VR Re-Embodiment in the Neurorobotics Platform

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ABSTRACT

We present the re-embodiment of human users inside the Neurorobotics Platform [8] as a work-in-progress. The Neurorobotics Platform (NRP) is built to design and perform robot embodiment experiments in simulations. Virtual experiments consist of a simulated environment as well as artificial actors in the form of robots with simulated brains. The goal is to allow users to spawn their personal humanoid robotic body into an experiment, take control over it through VR hardware and with this become active participants in experiments alongside and in cooperation with the simulated robots/brains.

KEYWORDS

virtual reality, embodiment, re-embodiment, neurorobotics

1 INTRODUCTION

The Neurorobotics Platform

To give a brief overview, the NRP allows simulated robot embodiment experiments. Such a simulated experiment traditionally features three main components:

- a brain simulation (spiking neural networks)
- a robot simulation with actuators and sensors that are connected to the brain simulation (the embodiment of the brain)
- an environment simulation providing input and output interactions with the robot's actuators/sensors

We will use the colloquial short term "robots" for the combination of brain and robot body as a distinct entity within an experiment and differentiate them to the "avatar" - the artificial humanoid robotic body that the user controls. The term (NRP) experiment here refers to an instance of such a setup with all components being present, where the robot(s) and the avatar(s) are part of the same experimental environment.

MuC'19 Workshops, Hamburg, Deutschland

https://doi.org/10.18420/muc2019-ws-585

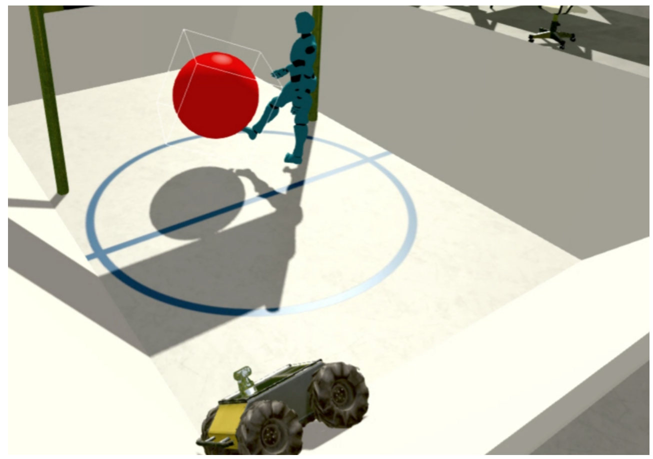

Figure 1: Avatar being controlled to kick a ball.

The Goal

The goal is to extend the NRP's features and make it a platform where VR/robot re-embodiment experiments as well as natural human behaviour and task performance are part of the ecosystem, serving as a base for future research. This work focuses on how to bring humans into the NRP's virtual experiments using VR devices. The idea is to create a humanoid robotic body (the avatar) and let the user take control over it, i.e. re-embodying the user inside this avatar. Then this new body is placed into a simulated NRP environment, allowing the user physical interactions with the environment and its other inhabitants (the robots). Both the user-controlled avatar and the brain-simulation-controlled robots are actors with their own agency. They are also subject to the same physics simulation, meaning they can possibly run into each other and their bodies will react to the resulting forces.

There are several reasons why one might want humans re-embodied inside an experiment with their natural human movement and behaviour:

- When it comes to humans, scripted or otherwise non-interactive simulations of human behaviour might be insufficient or not feasible at all.

- Imitation learning is an interesting approach for training brain models [5–7, 17]. Human performance of a task could provide good training data to learn from and further support imitation learning approaches.
- Human-Robot-Interaction experiments could be performed with increased realism inside the platform.
- Robot re-embodiment experiments could be simulated on the platform [1, 2, 12, 18]. Scenarios where robot re-embodiment would be useful mainly focus on hazardous, catastrophic or far-away environments. Simulating these could save time and money.

This should also serve as a platform for investigations on how the user's sense of body ownership over the avatars artificial body can be best achieved. The final goal is to have interactions inside the virtual environment that feel natural to the user. Another work by Matthes et al. [14] also investigated integrating users into the NRP on a visual level while this work focuses on physical interaction.

As the NRP is an open development platform, the goal was to find solutions that are accessible from a cost and setup perspective and also re-usable and extendable by others. Therefore, the hardware used exclusively consists of standard available consumer products (HTC Vive) and all software components are available or provided openly.

2 RE-EMBODIMENT: HANDLING DISCREPANCIES BETWEEN TWO REALITIES

Embodiment vs. Re-Embodiment

Besmer [2] already explored these two terms and used perceptual "distance" to distinguish between them. He argues that without proprioceptive or tactile feedback from the artificial objects extending our agency - i.e. the one that should be embodied - we have to rely on pure visual feedback. He uses this distinction to draw a line between, for example, a tool held in hand that can with time and practice become transparent in its use to the wielder (much like a typical VR/game controller where you stop thinking about the button press itself) - becoming part of the wielder's body schema. In contrast, the "remote" avatar is part of its distinct (simulated) reality and as such is always the subject of (more or less) conscious control effort - therefore staying at the level of body image integration.

In the current state of implemenatation, if the avatar's arm is pushed aside there is no feedback to the user without looking at the arm. We follow Besmer's argumentation and therefore find the term re-embodiment to be more fitting in this context.

Re-Embodiment in VR

The goal is for the avatar to replicate the posture of the user wearing the VR devices as close as possible. The general idea is to use the tracking information to approximate the user posture inside our VR client. The VR client can communicate this target posture to the simulation server where the avatar controllers can then try to reach this target. Since we use the HTC Vive room-scale tracking and want to keep the complexity of the setup to a minimum (i.e. make it quick and easy to use), we rely on a reduced number of tracking targets for an inverse kinematics solver that gives us the estimate posture without relying on full-body tracking. Comparative studies from Roth et al. [16] showed that this is a viable approach for embodiment.

However, any re-embodiment scenario is dealing with two different "realities" that potentially diverge. In this case it is, on the one hand, the reality of the VR user standing inside the room-scale tracking volume and, on the other hand, the avatar inside the simulated experiment.

Consider a situation where inside the experiment's environment there might be a blocking object for the avatar, e.g. a wall, while the user could be free to move within the bounds of his/her room-scale tracking setup. As the re-embodiment scenario should not break the physical boundaries of the experiment environment the avatar might simply not be able to follow all movements that the user is free to perform, e.g. taking a step through where a virtual wall exists. Conversely, forces affecting the avatar will not affect the user. If, for example, the robot were to hit the avatar then either of them might be pushed to the side. Outside forces affecting (parts of) the avatar can move it away from a user's resting position.

If the stereoscopic viewpoint on the VR HMD would be attached the avatar's eyes these two scenarios would reflect typical circumstances for inducing cyber sickness [11], especially if movements of the avatar's head are not consistent with the user's head movements. Additionally, any divergences in positioning is potentially disorienting to the user, e.g. if the avatars arm or leg movement was blocked and the user did not receive any feedback this is happening. For these reasons we introduced a client-side instance of the avatar with ghostly appearance indicating the approximate posture of the user (see Fig.2). This way the user would get visual feedback on the differences between his estimate body pose and the avatar's body pose.

This decision opens up another point for investigation. Embodiment experiments like [4, 9, 13] show the importance of temporal correlation between the proprioception of body movement and its visual feedback. Here we have two concurrent visual expressions of the artificial body that are identical but one is lagging behind the other (network latency, physical simulation process). The question is then how this affects a sense of embodiment for the user. Does the ghostly client-side appearance take precendence over the delayed avatar body and diminish any embodiment for the

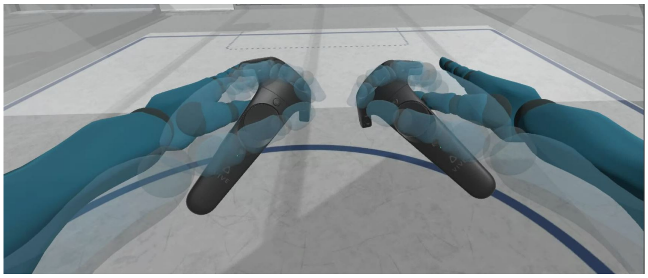

Figure 2: First-person view of arms. Ghostly client-side target posture as well as real avatar in the process of assuming the same posture. Vive controllers as hand targets for IK also included.

remote body as it is more closely correlated with the user's movement?

Solutions presented by Boldt et al. [3] and Rietzler et al. [15] could prove valuable in extending the feedback to the user beyond visuals and improve embodiment of the avatar in the future.

3 TECHNICAL IMPLEMENTATION AND DIFFERENT APPROACHES

For the avatar model, an openly available rigged model was used and imported to both the Unity client and the NRP running Gazebo [10]. The intention was to make any rigged model usable and have a flexible process.

The NRP itself ran on a server, constantly sending simulation updates so a VR client (Unity3D) could create a live reconstruction of the experiment. This setup allows multiple users to connect to the same simulation. To increase availability and usability of our approach we focused on consumer VR hardware (HTC Vive Pro + 3 Vive Trackers) to capture target poses for head, hip, hands and feet and then estimate the user's posture through inverse kinematics. This target body posture would then be communicated back to the server. For the server-side avatar controller two mechanisms were tested.

First, the "puppeteering" approach would take the 15 individual body parts and apply linear velocities on each of them in order to drag them to their target positions - much like strings attached. Even though the effective velocity was regulated via a PID controller it still showed problems like overshooting rotations resulting in continuous piruettes or "entangled" states where two parts would pull in opposite directions, keeping each other from reaching their target. More involved mapping approaches like Stanton et al. [18] could help finding the right PID parameters but the hierarchical dependency between the body parts seemed to cause many of the problems as each part dragged the connected along.

Second, a more traditional robotics approach of PID position controls for the 14 joints showed more promising immediate results. Linear and angular velocities had to be applied to the hips to control the global pose of the avatar which caused the rest of the body to be dragged behind but this behaviour could be reduced to acceptable levels for natural movements.

4 CONCLUSION

We illustrated that it is possible to create VR re-embodiment experiments within the NRP that integrate humans in a physical manner into the experiment using an avatar. The control mechanisms for the avatar offer a wide space for future research and optimization until a much improved re-embodiment with fast and natural movement of the avatar is achieved.

The focus on usability and accessability hopefully serves as an easy starting point for other researchers interested in the fields of imitation learning, human-robot-interaction or VR re-embodiment experiments that might find the NRP a useful tool to conduct their research.

A combined approach of the exceptional visual fidelity that Matthes et al. [14] offer with the physical integration of the approach presented here would be very interesting to conduct in the future.

5 ACKNOWLEDGMENTS

This research was supported by the HBP Neurorobotics Platform funded from the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 785907 (Human Brain Project SGA2).

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