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Remote Lab meets Virtual Reality – Enabling immersive access to high tech laboratories from afar

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Abstract

Virtual Reality is currently one of the strongest trends in the consumer and gaming industry, while the typical Remote Lab in engineering education uses traditional 2D visualization options for desktop PCs. In this paper those two domains were combined by establishing state-of-the-art frontends for an existing engineering education Remote Lab. As the whole nature of this approach is experimental, the authors aimed at a variable degree of immersion and established two different approaches for the creation of a virtual environment. The first approach is to display the representation of the physical laboratory with 360°-images in a Street View type fashion. The second approach is a completely reconstructed virtual 3D-model of the existing physical laboratory. Both approaches were realized with the Unity engine and tested in the concerning laboratory.

Keywords: Remote Lab; Virtual Reality; Engineering Education; Unity Engine; LabVIEW;

1. Introduction

Remote Labs and Virtual Reality are much discussed tools in the educational context. They offer a practical and motivating way for teaching students and are therefore an interesting subject for scientific research [1].

The term “Remote Lab” describes laboratory experiments that can be controlled and monitored remotely from a distant location [2]. This offers numerous advantages in education scenarios in comparison to a classic laboratory [3]. An advantage is the possibility that Remote Labs can be supplied to a vast number of students around the world, that otherwise would not be able to access the physical laboratory [4]. The access to a Remote Lab can render the need of a real physical laboratory at one’s own location redundant. Therefore, a smaller number of physical laboratories are needed to reach a greater number of students, leading to a reduced amount of wasted resources and

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work needed to sustain a fully functioning laboratory. This making Remote Labs a sustainable alternative to physical laboratories.

Before accessing a Remote Lab and starting the experiments, it is often necessary for the users to acquire the needed skills to conduct the remote experiment in an appropriate and safe manner. Safety in this context means "without damage to the equipment", as the user is in a safe remote location away from the experiment. This leads to a high responsibility for the user, which can have a positive effect on the user's motivation [5]. Although Remote Labs already are a great educational tool, the user experience can still be optimized for example with immersive Virtual Reality User Interfaces [6], [7].

In general, Virtual Reality is a term used for depiction techniques that mimic the real world [8]. Depending on the level of detail, users can practically dive into the corresponding simulations and gain experiences that sometimes even surpass those of real surroundings. Therefore, Virtual Reality is a powerful tool that is often used in an educational context [9].

The goal of this contribution is to combine a Remote Lab and Virtual Reality in a way that those educational techniques benefit from each other and amplify the educational value. Pruna et al. have shown that a Virtual Lab for a cascade control can be controlled and monitored with a Human Machine Interface via virtual reality [10].

The motivation for the paper at hand is to participate in educational efforts to expand teaching into digital worlds, as presented by Frerich, S., Heinz, E. & Müller, K. [11], and to enable future efforts to modernize LabVIEW based laboratories for widely available and barrier-free access.

2. Aims and Requirements

This work is based on a previously built Remote Lab, addressing fluid flow in porous media. The general goal for the paper at hand is to increase the immersion for this existing Remote Lab by changing its Graphical User Interface (GUI or frontend), which is based on the legacy LabVIEW browser-plugin, to mimic the experience in the actual physical laboratory. To achieve this goal, head-mounted virtual reality devices are the key component, together with adequate virtual environments. To offer the accessibility of the old, and deprecated, web-based frontend, an additional version of the immersive VR application must be available on PCs with standard input and output hardware, i.e. mouse and keyboard.

It is mandatory to maintain all controls and monitoring functionalities of the current visualization of the Remote Lab, as it was already implemented in student working groups and courses. In addition, a direct comparison between the old and the new approach will be valid, once the implementation is done. The analysis of data generated with the experiments of the Remote Lab is not in focus of this paper, and therefore not explained in further detail. The targeted solutions should provide an improved audio-visual immersion. One of the long-term goals is to evaluate the possible advantages of immersion when working remotely in regards to learning quality and motivation.

3. Concept

To achieve a variable degree of immersion and/or independence from specialized virtual reality hardware, the authors established a concept with two different visualization methods. The first one mimics the existing physical laboratory with a combination of 360°-images. The second approach displays the Remote Lab as 3D-model based virtual copy. Those concepts were realized with the Unity engine, which enables the use of the same protocols and algorithms for both approaches. Another advantage that comes with the usage of Unity is the ability to compile cross-platform compatible applications.

The existing Remote Lab consists of physical controls in the laboratory that are connected to a central PLC (Programmable Logic Controller), which in turn uses the proprietary LabVIEW hardware to connect to a desktop computer. The software LabVIEW is used to control and monitor the laboratory equipment. It is also used to establish the remote access by distributing the laboratory data to an iLab server. The iLab server can be accessed via internet connection and manages the usage of the Remote Lab in pre-selected time slots. Interested users can book such a time slot, to use the Remote Lab and run an experiment. To use the web-based LabVIEW frontend, a web browser with the legacy LabVIEW plugin is needed. Figure 1 shows the desired architecture based on current infrastructure and the compatible new frontends in both desktop- and VR-based modes.

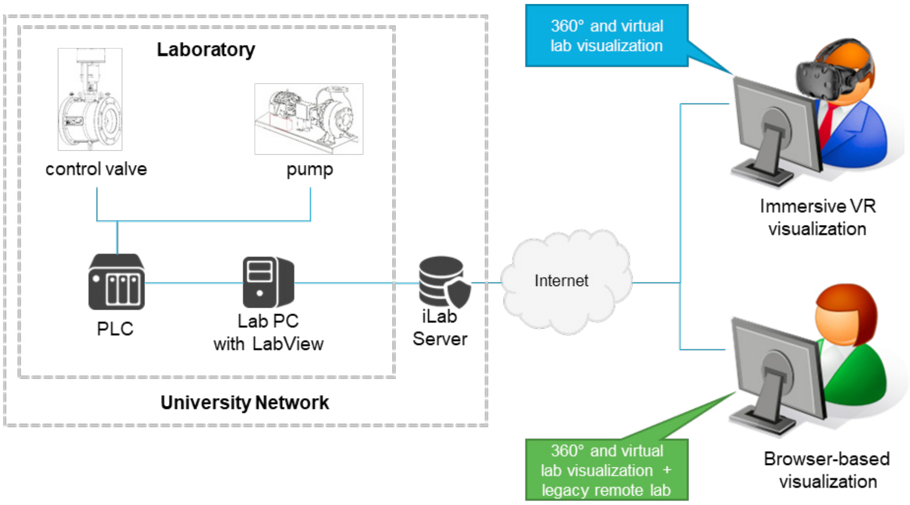

Fig. 1. Desired architecture of the complete Remote Lab.

Currently, the user can control and monitor the Remote Lab by using a LabVIEW frontend, which is shown in Figure 2 (see reference [12] for further information). In general, the user can monitor the temperature, the pressure and the flow speed in different components of the Remote Lab. By using the GUI, the state of a pneumatic valve (open/closed) and the speed of the pump can be changed incrementally. Both the pump and valve controls can be achieved with slider controls. By using the LABVIEW software, the user activates a WatchDog service, which assures a valid connection between the physical laboratory equipment and the GUI. In case of software failures or errors, the WatchDog service is deactivated, and thus, the Remote Lab shuts down for safety reasons. All these options and mechanisms must be maintained in the implementation of the new frontends.

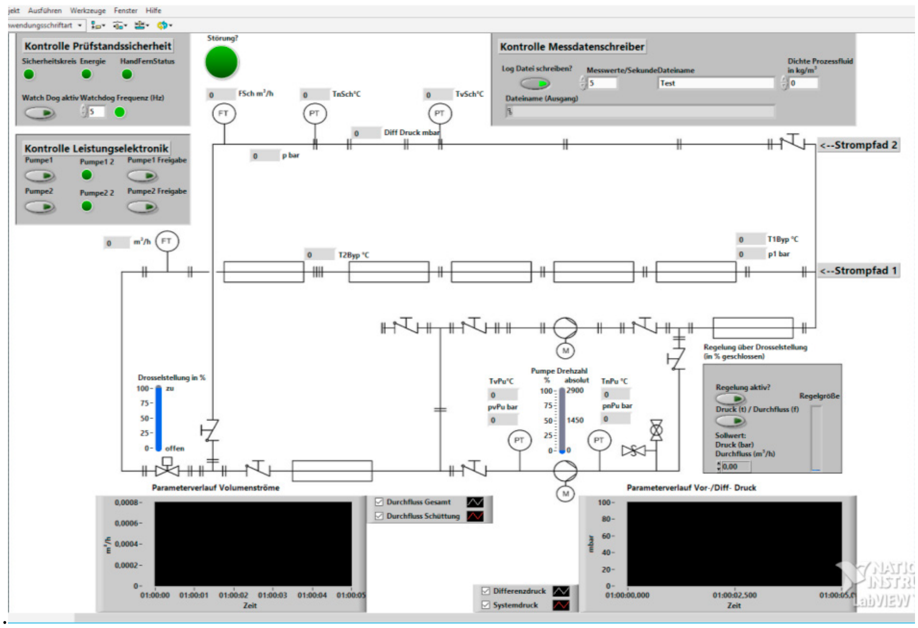

Fig. 2. LabView User Interface for the existing Remote Lab [12].

4. Prototype Implementation

For the implementation, the authors used NI LabVIEW 2018 and Unity 2019.1.3f1. Instead of relaying the communication via the iLab server to the internet as shown in Figure 1, the first prototype uses a TCP (Transmission Control Protocol) server/client communication that directly communicates with LabVIEW on the computer which is controlling the experimental set-up in the laboratory. This was done to simplify the prototype implementation, without concerning the iLab user management and any possible firewall restrictions of the local intranet. Therefore, the communication works between LabVIEW on the laboratory PC and the Unity application running on the user's PC. The TCP interface which allows the communication between the laboratory data and the GUI are identical for both concepts, the 360°-image based virtualization and 3D-model based virtualization. In addition, both concepts offer sound effects such as the rotational sound of the pump or the hissing of the pneumatic valve control. The details of those concepts are discussed in the following section. The TCP is implemented in Unity, which runs on the user's PC and calls LabVIEW every 500 milliseconds, just as the WatchDog component does. Consequently, the controlling and monitoring of the lab is done at the same time.

In the real laboratory, changes to the experimental machine are either done by hand (not part of the standard procedure) or via LabView's GUI on the laboratory PC. As the user interface now takes hold in the three-dimensional space surrounding the immersed user, a quick way to mimic and access the current controls is to introduce a 2D space in the 3D surroundings. The authors created a virtual tablet to give users a quick way to access standard functions like setting up the connection to the Remote Lab (Fig. 3) or controlling the experiment.

Through the virtual Tablet, a connection panel (Fig. 3 a) is shown to the user. After a successful connection the virtual tablet automatically changes to a control panel (Fig. 3 b). The control and monitoring elements usually found in the LabView GUI are presented in this control panel. The virtual tablet can be brought into view or hidden as required. By this means the user can explore a virtualized version of the physical laboratory and control this physical laboratory at the same time.

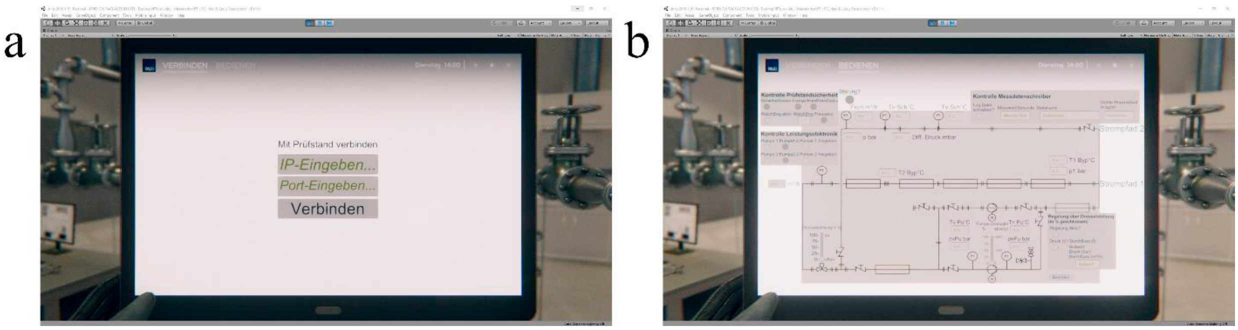

Fig. 3. virtual Tablet (a) connection panel; (b) control panel.

4.1. 360°-Image Based Virtualization

The 360°-images of the physical laboratory needed for this concept were taken with a YI 360 VR camera with 60 cm distance between each location surrounding the physical experimental setup. This distance roughly represents a step size of a person with average height and allows full exploration of the scene. The images were then combined to an 360°-tour (like Street View) using the Unity engine. The resulting scene is shown in Figure 4. The user can look around in the scene by using the mouse in desktop mode or by looking around in VR mode, as the movements of the head are tracked. Navigating through the lab is possible by using the arrow buttons that are situated in the corners at the bottom or by clicking on the floor in the desired direction for moving around. The click is done by mouse or VR controller. The virtual tablet to control and monitor the laboratory is hinted in the bottom left corner of the scene.

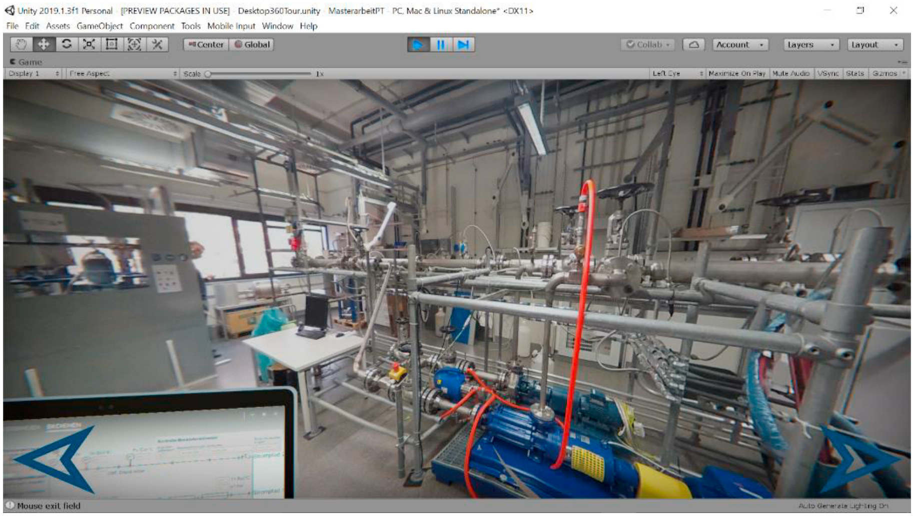

Fig. 4. 360°-image based version of the physical laboratory.

4.2. 3D-Model Based Virtualization

The 3D-model based virtualization was also designed in Unity. Parts of the hydraulic portion of the physical laboratory were reconstructed with commercial piping assets from Unity's Asset Store. The components of the piping represent both the physical machine, as well as the Process and Instrumentation Diagram (PI&D) of the LabVIEW frontend. The slightly different appearance of the virtual laboratory does not interfere with the subjectively perceived workings of the machine. The user can move around in the scene freely. In desktop mode, arrow keys and mouse enable movement. In VR Mode, the locomotion is realized via room-scale tracking, head tracking with a Head Mounted Display (HMD, VR glasses) and controller-based teleportation. Teleportation in virtual reality is one of the most tolerable ways of navigating virtual spaces, as a displayed continuous motion (i.e. moving in any direction) without moving one's body often leads to the so-called VR-Sickness due to irritation of the conflict between optical sense and inner ear.

The control and monitoring of the laboratory can be done in the same way as in the 360°-image solution, using the virtual tablet. Figure 5 shows an overview of the reconstructed laboratory environment.

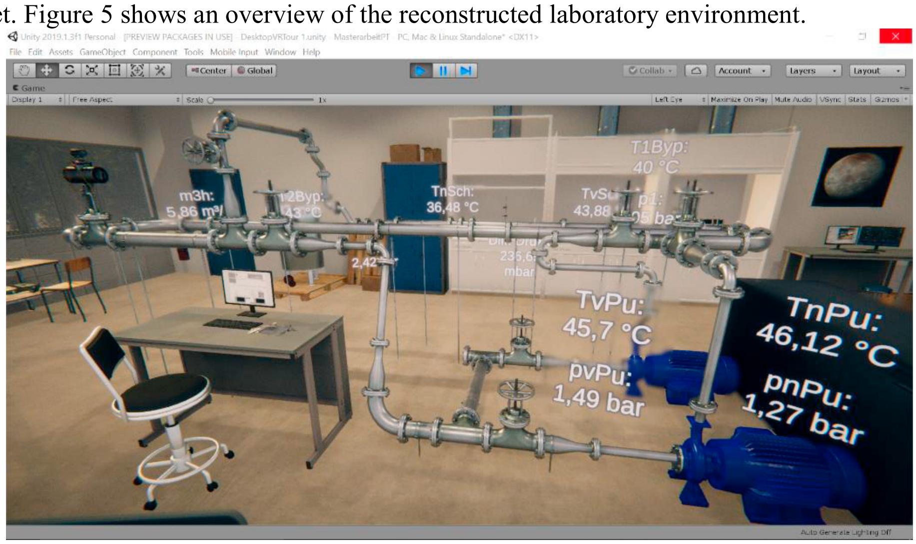

Fig. 5. 3D-model based version of the physical laboratory.

4.3. Implementation Overview

An overview over the whole implementation is shown in figure 6. The implementation is separated into Unity, Remote Lab, Inputs and Outputs. The Unity-section itself is separated between the Scene and the used Scripts. The connection between individual components is displayed with arrows. The connections are either unidirectional or bidirectional as indicated by the arrows. The shown figure is based on the 3D-model based version which is designed for PC usage. The structure for the 360°-image based version or for HMD usage would be slightly different in minor details. In this case the user inputs are done via mouse and keyboard. The user input commands are distributed to the GUI Manager script which communicates on one hand with the connection- and control panel of the virtual tablet and on the other hand with TCP based Communication between the application and the physical laboratory. The input commands are furthermore directed to the Camera Rotation and Camera Movement Scripts which changes the position and orientation of the scene camera and the audio listener in the scene. The view and the sound perceived by these two components are distributed to the user through the outputs, display and speaker.

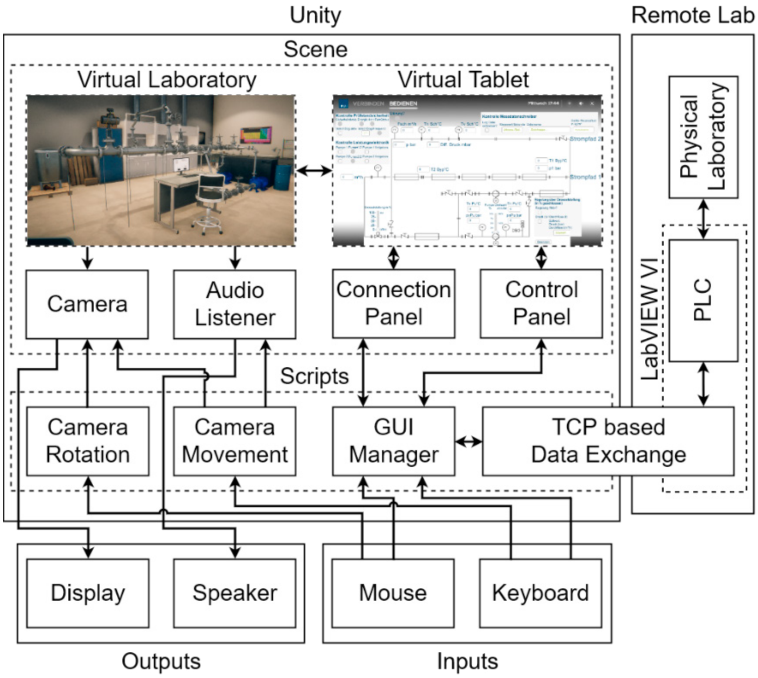

Fig. 6. Implementation structure overview.

5. Conclusion

This contribution has shown two alternative approaches based on different virtualization methods of which both are plausible ways to virtualize existing Remote Labs for enhanced immersion. The current applications can either be used with standard PC hardware like display, speaker, mouse and keyboard, or with an HTC Vive system that contains of a Head Mounted Display (HMD, VR glasses) with its accompanying controllers as the primary Human Machine Interface.

For better accessibility, the frontends can also be exported as WebGL (Web Graphics Library) applications. This enables the usage of the interactive 3D content in a web browser and therefore the direct integration into an e-learning environment.

Currently, only one user can interact with the Remote Lab at a time. This is a flaw shared by both the old LabVIEW and the newly created frontends. Future work will show if it is feasible to offer a master user control of the Remote Lab and have a theoretically unlimited number of spectators in the Remote Lab without the possibility to control, but to watch and listen to the real events mimicked by the virtual surrounding.

Additionally, the whole Remote Lab can be converted into a Virtual Lab, which simulates the behavior of the actual physical Laboratory. A Virtual Lab has the advantage that it can be distributed to more than one student simultaneously [13].

The enhanced immersion into Virtual Reality and especially its educational benefit for participating students will be evaluated in future work. Our aim is to conduct a study via both self-assessment of students and the quality of their results gained in experiments undertaken with the Remote Lab.

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