning approach [5-7].

VR is being used to similar advantage in many domains outside the clinical field, as in research and education. In particular, this technology has revealed to be a useful tool for cognitive neuroscience [10]. In experimental neuroscience, researchers are faced with the problem of carrying out experiments in an ecologically valid situation, to ensure that results can be generalized. On the other hand, they need to maintain control over all potential intervening variables, and this can be a difficult if not even impossible task when the experiment is carried out outside a scientific laboratory.

Using VR, researchers can model realistic environments in which the subject can interact as in real settings. By using this technology, the experimenter is allowed to measure and monitor a wide variety of responses made by the subject. Further, VR can provide new opportunities and challenges for collaboration and sharing of information, to build increasingly comprehensive models of the brain. Computational neuroscientists need to visualize complex set of data originating from their research.

Using VEs, multimodal data can be simultaneously displayed, enabling different types of data to be merged in a single model. For example, the dynamic processes observed by the electrophysiologist can be combined with the receptor binding studies and histological information obtained by other researchers. This capability provides an opportunity for both enhancing scientific discovery (i.e. detecting new patterns and relationships between data) as well as reducing misinterpretation (observing patterns which are artifacts of the techniques employed).

As concerns learning and training applications, the advantages provided by the use of VR are quite obvious. First of all, there is universal agreement among educators of the value of experiential learning – as Bruner put out, "knowledge begins with enaction" - and VR is the experiential medium *par excellence*. Further, in VR learning environments students can interact with complex information sets in an intuitive, non-symbolic way. For example, the VE MaxwellWorld has been designed to enable the examination of the nature of electrostatic forces and fields, to aid students in understanding the concept of electric flux, and to help them empirically discover Gauss's Law.

Another key feature of VR for learning is involvement and motivation of the student. Research conducted to assess the psychological effects of VR suggests that users can be highly engaged and involved in VEs, at the point that they can perceive that they are acting in a space that is different from that they are physically located – a feeling that has been labeled “sense of presence” [11]. Finally, VR systems can provide safe and controlled training environments, that can be used in those applications in which the practice of technical skills can be dangerous or harmful.

For this reason, VR simulations are becoming the training method of choice in medical schools. For example, within a virtual operating room the trained student is allowed to practice both the surgical procedures and the anatomic-physiological background of operations and diseases [12].

In sum, technical progresses in VR have opened up several new applications in clinic, research and education. Most researchers in these fields agree that VR can help to improve significantly the quality of their work and their productivity, however this approach is still not widespread, and the majority of VR applications are still in the laboratory or investigation stage. If, as we have seen, technology costs are no longer a burden, what are the factors that limit the diffusion of this approach?

3 The Need for Easy-to-Use and Open-Source VR Software

Across the last five years, we have conducted an in-depth analysis for understanding the factors that influence the acceptation and adoption of VR technology in both clinic and rehabilitation domains. Results of this investigation allowed us to identify two main factors that limit a wider diffusion of this approach.

A first problem is related to the lack of technical skills among end users. For example, many psychotherapists and rehabilitation professionals are interested in VR, but only a small percentage of them is familiar with the use of computer systems.

Thus, a first challenge that must be faced is to develop VR interfaces that are easily understandable and learnable also for users without technical background.

Strictly connected with this problem is the issue of customization of the content.

The majority of VEs that are available for clinic and research applications are closed-source and cannot be changed, and this prevents the user from the possibility of tailoring the content of the virtual scene according to his needs. This is a significant issue, as often users need to adapt the stimuli to a specific clinical problem. For example, a VE designed treating spider phobia cannot be used for other types of phobia. The same problem applies to research applications. In this case, the need for customization is even more significant, as the stimuli presented to the subject and the experimental parameters that must be controlled can vary notably in accordance to the hypothesis to be tested. In these cases, the researcher is faced with two possibilities.

The first is to create his own virtual application from scratch, asking a software developer company to do the work.

However, this solution can be very expensive. Actually, it has been estimated that the cost of designing and testing a clinical VR application is comprised between 25.000 US$ and 200,000 US$ [13]. The final cost is dependent on many factors, i.e. the need of photorealistic content, the number of virtual scenes, the amount of objects included in the VE, and the complexity of the interaction. Further, optimizing a VE demands significant effort in testing its usability and efficacy, especially if it is designed for clinical applications. Since the option of creating a VE is generally not feasible, the alternative solution available for professionals and researchers who do not have access to large research fundings is to look for commercial computer-gaming platforms. Some of these software applications allow to adapt existing content or create some new games, which can be customized according to the specific needs of the user. A shortcoming of this approach is intellectual property. Because of copyright restrictions, the VEs created by the user cannot be easily distributed or published. As a consequence, the impact of results on the research community is reduced. Further, most of the editors included in gaming platforms are not easily understandable by non-technical users, and require a minimum amount of coding to create a new gaming environment.

The open-source approach holds great promise for achieving enhanced accessibility and fostering the adoption of the VR approach in the clinic and research community. As widely known, the aim of this approach is to make software resources available to the general public without intellectual property restrictions (or with relaxed ones). In recent years, more and more academic and non-academic groups interested in VR are looking towards implementing open-source resources to improve access to this technology, and stimulate a collaborative environment for creating new applications. At present, most application-oriented open-source projects in VR are concentrated in the domains of scientific visualization, architectural design and medical education, while little work has been done so far in the field of therapy and rehabilitation.

Starting from this need, we have designed and developed NeuroVR, a software platform based on open-source components that provides the users with a cost-free VE editor, which allows non-expert users to easily modify a virtual world, to best suit the needs of the clinical or research setting.

4 The NeuroVR Project

4.1 General Characteristics

NeuroVR is a cost-free virtual reality platform that has been designed to allow non-expert users to easily modify a virtual environment and to run it using an immersive or non-immersive system.

The NeuroVR platform is implemented using open-source components that provide advanced features, including an interactive rendering system based on OpenGL which allows for high quality images. The NeuroVR Editor is created by customizing the User Interface of Blender, an integrated suite of 3D creation tools available on major operating systems, under the GNU General Public License; this implies that the program can be distributed even with the complete source code.

Thanks to these features, clinicians and researchers have the freedom to run, copy, distribute, study, change and improve the NeuroVR Editor software, so that the whole VR community benefits.

4.2 The NeuroVR Editor

The majority of existing VEs for psychotherapy are proprietary and have closed source, meaning they cannot be tailored from the ground up to fit specific needs of different clinical applications [11]. NeuroVR addresses these issues by providing the clinical professional with a cost-free VE editor, which allows non-expert users to easily modify a virtual scene, to best suit the needs of the clinical setting.

Using the NeuroVR Editor (see Figure 1), the psychological stimuli/stressors appropriate for any given scenario can be chosen from a rich database of 2D and 3D objects, and easily placed into the pre-designed virtual scenario by using an icon-based interface (no programming skills are required). In addition to static objects, the NeuroVR Editor allows to overlay on the 3D scene video composited with a transparent alpha channel. The editing of the scene is performed in real time, and effects of changes can be checked from different views (frontal, lateral and top).

Fig. 1. Screenshot of NeuroVR Editor graphical user interface

The NeuroVR Editor is built using Python scripts that create a custom graphical user interface (GUI) for Blender. The Python-based GUI allows to hide all the richness and complexity of the Blender suite, so to expose only the controls needed to customize existing scenes and to create the proper files to be viewed in the player.

Currently, the NeuroVR library includes 12 different pre-designed virtual scenes, representing typical real-life situations, i.e., the supermarket, the apartment, the park.

These VEs have been designed, developed and assessed in the past ten years by a multidisciplinary research team in several clinical trials, which have involved over 400 patients. On the basis of this experience, only the most effective VEs have been selected for inclusion in the NeuroVR library.

An interesting feature of the NeuroVR Editor is the possibility to add new objects to the database. This feature allows the therapist to enhance the patient's feeling of familiarity and intimacy with the virtual scene, i.e., by using photos of objects/people that are part of the patient's daily life, thereby improving the efficacy of the exposure.

Future releases of the NeuroVR Editor software may also include interactive 3D animations controlled at runtime. A VRML/X3D exporter and a player for PocketPC PDAs are planned Blender features, too.

4.3 The NeuroVR Player

The second main component of NeuroVR is the Player, which allows to navigate and interact with the VEs created using the NeuroVR Editor.

NeuroVR Player leverages two major open-source projects in the VR field: Delta3D (http://www.delta3d.org) and OpenSceneGraph (http://www.openscenegraph.org). Both are building components that the NeuroVR player integrates with ad-hoc code to handle the simulations.

The whole player is developed in C++ language, targeted for the Microsoft Windows platform but fully portable to other systems if needed. When running simulation, the system offers a set of standard features that contribute to increase the realism of the simulated scene. These include collision detection to control movements in the environment, realistic walk-style motion, advanced lighting techniques for enhanced image quality, and streaming of video textures using alpha channel for transparency.

The player can be configured for two basic visualization modalities: immersive and non-immersive. The immersive modality allows the scene to be visualized using a head-mounted display, either in stereoscopic or in mono-mode; compatibility with head-tracking sensor is also provided. In the non-immersive modality, the virtual environment can be displayed using a desktop monitor or a wall projector. The user can interact with the virtual environment using either keyboard commands, a mouse or a joypad, depending on the hardware configuration chosen.

4.4 The NeuroVR Website

One of the main problems faced by clinicians and researchers who are interested in the use of VR is poor communication. Besides the possibility of disseminating their results on official publications in scientific journals or conferences, they do not have many options to collaborate. Further, most groups are disseminated in different countries and this poses further limitation to the integration of their efforts.

In an attempt to overcome this problem, we have created a website (http://www.neurovr.org) that allows VR researchers to share knowledge and tools generated by their research. The website is designed as a virtual laboratory, where clinical professionals and researchers can interact to foster progresses on their respective application fields. The website contents are in English and provide different types of information and resources. The main section is dedicated to the NeuroVR software. From this section, users can download the latest release of the application, the video tutorials, and the manuals of use. The dissemination section includes an introduction to VR and its various applications. Further, the portal include online usability questionnaires, which NeuroVR end users can fill out to evaluate the system. This feedback is then used by the NeuroVR developers to fix ergonomics problems and bugs. Finally, a scientific section provides users with the latest results and clinical protocols developed by the research community.

5 Conclusions

Although VR has finally come of age for clinical and research applications, the majority of them are still in the laboratory or investigation stage. Key limitations to the adoption of this approach include the lack of standardization in VR hardware and software, and the high costs that are required for building and testing a VE from scratch. Actually, the development of a VE requires special software and programming skills that are often unavailable for researchers and clinical professionals. Further, the majority of existing VEs are proprietary and have closed source, meaning that they cannot tailored to fit the needs of a specific clinical or experimental setting.

In this paper, we have described the main features of NeuroVR, a cost-free virtual reality platform used for therapeutic and research applications. NeuroVR allows non-expert users to easily customize a VE, by using a set of pre-designed virtual scenes, and to display them using either an immersive or non-immersive system. A future goal is to provide software compatibility with instruments that allow collection and analysis of behavioral data, such as eye-tracking devices and physiological sensors.

The NeuroVR software is available for download on the NeuroVR project website which has been created to provide researchers and clinical professionals interested with state-of-the art information on VR hardware and software as well as the latest clinical protocols published by the VR community.

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