The Collaborative Virtual Reality Neurorobotics Lab

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Abstract

We present the collaborative Virtual Reality Neurorobotics Lab, which allows multiple collocated and remote users to experience, discuss and participate in neurorobotic experiments in immersive virtual reality. We describe the coupling of the Neurorobotics Platform of the Human Brain Project with our collaborative virtual reality and 3D telepresence infrastructure and highlight future opportunities arising from our work for research on direct human interaction with simulated robots and brains.

1 Introduction

The *Human Brain Project* (`www.humanbrainproject.eu`) is an interdisciplinary European research project, in which scientists from neuroscience, medicine, physics and computer science work together to simulate the human brain in the computer. In the Neurorobotics subproject, the simulated brain models are connected to robots in order to investigate how the brains react to stimuli in order to develop brain-inspired robot controls. For this purpose, the *Neurorobotics Platform* (NRP) [11] was developed, which facilitates the creation, execution and evaluation of brain-controlled robot simulations.

In this paper, we describe our vision and progress towards a collaborative Virtual Reality Neurorobotics Lab, which adds an immersive interface to the NRP. To this end, we coupled the NRP with an innovative soft- and hardware infrastructure for collaborative virtual reality. In a first step, multiple users can observe and test the control of robots by the virtual brains in virtual environments. In a second step, the users will be integrated into the robot simulations by realistic avatar representations. Hence, our system does not only allow users to observe and interact with the simulated robots in real time but also enables robots to detect the avatars through their virtual sensors and react accordingly.

This work-in-progress paper is organized as follows. First, we provide brief overviews of the Neurorobotics Platform and our collaborative virtual reality systems. Afterwards, we present our combination of both technologies, which enables the exploration of neurorobotics experiments for multiple users in immersive virtual reality. Finally, we highlight our vision of future interaction opportunities for developers and users of the Neurorobotics Platform.

2 The Neurorobotics Platform

In the Human Brain Project, scientists aim to advance our understanding of the human brain and to develop novel brain-inspired technologies. Generally, the human brain exercises control over a body to manipulate its environment and thus, through means of the body, it learns in a feedback loop with the world. The Neurorobotics Platform [11] is an open-source system that combines robot simulation and spiking neural network technologies to enable the simulation of robot bodies controlled by virtual brain models. The NRP facilitates the setup and execution of real-time closed-loop simulations in physically-simulated virtual environments that generate realistic responses for simulated robots and brains.

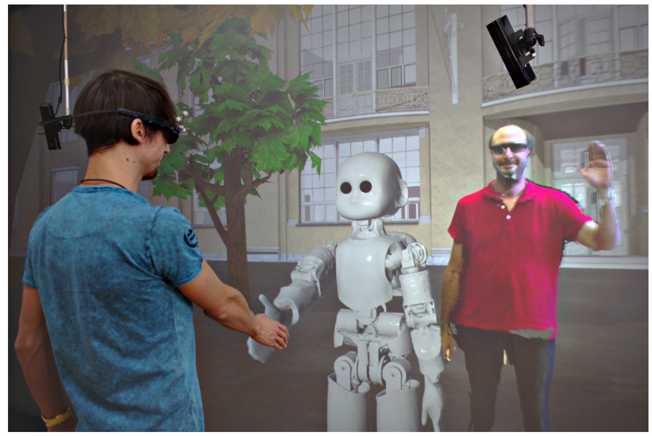

Figure 1: A local user meets a virtual robot and a remote user inside our proposed collaborative Virtual Reality Neurorobotics Lab. Each user perceives a correct stereoscopic view of the virtual environment. In addition, the users are captured by multiple RGBD-sensors and are represented as 3D video avatars in real-time using our telepresence system. Consequently, beyond exploring the virtual experiment, users are part of the virtual environment and are thus able to influence the neurorobotics simulation.

The NRP is based on a closed-loop engine, a software abstraction which enables the connection of robot simulators with a number of different brain-inspired, classic or neural network-based controllers. As of today, the Closed-Loop Engine uses Gazebo [12] as the world simulator, and Nest [9] or Nengo [5] as neural simulators. Gazebo relies on open-source rigid body dynamics simulators and has been augmented with a muscle simulation framework. The virtual world is connected to neural simulators via transfer functions, enabling neuroscientists and roboticists alike to specify the precise nature of data exchange between the world and brain simulators.

The NRP is a client-server application, which allows for both web and non-web clients. The web frontend, also called Web Cockpit, is a low resolution client replicating the 3D world in a browser-embedded OpenGL framework. In addition, the NRP supports a number of high-resolution clients and frontends, which can even be used simultaneously to visualize and interact with a single simulation. In this work, we extend the NRP with a collaborative VR frontend and 3D telepresence capabilities.

3 Collaborative Virtual Reality

Immersive virtual reality enables the realistic and plausible experience of virtual environments and interactions with the virtual world

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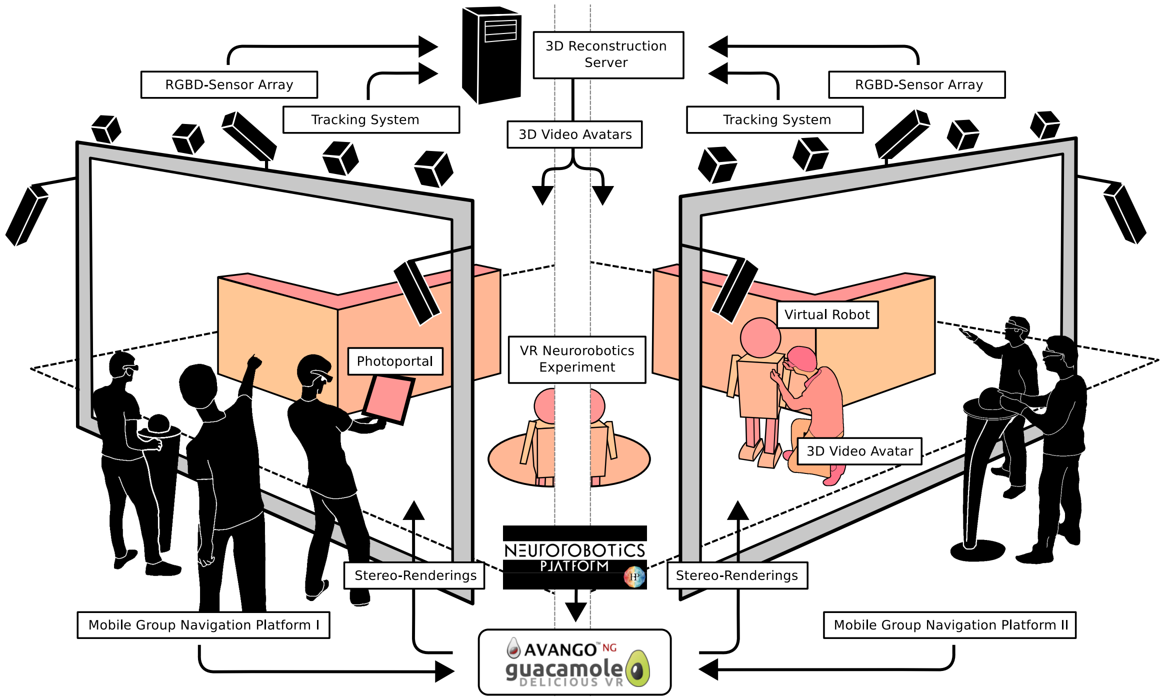

Figure 2: Schematic illustration of two remote groups participating in a shared virtual experiment involving two robots. Each group is located in one of our VR Neurorobotics Labs in front of a large stereoscopic multi-user projection wall. Each user is tracked and provided with individual stereoscopic views of the virtual world. In addition, both groups are captured by multiple RGBD-sensors and represented in the virtual space in form of 3D video avatars in real time. In the illustration, a remote user is represented in the virtual environment as a 3D video avatar while inspecting a virtual robot. Our immersive group-to-group telepresence system enables full-body participation and immersion of up to 12 users in a neurorobotics experiment. Spatial audio facilitates verbal communication between groups. Each multi-user projection setup is represented as a group navigation platform that moves the whole group through the simulation.

and other users. This offers important advantages for the observation, discussion, and understanding of neurorobotics simulations running on the NRP. The resulting activities of the simulated robots can be presented in various forms, but immersive virtual reality can trigger realistic human reactions [20]. We believe that this can be helpful for the evaluation of complex behavior of the virtual robots and their brain-inspired controls.

Our research focuses on collaborative virtual reality systems that allow multiple users to jointly experience themselves and others interacting with virtual environments. Being able to interact with other human collaborators creates a shared social experience that enables all participants to manipulate and discuss virtual content in real time. This collaboration can be *collocated* for users in the same physical location and *remote* between different locations using immersive telepresence technologies.

3.1 Collocated Collaboration

Most virtual reality interfaces were designed for single users, which prevents the collaborative exploration of virtual content. However, several research prototypes demonstrated advantages of multi-user collaboration in virtual reality (e.g. [1, 8, 10]). These systems allow the perspectively correct and consistent visual perception of virtual 3D objects in a shared interaction space.

Our setup is based on projection-based multi-user virtual reality systems, which provide up to six users with individual stereoscopic views of a virtual environment [13]. We track the movements of all users in front of the projection screen and display their corresponding perspectives using stereoscopic rendering. Two dedicated 360 Hz projectors display the twelve different images for the six users. The users' image pairs are displayed in a time-sequential manner, and the left and right eyes are separated by circular polarization. A user can perceive their corresponding stereo pair at an update rate of 60 Hz by wearing synchronized custom shutter glasses. As a result, the physical space including the bodies of each user and the displayed virtual scene merge into a coherent mixed reality. Navigation of the group through the virtual scene is provided by a large central input device (Spheron) accessible to all participants.

3.2 Remote Collaboration using 3D Telepresence

Recent developments in 3D telepresence offer a communication platform that enables people to virtually meet in spatially consistent virtual or augmented environments [4, 7, 15–18]. A fundamental basis for mutual awareness and exchange in such distributed settings is the representation of the users by avatars. When using abstract or computer-generated avatars, however, many facets of a user's facial expression and gestures might not be represented well [18]. Instead, modern immersive telepresence systems use realistic three-dimensional user representations (3D video avatars), which is a key to mutual awareness and trust [4, 6, 17, 18].

Our in-house immersive group-to-group telepresence system [4] builds on state-of-the-art technology. At its core, we use multiple calibrated 3D capturing systems based on color and depth (RGBD) sensors [2, 3], projection-based multi-user displays [13], and the virtual reality framework *Avango/Guacamole* [19, 21]. *Avango/Guacamole* features an efficient distributed 3D reconstruction pipeline to create realistic life-size 3D video avatars from the captured RGBD-sensor streams in real-time. The 3D video avatars are simultaneously exchanged over a network between remote locations and are seamlessly integrated into a shared virtual scene. Therefore, each local user can perceive the poses, gestures as well as facial expression of the remote users in real time and vice versa.

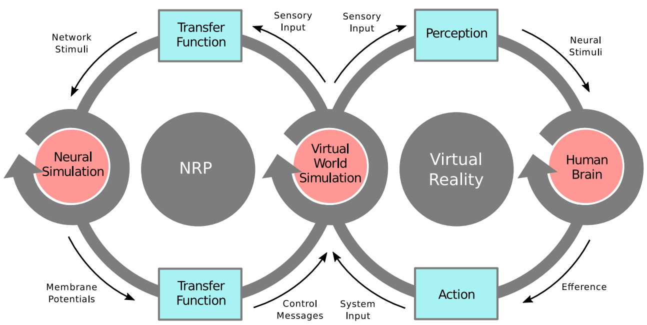

Figure 3: The VR Neurorobotics Lab connects the human perception-action loop with real-time closed-loop neural simulations in physically-simulated virtual environments. This allows us to experiment with realistic responses of simulated brains as well as realistic behavior and reactions of real humans using our systems.

Figure 4: Two users stand in front of a multi-user virtual reality projection wall. The user on the right uses a group navigation device (Spheron) to follow a robot through a simple maze.

4 The VR Neurorobotics Lab

We believe that modern virtual reality technologies provide a unique opportunity to explore, understand and participate in behavioral simulations. In our collaborative Virtual Reality Neurorobotics Lab, we integrated neurorobotics simulations into our state-of-the-art VR framework, which enables collocated and remote participation in a real-time neurorobotics simulation. Figure 2 shows a schematic illustration of a spatially distributed Virtual Reality Neurorobotics Lab, where two remote user groups work on a shared neurorobotics experiment using multi-user VR technology. The simulation of the experiment is handled by the Neurorobotics Platform, which distributes the resulting changes to the render clients driving the multi-user projection walls. Figure 4, for example, shows two collocated users in front of a multi-user projection wall jointly observing a neurorobotics experiment, in which a virtual robot brain is trained to perform basic wayfinding tasks. Figure 1 shows a local user interacting with a virtual robot together with a remote participant using our telepresence system. Eventually, we will feed interaction inputs by users of the system back into the simulation, allowing the participants to directly manipulate any object of the experiment in real time. This will fully integrate the human perception-action loop with robot simulations of the Neurorobotics Platform in a shared virtual environment (see Figure 3).

Our 3D video avatars will allow the collocated participants to use natural full-body language to interact with the simulated entities by the Neurorobotics Platform and remote human collaborators. Using our immersive multi-user virtual reality display hardware, the users of our lab become a part of the experiments themselves rather than just being distant observers. This enables users to perceive the experiments in a very natural and realistic fashion. In particular, experiments can also be perceived from the robot's perspective or by looking over the robot's shoulders, which enhances the understanding of the studied simulations. Moreover, direct 3D interaction with the shared virtual environment facilitates the generation of training data for robots, for example by direct gestural demonstration.

The integrated telepresence capabilities allow spatially distributed researchers to realistically meet each other in the virtual environment. In conjunction with a spatial audio implementation, this enables a very natural form of discussion among the collaborators. Expert analysis tools like Photoportals [14] help to enhance this discussion by providing additional access points to the scene for direct comparisons. Our 3D video avatars can also be recorded and played back later, which can help e.g. to investigate the effects of different brain models using identical visual stimuli.

5 Conclusion

We are in the process of developing and setting up the software and hardware infrastructure for an advanced virtual reality lab for the collaborative and immersive exploration of real-time neurorobotics experiments. In summary, we identify the following central benefits of our proposed collaborative Virtual Reality Neurorobotics Lab:

- **Perspective Taking:** An experiment can be immersively experienced from various viewing angles, including the robot's perspective.
- **Real-World Inputs:** Robot brains can be trained with and react to complex inputs coming from real human full-body postures, gestures and movements.
- **3D Telepresence:** Spatially distributed researchers can meet in ongoing experiments and discuss about them as if they were standing next to each other.
- **Human-Robot Interaction Studies:** Rich, realistic and natural interactions between virtual robots and humans that can be recorded and played back for reproducible studies and improved evaluations.

Overall, the collaborative Virtual Reality Neurorobotics Lab has the potential to improve the understanding of neurorobotics experiments and facilitates the discussion and decision making processes among spatially distributed scientists.

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