Scale and Spatial Resolution Guidelines for the Design of Virtual Engineering Laboratories

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Abstract In this paper we report on a pilot study conducted to identify tasks and understand scale and spatial resolution limits for the design of virtual engineering laboratories. The virtual environment is based on using the Oculus Rift SDK2 headset combined with the Leap Motion Controller (LMC) mounted on the headset. We first discuss a functional break-down structure to identify typical tasks conducted in a laboratory. From this functional breakdown basic gestures are identified to assist in virtual laboratory operations. Using this breakdown as a guide we developed two virtual environments. The first familiarizes the user with basic capabilities of the Rift and LMC. While the second environment was developed to measure scale and spatial effects of interfaces. This data will be used to guide the development of virtual laboratories environments for use in engineering degree programs and improve testing of these and other interfaces.

Keywords Virtual reality · Modeling and simulation · Engineering · Laboratories

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1 Introduction

Online and other distributed learning environments are changing the academic landscape. This has the benefit of making education more accessible to a larger number of students, but this revolution in education does not come without challenges. Technically oriented degrees, for example, must meet accreditation requirements for interactive laboratories and team oriented experiences [1]. Team experiences are obviously a challenge when students are distributed both temporally and geographically. Some of this can be overcome with existing web-based communication tools like Blackboard® where students interact in written format. Plus, there are several other real-time virtual meeting environments such as Google Hangouts® and Skype®. These tools help students exchange ideas and practice their teamwork and communication skills. The primary challenge is to develop well crafted assignments and projects that require students to engage with each other in a meaningful manner.

There is not an equivalent level of capability to address the experimental aspect. Academic institutions can address this need to some degree through arrangements with local institutions and remote laboratories [2, 3]. However, this is not a global solution since they are not always available. Further, they do not offer the break from traditional teaching strategies that may be enabled by a technology-rich environment. More accessible solutions are possible with web-based modeling and simulation virtual environments. See for examples [4, 5], Virtual Labs (http://www.vlab.co.in/), and PHET Interactive Simulations (https://phet.colorado.edu/). These demonstrate terrific examples of the capability web-based tools can provide.

New technology, such as the Oculus Rift SDK2 and Leap Motion Controller (LMC), offer an increase in the interactivity and immersive capability possible over current, screen space environments mentioned above. The LMC is a 6 DOF positional tracking, contact-free input system for gesture-based human-computer interaction. It is primarily designed for hand gesture and finger position detection in interactive software applications (http://www.leapmotion.com). Together VR devices such as the Rift and the LMC can be used to develop immersive, interactive environments without the need of additional external devices such as a mouse or game controller.

2 Functionality and Usability of Input Devices

There is limited information reported in the scientific literature with respect to either the Rift or the LMC, but some studies are beginning to emerge. Bachmann et al. [6] conducted a study based on a Fitts' law-based analysis to measure user's performance in selection tasks with the LMC compared with a standard mouse. They reported an error rate of 7.8 % for the LMC and 2.8 % for the mouse device, movement times twice as large as for a mouse device, and high overall effort ratings. The LMC's performance as an input device for everyday generic computer pointing tasks is rather limited, at least with regard to the selection recognition provided by the LMC [Bachmann]. They went on to report that for target widths of 40–20 mm and target distances up to 80 mm the LMC showed comparable error rates with a standard mouse device. Scicali and Bischof [7] developed several games to gauge user performance in different 3-D environments. They obtained excellent general information about several usable gestures. McCartney et al. [8] used data collected data from over 100 participants to train a 3D recognition model based. They reported an accuracy rate of 92.4 % with the goal of trying to gain support for the creation of a gesture-based language. Weichert et al. [9] developed an experiment making use of an industrial robot. They demonstrated that a precision accuracy of was obtained under static conditions and 1.2 mm for dynamic conditions. Guna et al. [10] found similar results. So while not as accurate as a mouse, the leap motion controller may be reliable and accurate enough for use in virtual, interactive laboratories.

These previous studies have investigated reliability, capability, and some limitations of the LMC compared to conventional approaches, (i.e., screen-space, mouse interaction). As some have pointed out the LMC will most likely not replace the mouse for every day use. This makes sense since the current environments, such as Microsoft Office, were not designed with this technology in mind. Thus, as suggested by Wigdor and Wixon [11] a different design philosophy should be considered and the interaction should be designed with the system capability in mind. The Oculus Rift and LMC have some terrific capabilities, and we seek to explore them for the design of virtual engineering laboratories.

As a first step, in this paper we begin to investigate spatial and resolution limits of interfaces to help guide the development of the virtual environments. A review of the Unity Asset Store and Leap Motion application site show some interactive concepts are readily available and more are coming along at a rapid pace. As opposed to focusing on the design of a new interface concept at this time we chose to identify existing approaches and develop a test methodology to determine its suitability for our needs. The rest of the paper describes how these interfaces were selected by first identifying typical task a user would perform in a laboratory. We then designed a simple set of tasks for users to perform and also conducted a post interview to gain insight into the user's experience, thoughts on suitability of the environment, and suggested upgrades to the test and other environments to which they were exposed.

3 Task Breakdown and Experimental Setup

The first step in the design process was to conduct a functional break down to identify typical tasks performed when conducting laboratory activities. This is a significant step in that it serves as a guide when selecting, and or designing, interfaces. Within the virtual laboratory there may be multiple activities as shown in

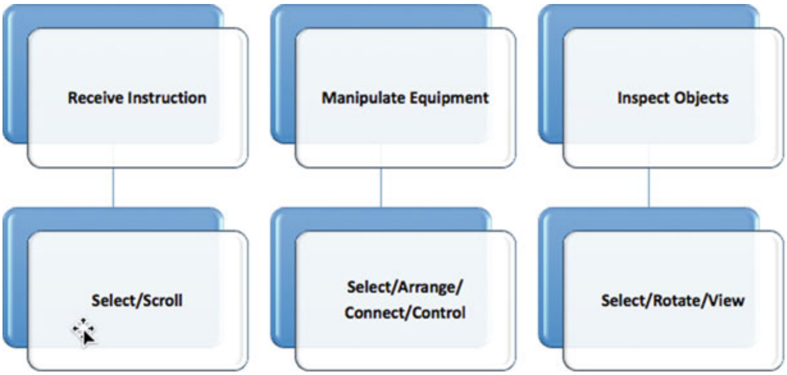

Fig. 1 Typical laboratory activities and tasks breakdown

Fig. 1. Activities can include receive instruction, manipulate equipment, and inspect experimental objects. When reviewing instructions, the ability to select and scroll pages of text maybe desirable. When it comes to the equipment control a user will want to be able to turn it on and off, precisely control some settings, yet at other times be able to freely explore a response space. We can also include the need to conduct basic observations and measurements on the experimental object of interest. For example, you may want to rotate an object to view it from multiple angles, measure its dimensions, etc.

From this basic construct we then identified different gesture based methods for which these activities could be performed. In this case, it would be appropriate to have binary controls to turn equipment on and off, smooth and continuous gestures to freely explore a design space or precisely select an experimental parameter on the piece of equipment. To meet these needs we selected the Leap Motion Widgets (…) as our first set of interfaces to evaluate. Widgets include buttons, sliders, and dials. All of which can be easily sized, configured, and integrated into virtual environments. In this investigation three mechanisms were tested: buttons, sliders, and dials. We report mainly on the feedback from the buttons here since they were the most detailed assessment.

Three different button sizes were tested in two different arrangements. As shown in Fig. 2 the buttons sizes included 5, 2.5, and 1.5 cm. This ranges from approximately the size of 2–3 fingers held together to the size of a standard keyboard key. Five buttons were arranged in two different configurations as shown in Fig. 3. For the configuration on the left the space between buttons is equivalent to the button size. Participants where given visual cues as to what button to press via information displayed in a heads-up-display (HUD) in the goggles and also an aural clue using the computer based text-to-speech capability. This test enabled us to explore the size and spatial arrangement of the interface as well as acquire user preferences about setup, environment, and interface feedback.

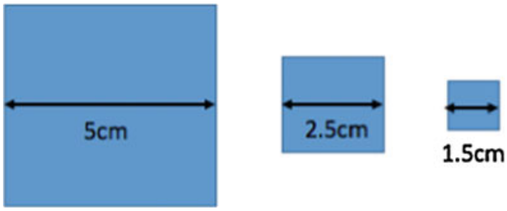

Fig. 2 Button sizes—not actual sizes but to scale

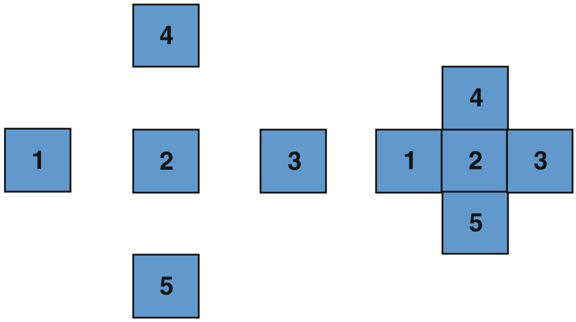

Fig. 3 Two button configurations tested

The physical setup is shown in Fig. 4. In this case one of the authors is shown in the seated position wearing the Oculus Rift goggles. The LMC is mounted on the front of the googles. The LMC has a Field of view of 150° with approximately 8 cubic feet of workspace (leapmotion.com). The largest area is about the size of a beach ball. It will be discussed later in the paper, but one of the interview questions sought to understand where users like to position their hands. The virtual environments were built in Unity3D®. All test were run on a Dell Precision T3610 workstation with 8 GB of RAM and a NVIDIA Quadro K4000, 8 GB graphics card.

Fig. 4 Virtual reality equipment and setup

4 Results, Discussion and Lessons Learned

The first environment to which users were exposed is shown in Fig. 5. The purpose of this environment was to familiarize the user with the immersive visual environment, operation of the LMC, and develop hand-eye coordination. The users motion was limited to head movement. So they were capable of rotating the view by turning their head to look around the scene as well as some translational movement. The participants were encouraged to explore the range of operation of the LMC as well as preferred hand positions. The preferred hand position was typically around 30–40 cm in front and slightly below eye level.

A few simple gestures in this environment included pushing various size blocks around the table top and swiping gestures to spin the basketball. Once the user became familiar with these tasks, they proceeded to explore pushing buttons (i.e., pushing blocks around the table) and adjusting the vertical and horizontal slider bars (i.e., spinning the basket ball). Users typically spent around 5–10 min playing in this environment and becoming familiar with how to operate in it. Feedback included wanting acoustic feedback and proximity awareness (i.e., some indication they were close to an interface). They stated it may help makeup for the lack of tactile touch. Also, while the user can turn their head close to 90°, it appeared to the test observer that it may be better to design environments where most of the interaction takes place in the ±60° range of the horizontal plane. A similar metric needs to be developed for the vertical plane. This was observed as users extended their arms well above their head to obtain the full motion of the vertical slider.

Typical results with the virtual button interfaces are shown in Figs. 6 through Fig. 8. Figure 6 shows a representative attempt versus response time. This was the time required to request the action (i.e., press button 5) plus the time it takes the user to complete the action. When first exposed to a scene there was some adjustment period, but the user quickly settled in. The data consistently showed a

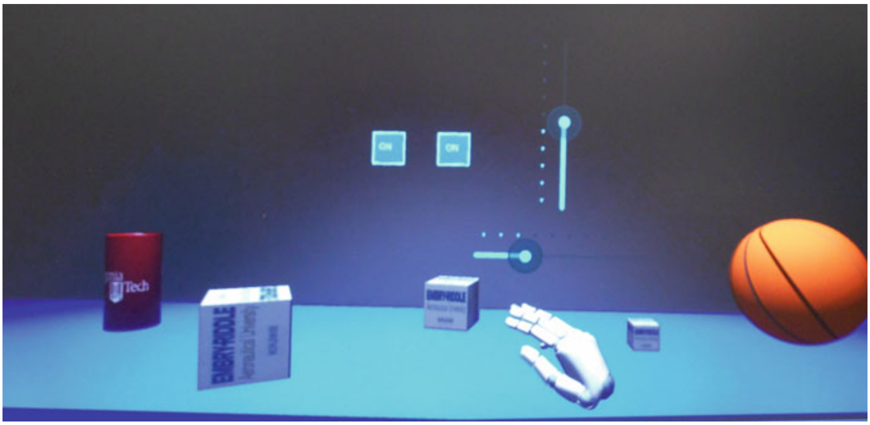

Fig. 5 User introduction to the virtual environment

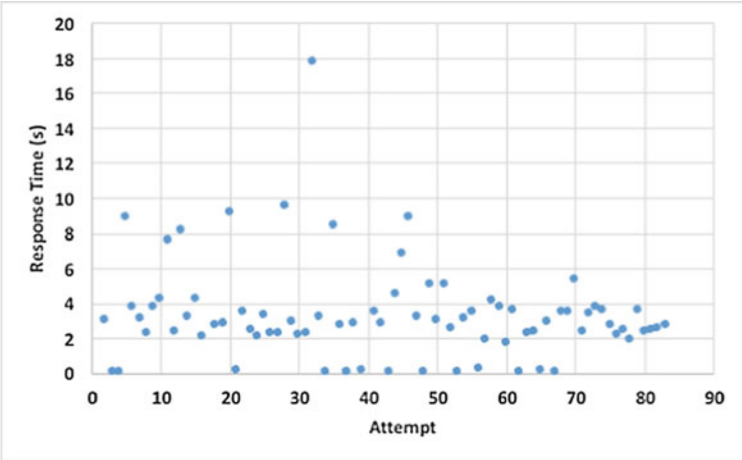

Fig. 6 Typical participant response pattern

tight band of response time. It this case it was in the 2–4 s range. The response times close to zero are errors. These were recorded when the user accidently pressed more than one button at a time. This is something that will be corrected in later tests. The longer times typically occurred when the participant was searching for an unobstructed path to a button such as for numbers 2, 3 and 4 for a right handed individual. This is an indication that different design patterns need to be considered.

Figure 7 shows the average response times per scene for all pilot study participants. Each participant first progressed through three scenes that used the

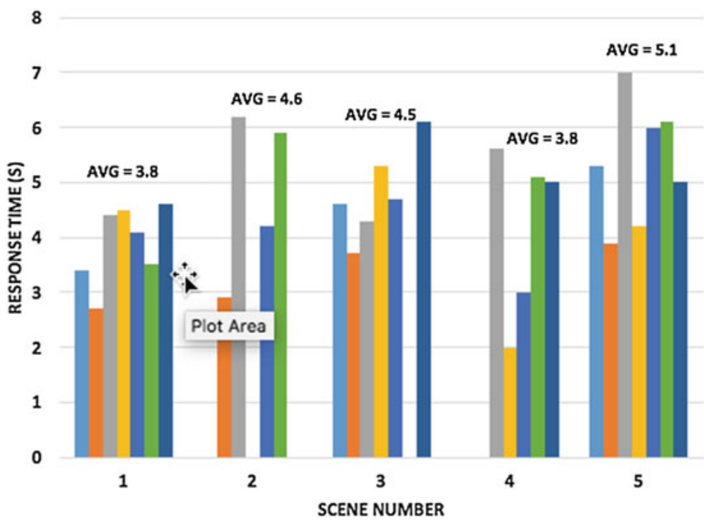

Fig. 7 Average response versus scene for participants

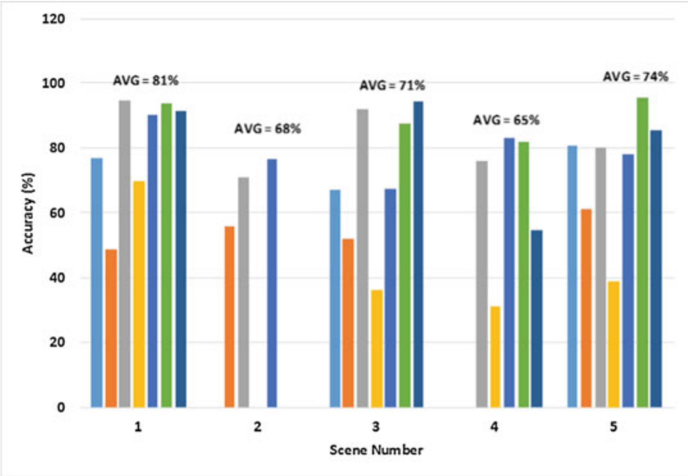

Fig. 8 Accuracy versus scene for all participants

configuration shown on the left side of Fig. 3. Those are labeled as scenes 1, 3, and 5 and the button sizes where 5, 2.5, and 1.5 cm, respectively. Then, some users explored Scenes 2 and 4 which used the configuration on the right side of Fig. 3 for the 5 and 2.5 cm size buttons, respectively. A slight rise in response time on the order of about 1.5 s was observed when progressing from Scene's 1, 3, to 5. This is not definitive at this point due to the small size and how errors were recorded. For example, if a user accidently pressed 3 buttons that might have been recorded as multiple errors with close to zero response time and thus bringing down the average. The test is being refined to record this as one error. The buttons themselves are nicely designed with visual feedback to indicate on/off positions and also engagement using a spring like motion. We also added some aural feedback in the form "beeps and squeaks", which the participants rated favorably. Several users expressed a desire for proximity feedback such as an indication that they were getting close to the interface or may have moved beyond it.

Figure 8 shows the average accuracy for all study participants and scenes. For less dense configuration (shown left side of Fig. 3), the overall average accuracy per scene dropped from approximately 80 % to the low 70 % range as the button size decreased. It dropped into the upper 60 % range for the denser configuration, which is shown on the right hand size of Fig. 3. Several participants expressed that the higher density arrangement had the advantage of not having to search for a clear path to a button. Again, the test approach needs to be refined and more data gathered but this information guides us in the arrangement. For example, maybe a grid structure (i.e., 3×3 arrangement) would work just fine, but it would need to be rotated out of the plane such that the bottom rows do not cause a path obstruction.

5 Summary and Conclusion

In this paper we reported on the results of a pilot study to identify and assess interfaces for the design of virtual engineering laboratories. This was accomplished using a combination of the Oculus Rift Head Set and Leap Motion Controller to track hand gestures. We explored using a task breakdown structure to identify typical laboratory activities and tasks to drive the selection of interface requirements. Tests were then conducted on a limited sample size to gage user satisfaction and ability with the interfaces, solicit feedback, and refine test procedures and data collection metrics. Task accuracies on the order of 75 % were observed with a response time on the order of 4 s. Additional data needs to be gathered to refine these metrics, but the interface shows promise for the design of the laboratories. This study also demonstrated the need to practice with this technology and maybe even design interfaces tailored to user skill level. Future tests will refine the data gathering processes and investigate suitability of other Leap Motion Widgets as well as other interfaces.

The implementation of this technology in more widespread uses outside the well-funded government and academic lab environment is inevitable. With the cost of this technology decreasing, and fidelity and resolution increasing, new uses such as the design of virtual engineering laboratories will begin to flourish and take advantage of these new capabilities. Developing applications that are tailored to utilize the new capabilities being offered makes sense and allows users and developers the ability to optimize and compliment existing education and training platforms such as online and distance learning that are currently limited compared to classroom based programs.

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