Exploration of Interactive and Educational Virtual Engineering Laboratories

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ABSTRACT

The purpose of this investigation is to explore design features of virtual reality (VR) laboratories and assess their potential as a learning environment for engineering students. Virtual laboratories are a promising solution for meeting accreditation requirements for distance learning programs. They can also enrich the educational experience by providing immersive, interactive experiences for remote students while simultaneously training students to work in these environments. This current effort focuses on the development and application of virtual engineering laboratories using the Oculus Rift SDK2 headset combined with the Leap Motion Controller (gesture based, human-computer interface (HCI) device). A virtual environment was created to train users and assess the applicability of different components that can fulfill tasks requirements typically encountered in engineering laboratories, such as equipment control. We build upon a pilot study that investigated basic human-performance measures of buttons and add assessments of sliders and dials. The interface is provided by the LMC, so it is a gesture based interactive system. The investigation varied scale and spatial resolution of these components to provide insight into how effectively users can interface with them. A virtual sound radiation experiment was developed using this technology and assessed for its usefulness in meeting course learning objectives. The investigation has led to a better understanding of how combinations of scale and spatial arrangements effect the user's ability to successfully interact with the virtual components and their usefulness in meeting task requirements. The user's assessment of how visual and aural feedback can make-up for the lack of tactile feedback is also documented. Finally, student and instructor feedback of the virtual laboratory as an educational tool was highly favorable. This data will be used to guide the design and implementation of future VR based engineering laboratories.

ABOUT THE AUTHORS

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INTRODUCTION

The ability for universities to offer courses using distributed modalities is on the cusp of a major evolution. Distributed modality encompasses both the synchronous or asynchronous instructional modalities. Synchronous instruction refers to a class being projected to multiple locations at the same time via video conferencing methods. While the asynchronous modality uses a web-based approach so a student can access the course material from anywhere at anytime. Non-technical degrees have thrived using these modalities. Emerging technology can open the door for more technical degrees that are typically limited to in-residence programs; thus, making these degrees more accessible to a larger group of students to include those in remote locations or deployed in the military.

A limiting factor in offering engineering degrees in a distributed modality is the lack of of access to laboratories. Laboratories and other team oriented experiences are an important part of the engineering student's education. They provide opportunities to more deeply explore fundamental engineering concepts and learn in collaborative environments. The Accreditation Board of Engineering and Technology (ABET; n.d.) directly measures such outcomes. For example, among ABET measured student outcomes is the ability to design and conduct experiments and work collaboratively on multidisciplinary teams (ABET, n.d., para. 3). Working collaboratively can be easily overcome with existing technology such as BlackBoard®, Skype®, Google Hangouts®, etc. The challenge is to design meaningful projects that require students to interact using them. A remaining challenge is how to offer engineering based laboratories and design experiences.

Modeling and Simulation (M&S) as a technology offers a potential solution to the engineering laboratory challenge. For this discussion the term M&S technology refers game engines (i.e., Unity3D®), virtual reality goggles, and other companion technologies such as gloves and hand sensors that enable the immersive and interactive environment. Games engines and rendering software enable the design of highly realistic environments. The capability is astonishing and can be observed in several games available in the market place. This same technology can be used for the design of virtual engineering laboratories that can be made available to anyone with a computer. These environments may not need to compete with the sophisticated graphic design aspect of a commercial game, but they should be physics based, environmentally accurate, and allow for an immersive capability that not only adds to the educational experience but also satisfies accreditation requirements. It also needs to take into account human performance considerations such that they are easy to operate, intuitive in nature, and realistic in design. Otherwise, students will expend great amounts of effort attempting to learn how to operate the mechanics of the interface and lose interest in the objectives of the exercise, making the learning objective of the exercise secondary and difficult to achieve.

This paper investigates the use of emerging technology to provide such a capability. The environment is enabled using virtual reality goggles and a gesture based sensor to design immersive and interactive environments. This is accomplished by designing two environments. The first is a familiarization and assessment environment. It is designed to give the user an opportunity to orient themselves in the virtual environment and develop hand-eye coordination with the new interfaces. It is also used to gather performance data associated with scale and spatial resolution of the interfaces. The second environment is a virtual engineering laboratory. It is an acoustics laboratory where students learn about sound radiation patterns. Students satisfaction with the virtual environment is discussed as well as the instructor's assessment of attaining the learning objectives of the laboratory.

BACKGROUND

Virtual Reality (VR) or Virtual Environments (VE) can be defined as a three-dimensional data set describing an environment based on real-world or abstract objects and data (Blade and Padgett, 2002). There are many different types of technology that have been used for VR interfaces ranging from minimally immersive standard personal computer desktop monitors to fully immersive head mounted displays (HMDs). The common thread linking all of these technologies and uses is the inclusion of a computer generated VE in which the user must navigate in order to successfully complete desired training or tasking. This technology is ideally suited for the technically savvy generation of students coming into engineering, and it is affordable. The current base technology suite (excluding the computer) can be purchased for a few hundred dollars. This is reasonable for a student when amortized over a four-year degree, and given the current growth of the technology it can be assumed that this price will decrease in the near future. This is an important factor considering that the application of this technology for distance learning will, at least in part, depend on how affordable it is to the average student.

Durlack and Mavor (1995) identified education as an important application domain for VR technology. They discuss that the challenges are social, political, and economic rather than technological. The authors agree with this observation in that it is not a technical barrier. It is also related to the implementation of the technology into an effective learning management system designed for engineering students that takes into account educational objectives and human performance capabilities. Careful consideration of these human factors elements is a focus of this project. The learning objectives can tell us what needs to be done, but the human factors aspect will provide information on the best mechanism for how to model and design the simulated environment for the students to succeed.

Documented examples of applying virtual environments in the classroom have shown promising results. Zhigeng et. al. (2006) explored educational uses of a virtual learning environment (VLE) concerned with issues of learning, training and entertainment. They revealed that VLE is a means of enhancing, motivating and stimulating learners' understanding of certain events, especially those for which the traditional notion of instructional learning has proven inappropriate or difficult. Hashemipour and Manesh (2011) presented a modular interactive teaching package, called Virtual Learning System (VLS), which can be used by people with little prior computer experience. VLS provides a comprehensive and conductive yet dynamic and interactive environment that can be incorporated into various courses in the field of Mechanical and Manufacturing Engineering. Ibanez et. al (2013), investigated collaborative learning in a multiuser, 3D simulation environment where they show interactions with elements in the 3D virtual worlds can enforce collaboration.

Combining 3-D visual effects with gesture based technology adds another dimension to the VE. One such technology that has emerged on the market is the Leap Motion Controller (LMC). There are only a few studies in the scientific literature that discuss the LMC, or for that matter, the Rift. For example, Bachmann et. al. (2015) 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. They point out that 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. They went on to report that for target widths of 40mm - 20mm and target distances up to 80mm the LMC showed comparable error rates with a standard mouse device. Scicali and Bischof (2015) developed several games to gauge user performance in different 3-D environments. They obtained excellent general information about several usable gestures. McCartney et. al. (2015) 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 (2013) developed an experiment making use of an industrial robot. They demonstrated that a precision accuracy of less than 0.2 mm was obtained under static conditions and 1.2 mm for dynamic conditions. Guna et. al (2014) 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 were mouse-like precision is not required. Thus, as suggested by Wigdor and Wixon (2011) a different design philosophy should be considered and the interaction should be designed with the system capability in mind.

VEs can be designed to accommodate virtually any task or application, and therefore, this type of computer generated environment should be capable of providing effective learning for any subject as long as the environment and tasking are designed to complement the training and learning needed. A fundamental advance still required for VEs to be effective is to determine how to maximize the efficiency of human task performance in virtual worlds. While it is difficult to gauge the importance of the various human factors issues requiring attention when dealing with VEs, it is clear that if humans cannot perform efficiently in VEs, then the pursuit of this technology may be fruitless, therefore, focusing on understanding how humans can perform most effectively in VEs is of primary importance (Stanney, 1995). Identification of tasking and learning events that can capitalize on technological aspects resulting in optimal learning through use of VR technology is the key to effective learning in these types of situations.

The Oculus Rift and LMC have terrific capabilities and attributes to base the design of interactive VE's, and this study explored their application for the design of virtual engineering laboratories. The investigation begins by assessing spatial and resolution limits of interfaces to help guide the development of virtual environments. As opposed to focusing on the design of a new interface concept existing approaches were evaluated and selected based on task requirements. They were then used to develop two VEs. The objective of the first was to train and assess a participant's ability to effectively use and manipulate the virtual controls. It provided a mechanism for the user to become familiar with the interfaces without the added complexity of meeting engineering learning objectives, and it was also a tool that enabled observation of their performance. This information aided in the design of a virtual engineering laboratory (the second environment) for use in a graduate acoustics course. The rest of the paper describes how interfaces were selected based upon typical tasks users perform in a laboratory, the assessment results obtained via simple task sets, and the design, application, and assessment of a virtual engineering laboratory. Results from post test interviews are to gain insight into the user's experience, thoughts on suitability of the environments, and suggested upgrades are also discussed.

EQUIPMENT

The experimental configuration is shown in Figure 1. In this figure one of the authors is demonstrating wearing the Oculus Rift goggles with the Leap Motion Controller (LMC). The Rift provides for total immersion in a 3-D VE via a head tracking system. Details on the operation of the Rift and the head tracking system can be found in the Oculus Rift Developer's Guide (oculus.com; n.d.). The LMC is the rectangular, IR-sensor mounted on the front of the goggles. Technical performance data on the LMC can be found on the Leap Motion website (LeapMotion.Com; n.d.) and futher discussed in the scientific literature (see for examples, Adhikarla et. al (2015), and Guna et. al. (2015)). The LMC field of view is an inverted pyramid centered at the devices center and extending outward (leapmotion.com, n.d.). The effective range is approximately 3-60 cm in front of the device. The largest area is about the size of a beach ball. The virtual environments were built using a professional license of Unity3D® version 5.3, version 2.3 of leap motion software development kit, and Oculus runtime version 0.8. All test were run on a Dell Precision T3610 workstation with 8GB of RAM and a NVIDIA Quadro K4000, 8 GB graphics card.

Figure 1. Oculus Rift and Leap Motion Headset Configuration

DESCRIPTION OF VIRTUAL ENVIRONMENTS

Task and Interface Selection

There are several features to consider with designing a virtual engineering laboratory. First and foremost, it should be based on the level of physics consistent with the learning objectives. There should also be some integration of statistical tools to reflect the variation in actual experimental data. The environment should be representative of a laboratory. Albeit, some artistic liberty can be taken with this aspect to add to the visual appeal and take advantage of unique opportunities of what the rendering software can provide, such as added effects to visualize the underlying physics or innovative equipment design. Sometimes it may be necessary to design equipment precisely. Especially if there is something unique about it. But the vast majority of equipment are rectangular boxes with all of the controls and displays on the front panel. In this case the emphasis can be placed on the functional design rather than exact replication. This flexibility should be suitable to satisfy accreditation requirements since the primary interest is in teaching how to operate equipment and how it fits into the experiment's design. It is similar to renting a car. The rental may be different from the one driven on a daily basis, but it has all of the same basic functions. This leads to a requirement to identify basic tasks performed when executing an experiment, which will lead to an identification of requirements for functional interfaces.

The first step was to narrow down the selection of interfaces by developing a holistic view of the virtual environment and then focusing on those aspects associated with the execution of the experiment. For example, if the entire environment is composed of three components to include instruction, play, and assessment modules then the task for each module can be identified. Sanders et. al. (2016) suggested some basic tasks conducted in these modules and are shown by the first three elements of the top row in Figure 2. In the instructional mode the student may need to select and scroll through basic theoretical material and instructions related to the laboratory content. The play and assessment phases can be designed to have the student practice and conduct experiments for assessment. This will involve the selection and manipulation of laboratory equipment and experimental objects. After the initial pilot study an additional set of desired tasks was added. This was the ability to control environmental features such as lighting and volume. This provides the user with the ability to adjust the environment to their individual comfort level. The important feature here is that you want to add all of this control to the virtual environment such that the user does not have to search for external mechanisms such as a mouse or game controller.

There are several innovative concepts available on the Gallery webpage found at Leap Motion website that can potentially satisfy these requirements. Therefore, as opposed to developing a separate concept at this point this investigated focused on measuring how well certain interfaces can meet the needs of the virtual engineering laboratories. The Widget interface suite shown in Figure 3 was selected for this investigation. Three components were selected for testing: Toggle Button, Slider, Dial Picker. These satisfy the basic needs of manipulating equipment and environment control as illustrated in Figure 2. It also provides a good transition into the virtual world for new users since they are familiar with these basic operations, and they are relatively familiar concepts for which to develop an assessment.

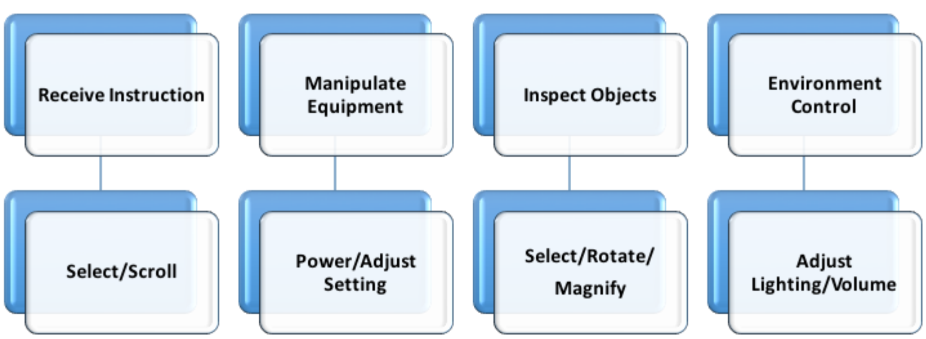


Figure 2 Typical Laboratory Activities and Tasks Breakdown

The Widgets are well designed and carefully take into account active visual clues when interfacing with them. For example, the Button and Slider Widgets have a visual "spring like" effect when engaging. This helps the user to visually sense proximity and engagement with them. The button has additional visual feedback in the form of on/off text status and the slider also has addition visual interactive features shown by the dots and fill bar. Finally, the dial provides a visual clue in the the form of lighting when the virtual hand is in contact with it. Preliminary results from the pilot study (Sanders et. al., 2016) indicated that users also want aural feedback when engaging with the Widgets.

So in this set of tests various aural effects where added to each widget interaction such as ticks to indicate that the dial is moving. Participants in the pilot study did not indicate difficulty working without the tactile feedback along as there was sufficient visual and aural feedback.

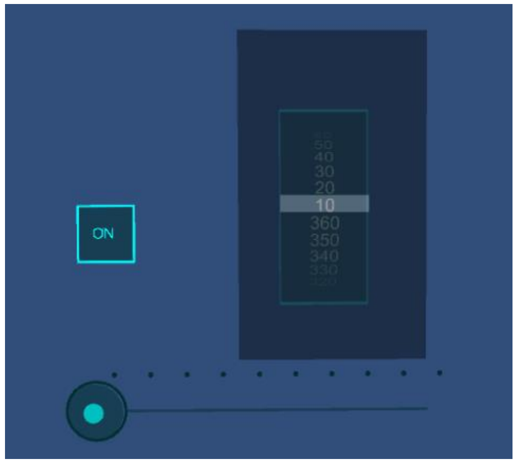
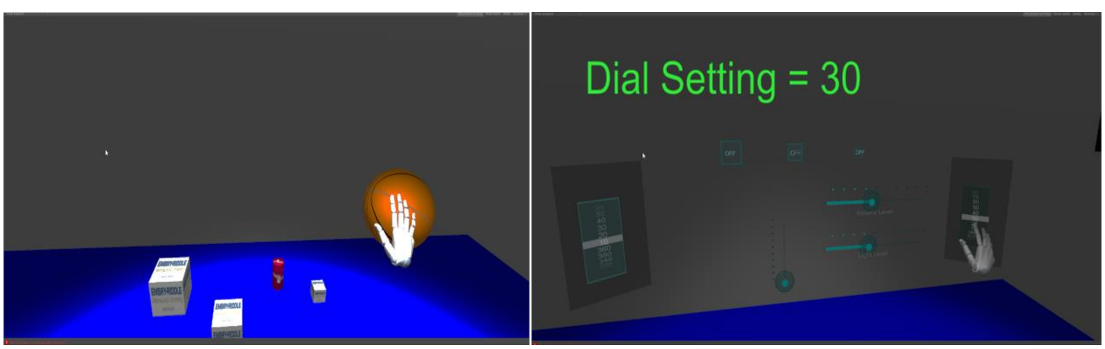


Figure 3 – Widgets: Toggle Button (left), Slider (bottom), Dial Picker (right)

Training and Assessment Environment

The training and assessment environment contained multiple scenes, two for training and three for assessment. The first training scene is shown in Figure 4a below. A virtual hand can be observed in each scene. In this scene the user is exposed to a few basic geometric objects (blocks and a cylinder) and a basketball. The basketball is fixed to not allow any translational movement. It could only rotate. The purpose here is to push the blocks around the table and spin the basketball. These motions are similar to pushing a button, pressing and adjusting the slider bar, and also manipulating the dial. The next scene shown in Figure 4b introduces the three widgets but in different orientations and sizes. For example, the buttons are shown in the top part of the screen in a horizontal arrangement with three sizes. Two sliders are positioned in the vertical position and one in the horizontal position. Finally, the dials are on the far left and right of the scene. Relative to ones hand these objects are large. There were no set rules, requested actions, or data recording in these scenes. They are meant to begin developing hand-eye coordination in the VE and to become familiar with the hand gestures required for interfacing with the various Widgets.



(a) **(b)**

Figure 4 – Training Scenes (a) Basic Gesture Training (b) Widget Interface Training

As mentioned throughout the paper obtaining scale and resolution of the interfaces is a major theme of this paper. It is an important aspect since as virtual labs are populated with Widgets and other interfaces it is necessary to understand how well users will be able to work with them. Interfaces must be designed to accommodate the limits of resolution of the VE components and the ability of the user to operate within that environment if efficient interface use is to be achieved. If not scaled and arranged properly a user will become distracted from the main learning objective or completely disillusioned with the laboratory exercise. This concerned was addressed in this paper by exposing the user to different arrangements and sizes of the Widgets. These are the three assessment scenes mentioned above. One for buttons, one for sliders, and finally one for the dials. In the button assessment scene, buttons are arranged in a cross pattern as shown in Figure 5. In the pilot study all buttons were on the same plane (Sanders, 2016). However, it was observed that buttons in vertical alignment (i.e., 4-2-5) were frequently inadvertently pressed. To help alleviate this they are arranged in stair step pattern for this set of tests. The font size of the button number was also significantly increased for easier readability. During these test the computer randomly directs the user to press a button. This information is transmitted to the user visually and aurally. Data is then recorded as to what was requested and what was pressed. Buttons sizes and center-to-center separation are shown below in Table 1. The first column is the scene number and will be referred back to when discussing results.

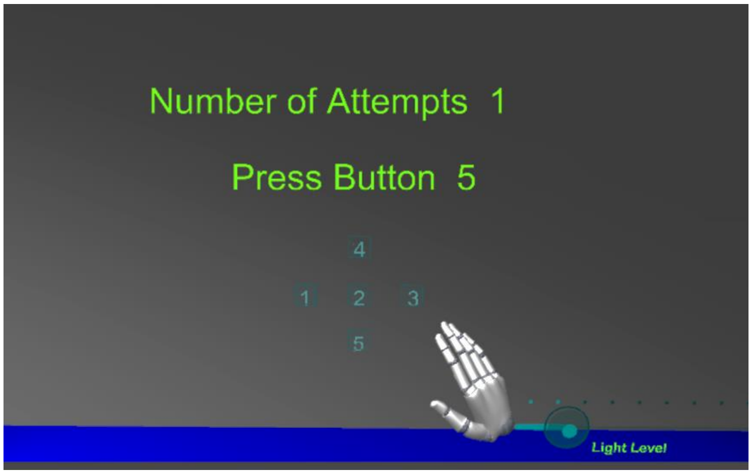


Figure 5 – Schematic of Button Arrangement

Table 1 – Button Size and Proximity Information by Scene Number

Scene	Button Side Dimension (cm)	Separation (cm)
1	5	10
2	5	5
3	2.5	5
4	2.5	2.5
5	1.5	3

In the second assessment sliders are arranged in horizontal and vertical configurations. The range of motion and disk size pair for each slider was (50 cm, 10 cm), (25 cm, 5 cm), and (1 cm, and 2.5 cm). In one set of tests users are asked to set a notional equipment parameter at a number between 0 and 360 degrees. The number displayed on the screen and there is a visual display (e.g., via a disk being filled on the screen) showing progress toward the goal. In a second set of test participants were asked to use the slider on actions to control the background music volume. Note that is a less precise task than that of setting a piece of equipment to a specific value. An alternative to using a slider mechanism is the dial, and the third assessment focused on this device. This is a more discrete setting and potentially more accurate for achieving precise positions or settings on a piece of equipment. Measurements similar to those for the slider Widget was reproduced for this mechanism. Three dials with the following height and width dimensions were in the scene (25 cm x 10 cm), (15 cm by 5 cm), and (10 cm by 4 cm) for participants to engage.

Acoustic Laboratory

Investigation of radiation patterns emitted from a circular speaker was selected to demonstrate the usefulness of a virtual laboratory environment. This activity is part of a graduate level acoustics course taught at Virginia Tech. The objective of the experiment is for users to measure far-field pressure radiated from a baffled piston. The far field sound pressure is a function of frequency, distance from the baffle, and angle (Russell et. al., 1999). This concept is illustrated by the schematic shown in Figure 6. In this figure the baffle is shown in the center in a constant position while the user (shown by the ear) moves around it at a distance r. In the virtual lab the inverse was implemented in that the user's position was held constant and the baffle was rotated.

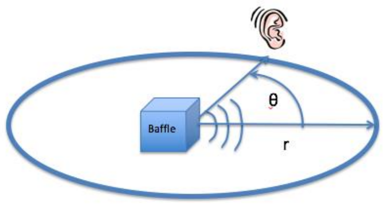


Figure 6 – Schematic of Baffle Lab Experiment

Another design aspect explored was the Widget and information arrangement. A combination of a heads-up-display (HUD) and a dashboard was explored. The fundamental difference being that the HUD tracks with the user's head movement while the dashboard is attached to the body. Information in the HUD was textural and consisted of experimental settings and data output such as frequency, angle, and dB. The dashboard is where the Widgets were arranged that controlled the frequency response, graphically displayed the sine wave signal, displayed the decibel measurement on a meter and contained a slider to control the speaker angle. This environment, shown in Figure 7, demonstrates several key design features mentioned above. First, the experiment is based on basic physics appropriate to the learning objectives. The anechoic chamber is the representative environment. The equipment is uniquely designed where necessary and more abstractly when not necessary. For example, the decibel meter is a unique piece of equipment. So it was decided to model that less abstractly than the function generator.

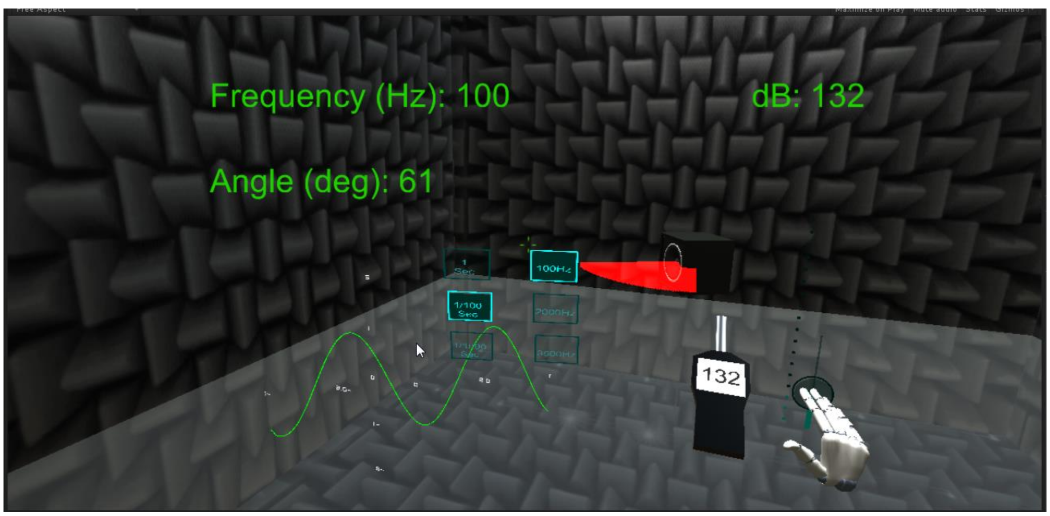


Figure 7 Configuration of the Acoustics Laboratory

METHODOLY

There were a total of 23 participants in the study. 12 participated in the scale and resolution component, and 11 students participated in the virtual acoustics laboratory demonstration and assessment. The 12 that participated in the scale and resolution experiments consisted of two groups. Group One contained 7 participants while the second group contained 5 participants. All of the participants were at the graduate student level or above. A few of the participants had some exposure to using a VR headset but none had ever been exposed to working with the VR goggles-LMC combination, so essentially all participants were novices with this technology.

Testing was partitioned into training and assessment modes. There were no time limits since the interest was more on accuracy and suitability rather than speed. Once the user reached a self-defined comfort level in the training environments discussed above they were run through formal assessment tests with Widgets or through the virtual acoustics experiment. For the students participating in the acoustics experiment they were asked to explore the radiation patterns for the follow frequencies: 100 Hz, 2000 Hz, 3500 Hz. They were asked to record and plot the decibel level as a function of speaker angle for the three frequencies. Typical plots are shown on Figure 8 below for these three frequencies and illustrate the directional dependency. The students were asked to identify the level of directionality for each frequency (i.e., non-directional, semi-directional, strongly directional).

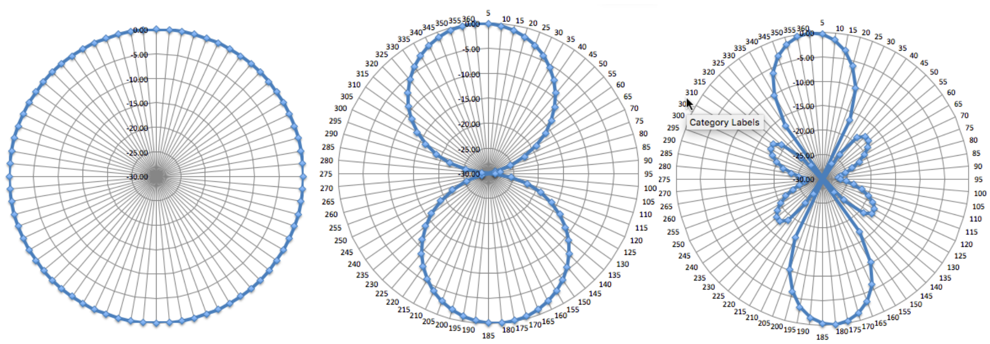


Figure 8 – Example of Low, Mid, and High Frequency Radiation Patterns

At the end of each test the student was asked the following three questions and requested an answer on a scale from 1-10 with one being the lowest and 10 being the highest:

(1) Satisfaction with the interfaces
(2) Realism of the environment
(3) Usefulness for learning the course material

RESULTS AND DISCUSSION

Users quickly became reasonably proficient working in the VE. They typically spent less than 5 minutes in the training mode. In the first group of participants comments included wanting aural 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 feedback. Also, while the user can turn their head close to 90-degress, it appeared to the test observer that it maybe better to design environments where most of the interaction takes place in the ± 45-degree 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. The training environment was rearranged for the second group of participants. More cause and effect relationships were added too. For example, aural feedback was added to the dials and slider action was tied to environmental factors such as lighting and volume control. Also, specific instructions were given to the second group to identify the visual feedback provided by the Widgets. Comments from the second group was that there was sufficient feedback from the mechanisms. Other indicators can still be incorporated such as when the virtual hand is in proximity or beyond the interface. A few of the participants did not realize they were behind the target.

Results of using the Widgets to meet the tasks requirements were positive and summarized in Table 2. For group 1 the accuracy for the pressing the requested buttons for scenes 1, 3 and 5 (highest spacing arrangement) were 81%, 71% and 74%, respectively. In group two the accuracy changed to 83%, 81%, and 77%. So there was a slight increase in accuracy. The speed of interaction for these same scenes was 3.8 seconds, 4.5 seconds and 5.1 seconds. While in the second set of tests it was 3.1 seconds, 3.9 seconds, and 2.8 seconds. So there was a slight improvement in accuracy but a more significant improvement in engagement time. This maybe the result of two factors. First, the font size of the button numbers made it easier for the participant to recognize. But perhaps more important is the arrangement. When all buttons were on one plane the observer noticed that it was much more laborious for participants to engage with the desired target as they tried to navigate to the to it without hitting anything else. Using the stair step arrangement, it was noticed that the participants required much less effort and more consistent gesturing.

Table 2 – Button Engagement Summary

		Scene Number				
		1	**2**	**3**	**4**	**5**
Group 1	Avg (%)	81	68	71	65	74
	Std	17	11	22	22	19
Group 2	Avg (%)	83		81		77
	Std	15		12		26
Combined	Avg (%)	82		75		75
	Std	15		19		20

Demonstration of the slider Widget followed two phases. In the first phase users were requested to set a parameter that ranged in value from 0 to 360. The full range of the slider was 0 to 360 and could be incremented in values of 1. The first seven participants were asked to set a value between 0 and 360. It was found that they could get to the requested value ± 10 without difficulty. However, seldom was a user able to set the specific value requested. For the second group three sliders were available for controlling the volume of the background music. Note that is a qualitative setting where precision is not required. Also, exact numerical feedback is not required. There was no preference to either the vertical or horizontal arrangement. However, users consistently stated that as the slider got smaller it was easier to interact when it was more perpendicular to the line of site. It was found that the dials had the most accurate control. Users were able to consistently obtain the desired setting on the dial. Similar to the slider bar it was desired to have the widget perpendicular to the line of site as it decreased in size.

In general student feedback on the acoustics laboratory was excellent. They gave the functionality of the interface an average value of 9.1. Most of the comments with respect to the arrangement addressed the range of head movement required. Most preferred to have all of the visual requirements within a range of approximately ±45 degrees of straight forward. In part this helps to make up for the lack of tactile feedback since they wanted to have the equipment in a direct line of sight from the experimental object. This is so as they could do quick scans of effects using the slider in this case to explore the entire parameter envelop. The realism question received a value of 7.3. While it is not required to achieve a 10 in this area it can easily be improved by incorporating better graphics for the environment and unique equipment design. Finally, their feedback on practice of the course material received the highest value with an average value of 9.7. Comments consistently came in the form of the ability to visualize the mathematical representation led to quickly enhancing their level of level of understanding course material. This was reinforced by the excellent grades received in the laboratory reports. This point can not be overstated as an important attribute that VE can provide. The ability to visualize mathematical relationships and physical phenomena is an important attribute for understanding engineering concepts. Not everyone has the same level of skill in this area and the VE can certainly help.

SUMMARY AND CONCLUSIONS

This study investigated the basic design of virtual engineering laboratories for educational purposes. Two environments were explored. One designed for training and assessment (T&A) while the second was a demonstration of a virtual laboratory to investigate sound radiation patters. The purpose of the T&A environment was to train new users to operate with in the VE. It also provided a good mechanism for which to assess scale and resolution of the interfaces and match them as suitable mechanisms to perform tasks within the virtual laboratory environment. While the second environment demonstrated the possibilities of this technology for meeting educational requirements in engineering degrees.

While additional data should be collected to obtain more accurate information on the human performance metrics, it was demonstrated that novice users can operate effectively within the designed VEs. This supports the finding that the VE's were intuitive and easy to learn, so they can be designed to not distract from the actual learning that needs to take place. Some key design features emerged such as how to arrange multiple buttons, including the combination of aural and visual feedback with the user interfaces, how to scale and arrange the sliders and dials for best user satisfaction, and aligning the type of Widgets that are best suited to achieve the identified laboratory tasks. This set of tests were conducted with novice users, so they most like represent upper bounds on the scale and spatial arrangements of the components. As users become more proficient they can be made smaller and more closely packed if required. The limitation is more on visual assessment rather than straight forward control of the interfaces. The virtual acoustics laboratory provided additional information on the usefulness of achieving academic performance, meeting course learning objectives, and potentially satisfying accreditation requirements of being able to conduct experiments and analyze data. These promising findings will lead to the design of future laboratories and open up a new frontier in globally accessible, educational opportunities.

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