Developing a Situated Virtual Reality Simulation for Telerobotic Control and Training

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Abstract. In this paper, we present the development of a situated virtual reality simulation for control and training in a telerobotic mining setting. The original research scenario is derived from a real-world rock breaking task in mining teleoperation. With the intention of having better situational awareness and user control model for this application, we simulate the entire setting in a 3D Virtual Reality (VR) environment. Therefore, users are able to obtain more information (e.g. depth information) and feedback from the remote environment in this simulation than only working with real video streams from the remote camera(s). In addition, the concept of natural interaction has been applied in building more intuitive user control interfaces than conventional manual modes. Both human eye gaze and head movements have been used to develop natural and interactive viewpoint control models for users to complete the teleoperation task. By using such a 3D simulation, training in the complex teletobotic control process can be effectively carried out with the capability of changing visual and control conditions easily. A user study has also been conducted as the preliminary evaluation of the simulation. Encouraging feedback has been provided by the experimental participants regarding task learning, which suggests the effectiveness of using the simulation.

Keywords: situated virtual reality, simulation, training, telerobotic control, teleoperation, 3D models, natural interaction, eye tracking, head tracking.

1 Introduction

Virtual Reality (VR) environments have been used extensively in a variety of fields, such as video games [13], industrial applications [1], medical simulations [4], education and training [9], and so on. VR environments are commonly recognized as computer-based simulations through which users can interact with virtual objects or stimuli that are modeled from the real world. Using such environments offers users numerous advantages and benefits such as being immersive, interactive and cost-effective.

There has been much research and development work regarding using virtual reality techniques to construct simulations for different types of teleoperation applications. Conducting effective training to improve user performance is the common motivation

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of building VR based simulations. In this research, we developed a virtual reality simulation which is able to connect to the modeled setting in the real world. By connection to the modeled setting, we mean the interaction between the user and the VR environment will have the same effect as the modeled setting in the real world. In terms of training purpose for using such simulations, it would provide us extra feedback from the real setting compared with only using pure VR environments.

Apart from the common advantage of using VR in teleoperation, which offers depth information [7] for the remote environment, we also import natural human interaction (e.g. eye gaze and head movements) into the user control part of the simulation. The entire motivation of this research work is to develop a VR simulation that is a sufficiently good 3D representation of reality with an improved user control interface by using natural interaction for the effective training in a particular mining teleoperation setting.

2 Development

The original mining teleoperation setting considered in this research development is a telerobotic control system for conducting remote rock breaking task in mining [2]. A lab-based version of the remote control system has been built mainly for demonstration and testing.

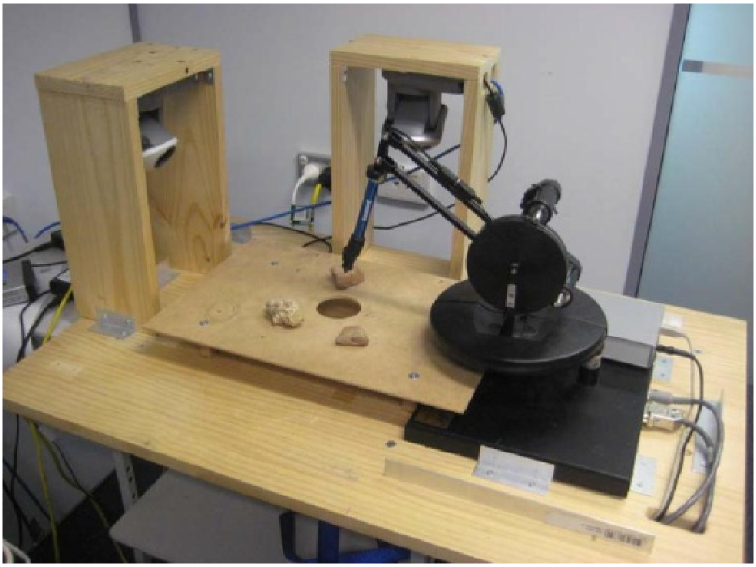

Fig. 1. The real lab-based rock breaker setting

As shown in Figure 1, the real lab-based rock breaker setting consists of a robot arm as the major control device which is very similar to the one used in the real mining setting in terms of its physical structure and possible movements. In addition, a pair of cameras has been integrated into this setting to provide real-time visual feedback from the remote environment back to the user to complete the mining teleoperation task.

2.1 System Architecture

The developed virtual reality simulation for the lab-based setting consists of several components:

1. 3D model of the entire environment
2. User control interface for devices
3. Real-time tracking of rocks
4. Natural interaction based virtual camera control

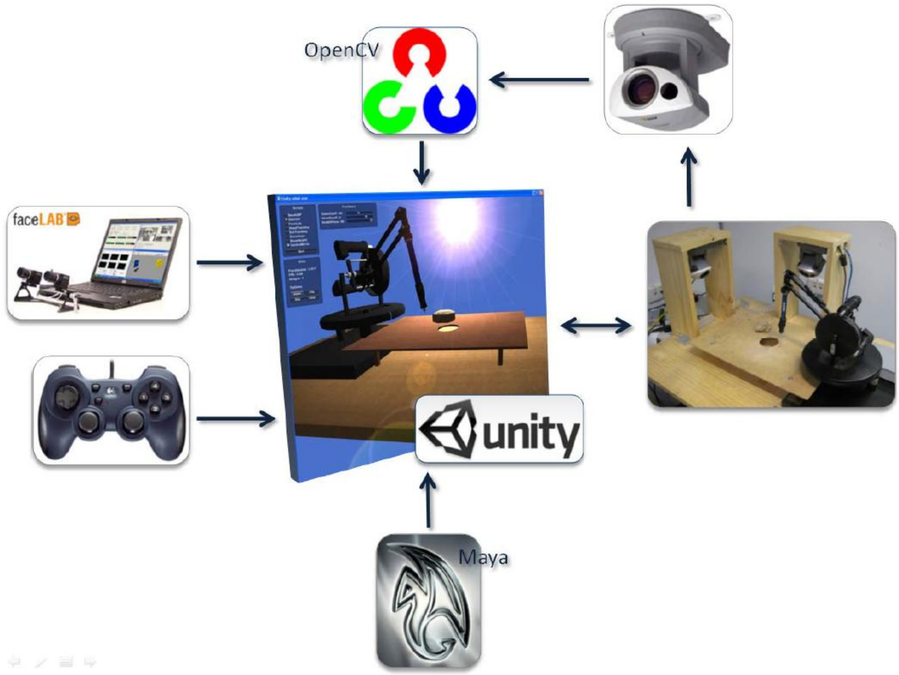

Fig. 2. Overall system architecture for the simulation

The overall VR simulation system architecture is illustrated in Figure 2. A number of software tools as well as hardware interfaces are used to develop the VR simulation. The major difference from building a traditional VR simulation is this system connects the VR environment to the real world setting which is being modeled.

2.2 3D Modeling

The 3D modeling for the entire environment setting is done in Maya [5]. As shown in Figure 3, the modeled virtual objects for being used in the simulation include the robot arm, wooden board and rocks. These models are only static 3D objects therefore they then have been imported into Unity3D [8] to have relative physics in animation (see Figure 4), such as all the possible movements of the robot arm.

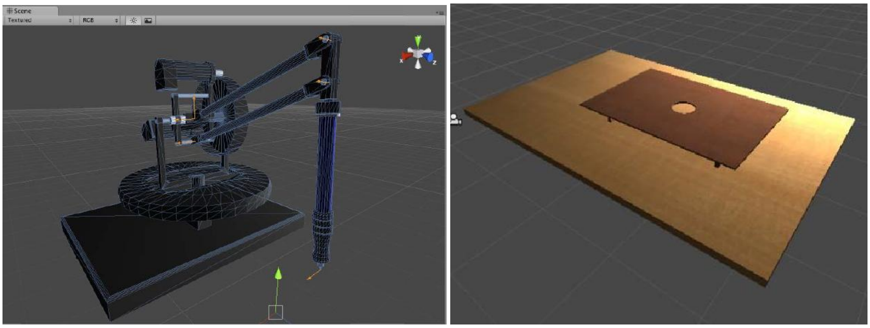

Fig. 3. 3D modeling in the simulation

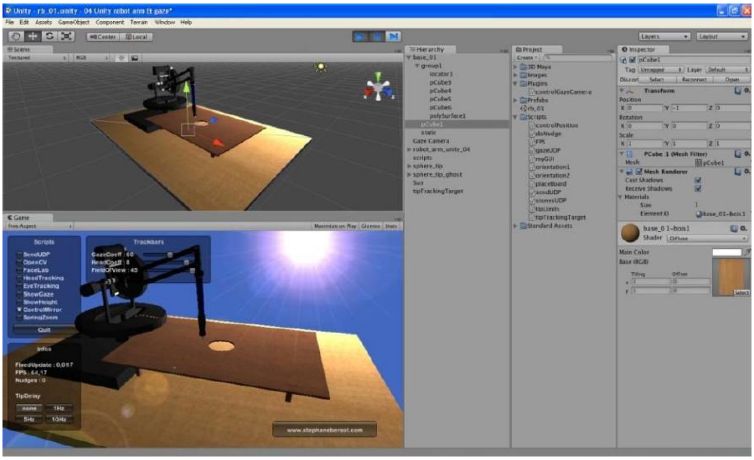

Fig. 4. Simulation in Unity3D

2.3 User Control Interface and Feedback

There are many options for user control interface to connect to the simulation in Unity3D platform. Conventional interfaces for instance mouse and keyboard are not always appropriate for a teleoperation task. Therefore, we chose to integrate a standard Logitech Dual Action Gamepad (see Figure 5) as the major user control interface for our simulation because it is easy to use, simple to implement or integrate into systems and cheap to replace.

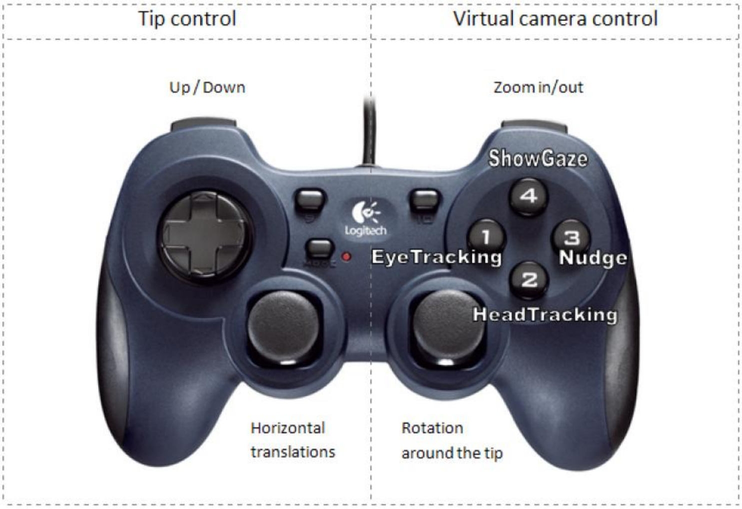

Fig. 5. Gamepad as user control interface

The 3D model of the robot arm is connected to the real robot arm via a UDP network. In practice, it is possible to encounter situations like the real robot arm is moving slower than the virtual one because of network latency or the real one can even be stuck at some point due to unexpected circumstances. Therefore, it would be very helpful for users to have visual feedback regarding the position difference between the virtual robot arm and the real one when such situations occur. In the simulation, we implemented a feature (called "*ghost*") to satisfy this requirement.

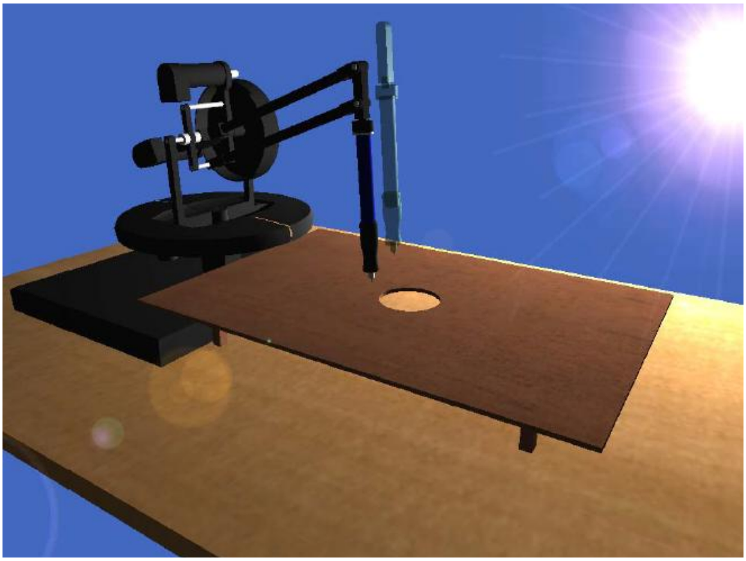

Fig. 6. The *ghost* robot arm

As shown in Figure 6, the *ghost* is actually a second 3D robot arm with a different colour and transparent pattern. It will appear when the position difference/error between the real robot arm and the virtual one exceeds a pre-defined limit. In this way, users have a direct visual feedback of the real robot arm's current position through the *ghost* and the position of the virtual robot arm which represents the intended position to move to.

2.4 Vision Based Rock Tracking

In order to simulate the movements of other objects especially for the rocks in the simulation, we developed a computer vision based rock tracking software approach. This solution is implemented by integrating OpenCV [6] into our simulation with further development of particular software functions for real-time rock tracking.

The basic feature used for the rock tracking is the colour information of the rocks as it is distinguished from other objects in the environment. Figure 7 shows the process of how the rock tracking works by our software solution on top of OpenCV. It takes the real-time video images from the remote cameras (shown in Figure 1) as the source inputs, then feeds them into a filtering function to convert the colour images into black and white where the white bits represent the rocks which need to be tracked. After completion of the filtering process, the position data of the detected rocks will be sent to Unity3D to create corresponding virtual rocks in the simulation. The entire process happens in real-time and it is capable of tracking multiple rocks simultaneously.

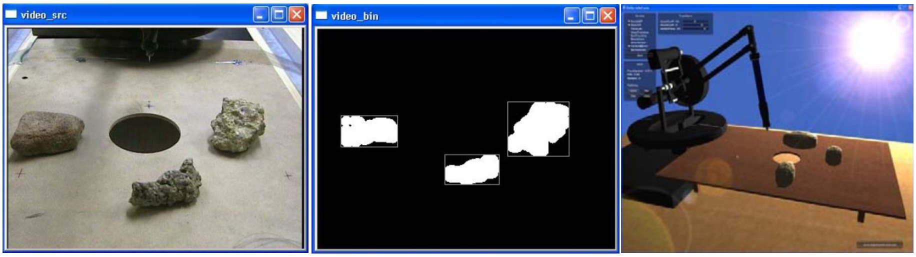

Fig. 7. Rock tracking using OpenCV

2.5 Head Movements and Eye Gaze for Viewpoint Control

The default implementation of virtual camera viewpoint control for the simulation is using the Logitech gamepad. However, recent research has also pointed out the effectiveness of using natural interaction such as human head movements [11] and eye gaze [12] as alternative user inputs for the camera viewpoint control in teleoperation settings. In order to develop such camera viewpoint control modes which are more intuitive than conventional manual interfaces, we integrated another external gaze and head tracking system (*FaceLab* [3]) into our simulation.

The *FaceLab* system (see Figure 8) is a computer vision based tracking device which provides the real-time head and gaze tracking at a 60 Hz frequency without the use of markers. This avoids the need to make the user wear any specialized sensors on their head, offering comfort and flexibility. Head mounted trackers may provide more accuracy and a higher tracking frequency but they are not comfortable to wear for long, therefore they were not considered for our simulation.

Fig. 8. The *FaceLab* tracking system

The detailed control mapping of using head movements and gaze for the virtual camera in our simulation uses head movements to control the camera position and zoom in/out, and using eye gaze to control the camera pan and tilt functions. This means when a user moves their head either left or right enough (more than a defined threshold limit), the virtual camera in the simulation will start to rotate clockwise/anti-clockwise around the robot arm with a constant speed. Moreover, if the user leans their head towards/backwards to the screen, the virtual camera will carry out corresponding zoom in/out functions. Another essential feature of developing such virtual camera control modes is this will effectively allow users to handle the common multi-tasking situation in teleoperation [10].

3 Preliminary User Study and Feedback

Compared to the relatively large number of features we intended to test in the simulation, we had a limited number of experimental participants available in the available time frame. Therefore, only a preliminary user study was conducted as the initial evaluation for the VR based simulation at this stage.

The actual experimental setup is shown in Figure 9. A total of 12 volunteers from a local university successfully participated in the study, including 8 male and 5 female, ranging from 21 to 49 years of age (M_{age} = 27.5, SD_{age} = 7.1). All of them were regular computer users (at least 1 hour a day) either enrolled in a computing/IT related major or working in close areas. They all had prior experience of using a gamepad interface for video games. None of them had any previous experience on any eye tracking or head tracking interfaces as well as the simulation. Several participants had corrected vision but all the participants' eye gaze could be calibrated with the tracker successfully in the user study.

Participants took part in the user study individually. Their experimental task was trying to nudge as many rocks as they could into the hole on the board in a limited task completion time, which was similar to the rock breaking process in the real mining setting. Each participant was given 3 one-minute working time period and in between they were asked to stop as the experimenter would be placing rocks back on the board. The number of rocks each participant completed within the limited time period was recorded as the performance measure. In addition, they were requested to give subjective comments regarding their experience of using this simulation after the completion of the experiment.

Fig. 9. The experimental setup

The overall performance was quite good. Regardless of previous video game experience, every participant was able to complete 4-7 rocks per minute on average. The best ones were able to finish 9-10 rocks per minute on average and the slowest participants did about 3-4 rocks per minute on average.

On the other hand, the subjective feedback from these participants was very encouraging as well. A majority of the participants directly commented that they were able to effectively carry out the rock nudging task in the simulation and they all agreed that this could be a useful training tool for the mining teleoperation task.

They were able to pick up the user control for the devices quickly and they felt the control interface as well as the control mapping was not difficult to get used to. Most participants commented that the entire experimental task was quite competitive and exiting, they felt their performance would be better if they had a bit more time for practice in the simulation.

Almost every participant gave feedback that the head and eye tracking interface for virtual camera control was very interactive and useful for this multi-tasking setting as they had to control the virtual camera and the robot arm simultaneously. Especially for the head leaning to the camera zooming control, they all commented that this was intuitive and exiting.

4 Conclusion and Future Work

In this research, we present the development of a virtual reality simulation for the training of a mining teleoperation task (rock breaking). The entire development includes implementation of the 3D modeling, user control interface, vision based object tracking and natural interaction based virtual camera viewpoint control. A number of features have been implemented in order to enhance user experience of using this simulation. From the results of the preliminary user study reported, initial positive feedback on the effectiveness of using this simulation for the training of the mining teleoperation task has been demonstrated by the experimental participants.

Future work will involve a formal empirical user study for the simulation in terms of different control conditions and testing features. Further improvement on development of the simulation would also be considered in terms of practical deployment of the simulation. Further future enhancements include improving the quality of rock tracking and being able to detect rocks when they are very close to each other.

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