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Effectiveness of Current-generation Virtual Reality-based Laboratories

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Effectiveness of Current Generation Virtual Reality Based Laboratories

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Virtual Reality (VR) laboratories will have a significant impact on the accessibility, type, and safety of educational laboratory experiences. While VR has significant potential, the acceptance of VR laboratories by faculty and students is paramount for its incorporation into a traditional STEM-based curriculum. Current generation VR hardware allows for unprecedented immersive capability and provides significant flexibility in the type and safety of experiments. In addition, VR labs will improve access to high-quality experiments for institutions lacking experimental capacity as well as for many students with physical disabilities. Students are increasingly required to use computer-based systems, such as Blackboard, Canvas and other learning management software (LMS) to complete course requirements and have demonstrated proficiency with computer-based homework and assignments [1]. However, utilizing VR experiments for traditional lab requirements with current generation VR hardware is relatively novel to both the faculty and the students. This study evaluates the participant's (the students) perceived effectiveness of performing VR labs using the HTC Vive VR hardware system.

Current generation VR hardware provide such a remarkable level of immersion and feeling of actual presence in the VR environment that the VR labs should be able to meet the objectives of undergraduate teaching labs. Typical objectives for STEM based labs reported in the literature include the following: allow students to better relate the theory to the physical phenomenon or practice [2]–[7]; provide students with skills in the investigation of research or design questions [6], [8], [9]; provide students access to current technology [8]–[10]; motivate students and encourage retention [4], [6]–[9]; promote new technology in the curriculum [10]; promote self-teaching and desire for lifelong learning [9]. It is generally accepted that lab experiences are necessary for many STEM disciplines such as engineering, chemistry, physics, and life sciences [11].

There is a strong motivation for adopting VR labs since state-of-the-art real-life labs are requiring an increasing variety of experimental topics. The essential need of experimental apparatus has led to an increased cost of lab equipment, maintenance, and technician support [12]–[15]. Feisel & Rosa [12] state "Department budgets are not always adequate to meet the needs of [the] modern instructional laboratory." Many programs cannot provide in-depth education on many STEM topics due to a lack of experimental capability [16]. In addition, many lab experiences for students are closer to demonstrations, where the student performs very few exploratory actions. These labs are typically not as open ended and educative as they are believed to be [17], [18]. Labs using a "cookbook" approach [19], where students complete a series of predetermined activities has been contrasted with a more student-directed or inquiry-based approach[17], [20]. Inquiry encourages students to generate questions related to the content, to consider applications to real-life and to problem-solve in a more independent fashion

[21]. After trying the VR lab, students have indicated that the VR environment would encourage experimentation since there would be no risk of equipment damage or personal injury. VR labs also permit a deeper understanding of the inner structure and physics of the experiments as well as the operation and interfaces of modern experimental equipment. Examples of using virtual environments to provide a deeper understanding of the inner workings of equipment can be seen in [22], [23].

VR labs, as used here, require the use of specialized hardware. The examples shown here have been developed for the HTC Vive, but can also be used with the Oculus Rift or other VR hardware. The HTC Vive and Oculus Rift are two competing commercial VR systems that were released in March and April of 2016 respectively. The Oculus Rift consists of a head-mounted display, shown in Figure 1a, with screens having 1080x1200 resolution per eye and incorporates headphones, gyroscopes, accelerometers, and a USB based stationary infrared sensor that tracks IR LEDs attached to the head mounted display [24], [25].

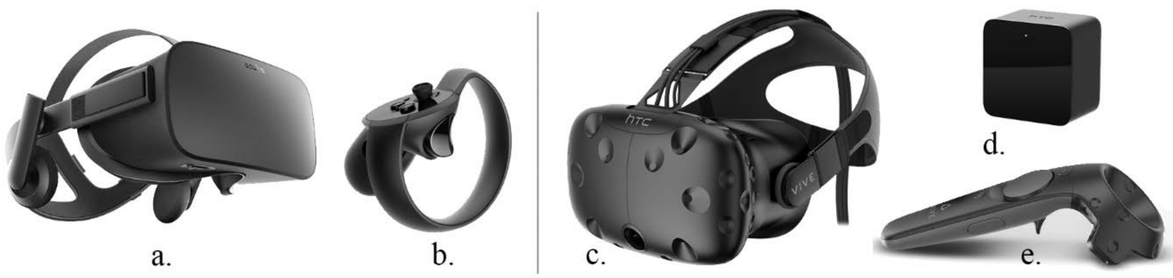

Figure 1. a - Oculus Rift Head mounted display, b - Oculus touch controller, c - HTC Vive head mounted display, d - HTC Vive base station, e - HTC Vive controller wand (images compiled from http://oculus.com & http://vive.com/us)

Rotational and positional movement of the user's head is tracked, and the display is updated in real time to allow the user to freely look around the virtual environment. This system will track an area 5 ft. x 11ft. but is designed predominantly for seated experiences. The HTC Vive uses a similar head-mounted display, shown in Figure 1c, but provides for even greater immersion in the environment through room-scale VR. The motion controllers, shown in Figure 1e, are wands that are held by the user and have track-pads, triggers, and buttons for the user to interact with the virtual environment. Room-scale VR allows the user to move around the virtual environment by walking and moving around the real environment (i.e. taking a step in real life moves the virtual avatar one step) and interact with virtual objects (picking up objects, flipping switches, pushing buttons, pulling triggers, ducking in real life will cause the virtual avatar to duck as well, etc.) The HTC Vive accomplishes room scale VR by using two linked base stations, shown in Figure 1d, that are mounted in a space as large as 15 ft. x 15 ft. Each base station sweeps horizontal and vertical lasers through the space which are used in conjunction with photodiodes mounted on objects, such as the controllers or the head mounted display, to accurately track the objects as they move through the space[26]. Combining the sensors and base stations results in superb object-positional tracking with latency in the range of 1ms, noise and jitter less than 0.3mm, and positional accuracy within 1.5mm [27]. Existing VR games require significant precision and accuracy to provide the user with a realistic experience. Game players can perform realistic activities, such as juggling [28], basketball, darts, billiards, or archery that require precise velocity and position measurements of the user's movements which are tracked in real time. Users of the HTC Vive commonly try to set items down on virtual tables, sit on virtual chairs or lean against virtual walls due to the level of immersion provided by the VR hardware. In addition, development of next-generation VR equipment is continuously underway, for example, new motion controllers that detect opening and closing of the user's hand has already been demonstrated for the HTC Vive [29]. As next-generation hardware becomes available, the immersive quality of VR systems will only improve.

Two prototype VR experiments have been created and used in this study. Figure 2 shows a screenshot from a VR Resistor-Inductor–Capacitor (RLC) circuits lab required for first-year physics. This VR experiment allows a student to construct and evaluate an RLC circuit using virtual electrical components.

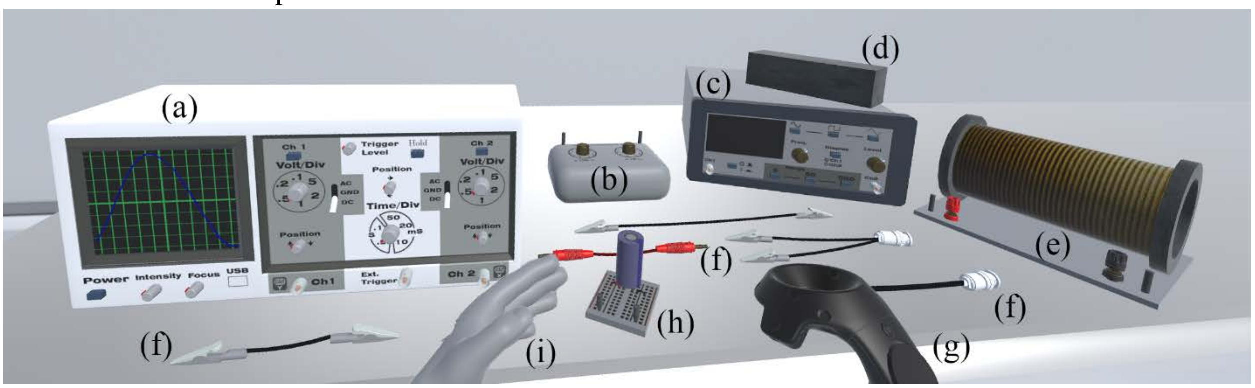

Figure 2. Screenshot of VRILE for investigating an RCL circuit. a) oscilloscope, b) decade resistance box, c) function generator, d) metal core for coil, e) coil, f) BNC, alligator and banana cables, g) HTC Vive Controller, h) capacitor on breadboard, i) hand replacement for controller.

Figure 3 shows a close up of the oscilloscope, capacitor, and function generator to provide an example of the detail viewable in the VR experience.

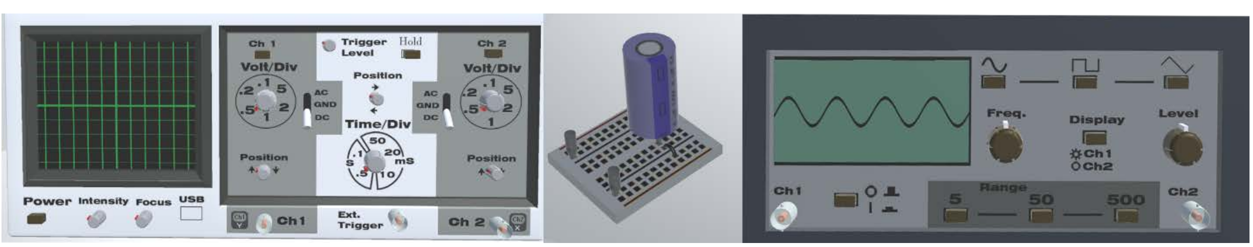

Figure 3. Close-up of oscilloscope panel, capacitor/breadboard, and function generator panel. Not to scale.

Figure 4 shows a screenshot of the second prototype experiment. This experiment is used to investigate the tensile strength and stress-strain response of materials.

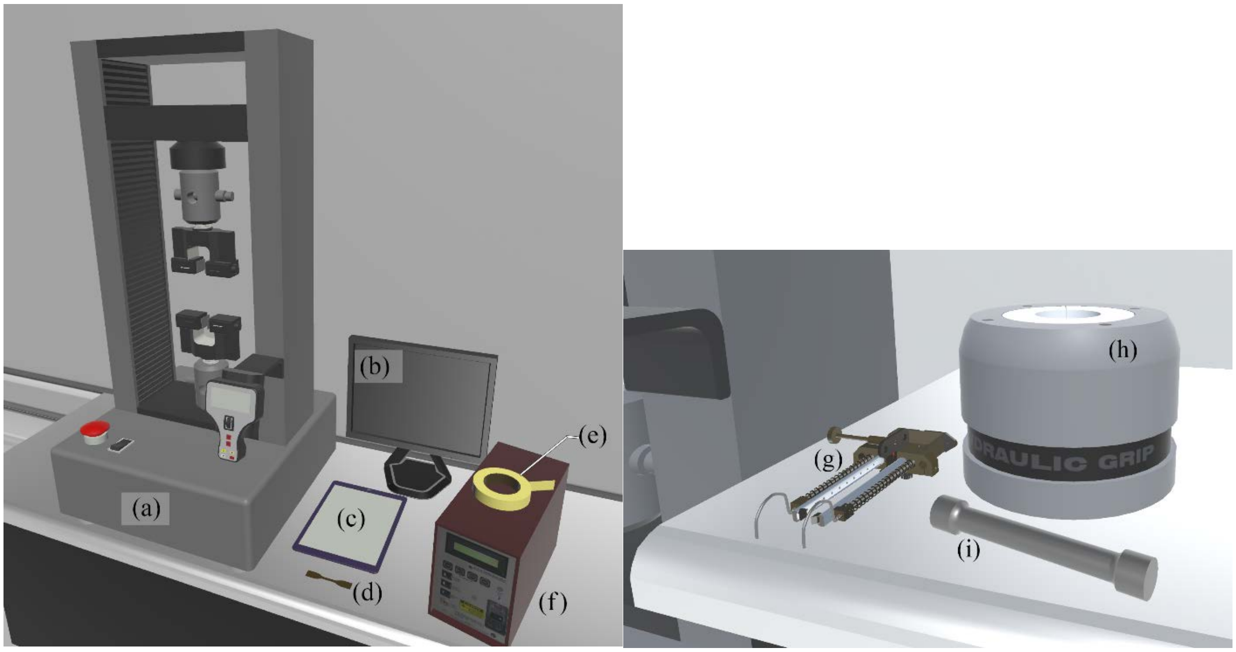

Figure 4. Screenshot of the VRILE for investigating tensile strength of materials. a) tensile testing machine, b) DAQ computer monitor, c) instructional tablet d) polymer specimen, e) reflective tape, f) laser extensometer, g) clip-on extensometer, h) grips for metal specimens, i) ASTM E8M-04 metal test specimen.

Each VR experiment performs a simulation of the physics required for the experiment. The simulation is deterministic but includes systematic and random error to make each VR experience a true digital experiment. In addition to the variability described above, the student's inputs also affect the results as shown in Figure 5.

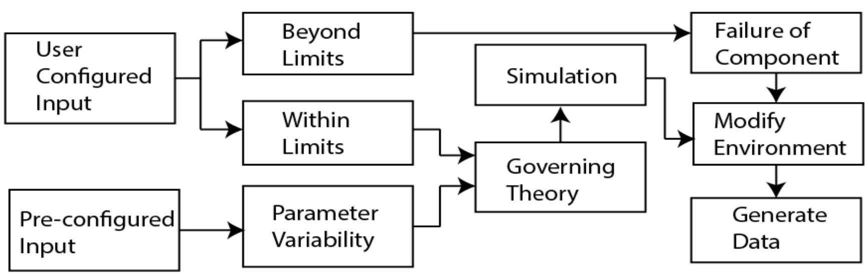

Figure 5. Flowchart of a single digital experiment.

A focus group of predominantly junior and senior students in an engineering program at IUPUI was used to evaluate the perceived effectiveness of VR experiments. Each student was provided a fifteen to twenty-minute directed session with the VR experiments. The facilitator of the focus group (a real person, not a component of the VR environment) would give a brief verbal introduction to the HTC Vive headset and wands which included information on how to adjust the headset for comfort and a description of the buttons and touchpads on the wands. The first experiment the participant performed was the tensile-test experiment since it requires less manipulation of objects and would allow the participant to acclimate to the VR environment. In addition, since the virtual machine controller was mapped to the HTC Vive wand, once the participant “grabbed” the machine controller in the VR environment, the motions to push the buttons on the virtual machine controller would result in pushing buttons on the wand so that there was a very similar tactile response between the virtual actions (pushing buttons on the machine controller in the virtual environment) and the real actions (pushing buttons on the HTC Vive wand). The participant was instructed by the facilitator on what steps to perform to complete the experiment. This is possible since the view in the head-mounted-display (participant’s view) is shown simultaneously on the computer’s monitor, therefore the facilitator could see exactly what the participant was viewing. This allowed the facilitator to give instructions such as “look a little more to your left” to the participant during the experiment. Below is a sample of the typical instructions a facilitator would give a participant:

“Do you see the machine controller on the right side of the machine? Walk over to it and pick it up by touching it and squeezing the grip button.”

“Try moving the pull-rod of the machine up and down using the machine controller. You can push the buttons on the controller. Now try closing and opening the top grip.”

“Grab the specimen and install it in the machine. Make sure the specimen is aligned with the axis of the machine.”

“Now that the specimen is installed in the machine, look at the monitor on your left. Go ahead and start the extension program using the touch-screen.”

The RLC circuit lab was the second experiment. This experiment required the participant to create a valid circuit using a resistor decade box, a capacitor mounted on a breadboard, a coil with a metal core, a function generator and an oscilloscope using a combination of BNC-to-BNC cables, BNC-to-banana adapters, banana-to-alligator cables, and alligator cables. The equipment behaved similarly to real equipment, i.e. after grabbing the end of an alligator cable, the participant would have to pull the trigger on the HTC Vive wand to open the jaws of the alligator clip, and then clip it on to a component. Since the only force feedback available to the participant is the vibration of the handheld wand, a visual feedback method was used to indicate when cables were in the correct positions to be connected to the components. This visual method consisted of highlighting the cable end when it was positioned correctly. This highlight method was also used for all of the cable types (BNC, alligator, and banana). All of the equipment requires the same manipulation as real equipment, i.e. turning on power, choosing channels, choosing waveforms, selecting frequencies and voltage outputs with knobs, choosing volts/div with knobs on the oscilloscope, choosing display channels on the oscilloscope, choosing between DC/GRND/AC on the oscilloscope etc. After creating a valid circuit and adjusting the equipment correctly the appropriate waveform is displayed on the oscilloscope screen. As the values of the components are changed by adjusting the resistance using the decade box or sliding the core into the coil, the waveform changes in real time. In addition, the function generator and oscilloscope both have two channels so that phase angle shifts and voltage attenuation can be studied as the circuit is altered by comparing the circuit output to the second channel output of the function generator.

After performing the virtual experiments, the participants were given a survey to evaluate the perceived effectiveness and their acceptance of using VR labs. The survey questions consisted of five Likert scale questions and three open-ended response questions. Table 1 shows the Likert questions and the results using the following scale: 5 – Strongly Agree, 4 – Agree, 3 – Neutral, 2 – Disagree, 1 – Strongly Disagree. In general, a strong positive response to the VR labs is a 5 and a strong negative response to the VR labs is a 1.

Table 1 Likert scale survey and results.

Question	**Average**	**Mode**	**Standard Deviation**
I was comfortable wearing the Head Mounted Display	4.17	4	0.37
The detail of the Virtual Reality Equipment was sufficient that I could recognize similar equipment in a real-life lab.	4.67	5	0.47
The actions needed to perform the Virtual Reality lab was similar enough to a real-life lab such that I could perform a similar real-life lab	3.83	4	0.89
The Virtual Reality lab would encourage experimenting with the equipment	4.5	5	1.1
Overall, I feel that a Virtual Reality lab would be an effective way to learn laboratory topics.	4.83	5	.37

As can be seen in Table 1, the participants in this study thought that VR experiments would be an effective way to learn laboratory topics and felt comfortable using the VR equipment to perform the experiments. The open-ended response questions focused on participant information, such as degree being pursued and year in school as well as what the participant perceived as the main advantages and disadvantages of virtual reality experiments as well as a request for additional suggestions for improvement. While the responses were varied the predominant advantages included: all equipment would be working and in good condition in the VR lab and that it would be possible to use the equipment without fear of breaking it. The predominant disadvantage was that there was no tactile feedback. The suggestions focused on controller improvement and making the environment more colorful. These results indicate that from the student's perspective, the use of VR labs is feasible and would allow for freer investigation and inquiry by the student. All of which should improve attainment of lab objectives.

VR laboratories will have a significant impact on the accessibility, type, and safety of educational laboratory experiences. While VR has significant potential, the acceptance of VR laboratories by faculty and students is paramount for its use. The prototype VR experiments shown in Figure 2 and 4 demonstrate the required capability to recreate virtual versions of the majority of teaching laboratories in STEM fields, including manipulating objects, interacting with realistic virtual versions of real equipment, creating visual and audio feedback based on the theoretical parameters and the student's inputs as well as generating realistic data from the experiment. Incorporating VR labs into a traditional lab sequence will allow students to interact with equipment not available at the institution and allow students to shift into an inquiry-based investigation experimental techniques and practices safely. This first study into the effectiveness of VR experiments as perceived by the participants (students) has shown that utilizing VR labs in a traditional STEM curriculum is feasible and would be accepted by the students.

References

[1] A. Jones, "Evaluation of Canvas-Based Online Homework for Engineering," presented at the 2017 ASEE Annual Conference & Exposition, 2017.

[2] A. Striegel, "Distance education and its impact on computer engineering laboratories," in *Frontiers in Education Conference, 2001. 31st Annual*, 2001, vol. 2, p. F2D–4.

[3] S. H. Johnson, W. L. Luyben, and D. L. Talhelm, "Undergraduate interdisciplinary controls laboratory," *J. Eng. Educ.*, vol. 84, no. 2, pp. 133–136, 1995.

[4] D. J. Olinger and J. C. Hermanson, "Integrated Thermal-Fluid Experiments in WPI's Discovery Classroom," *J. Eng. Educ.*, vol. 91, no. 2, pp. 239–243, 2002.

[5] A. M. Okamura, R. Christopher, and M. R. Cutkosky, "Feeling is believing: Using a force-feedback joystick to teach dynamic systems," *J. Eng. Educ.*, vol. 91, no. 3, p. 345, 2002.

[6] R. J. Robinson, "Improving Design of Experiment Skills through a Project Based Fluids Laboratory," *age*, vol. 7, p. 1, 2002.

[7] J. E. Ashby, "The effectiveness of collaborative technologies in remote lab delivery systems," in *Frontiers in Education Conference, 2008. FIE 2008. 38th Annual*, 2008, p. F4E–7.

[8] A. M. Bisantz and V. L. Paquet, "Implementation and Evaluation of a Multi-course Case Study for Framing Laboratory Exercises," *J. Eng. Educ.*, vol. 91, no. 3, pp. 299–307, 2002.

[9] R. J. Robinson and J. Wellin, "Introducing Data Acquisition and Experimental Techniques to Mechanical Engineering Students in the Freshmen Year," *age*, vol. 7, p. 1, 2002.

[10] A. Mendoza and N. Buyurgan, "A Hands-on Experimental Laboratory for RFID Education," in *IIE Annual Conference. Proceedings*, 2006, p. 1.

[11] A. D. Grant, "The effective use of laboratories in undergraduate courses," *Int. J. Mech. Eng. Educ.*, vol. 23, no. 2, pp. 95–101, 1995.

[12] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *J. Eng. Educ.*, vol. 94, no. 1, pp. 121–130, 2005.

[13] B. Bidanda and R. E. Billo, "On the use of students for developing engineering laboratories," *J. Eng. Educ.*, vol. 84, no. 2, pp. 205–213, 1995.

[14] D. Magin and S. Kanapathipillai, "Engineering students' understanding of the role of experimentation," *Eur. J. Eng. Educ.*, vol. 25, no. 4, pp. 351–358, 2000.

[15] M. Ogot, G. Elliott, and N. Glumac, "An Assessment of In-Person and Remotely Operated Laboratories," *J. Eng. Educ.*, vol. 92, no. 1, pp. 57–64, 2003.

[16] P. C. H. Liu, A. Trivedi, and B. P. Lee, "Implementing Automatic Data Collection and Identification Laboratory," in *Southcon/96 Conference Record*, 1996, pp. 222–226.

[17] T. Lord and T. Orkwiszewski, "Moving from didactic to inquiry-based instruction in a science laboratory," *Am. Biol. Teach.*, vol. 68, no. 6, pp. 342–345, 2006.

[18] S. W. Rissing and J. G. Cogan, "Can an inquiry approach improve college student learning in a teaching laboratory?," *CBE-Life Sci. Educ.*, vol. 8, no. 1, pp. 55–61, 2009.

[19] J. P. Suits, “Assessing Investigative Skill Development in Inquiry-Based and Traditional College Science Laboratory Courses,” *Sch. Sci. Math.*, vol. 104, no. 6, pp. 248–257, 2004.

[20] J. Spears and D. Zollman, “The influence of structured versus unstructured laboratory on students’ understanding the process of science,” *J. Res. Sci. Teach.*, vol. 14, no. 1, pp. 33–38, 1977.

[21] N. R. Council, *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press, 2012.

[22] H. A. El-Mounayri, C. Rogers, E. Fernandez, and J. C. Satterwhite, “Assessment of STEM e-Learning in an Immersive Virtual Reality (VR) Environment,” 2016.

[23] M. V. K. Karingula and H. A. El-Mounayri, “Assessment of Virtual Physics Lab (VPL) in summer course for pre-college preparation.,” *age*, vol. 23, p. 1.

[24] A. Binstock, “Powering the Rift.” [Online]. Available: https://www.oculus.com/blog/powering-the-rift.

[25] K. Orland, “The Ars review: Oculus Rift expands PC gaming past the monitor’s edge,” *Ars Technica*, 28-Mar-2016. [Online]. Available: https://arstechnica.com/gaming/2016/03/the-ars-review-oculus-rift-expands-pc-gaming-past-the-monitors-edge/.

[26] S. Buckley, “This Is How Valve’s Amazing Lighthouse Tracking Technology Works,” *Gizmodo*. [Online]. Available: https://gizmodo.com/this-is-how-valve-s-amazing-lighthouse-tracking-technol-1705356768.

[27] O. Kreylos, “Lighthouse tracking examined | Doc-Ok.org.” [Online]. Available: http://doc-ok.org/?p=1478.

[28] OwlchemyLabs, *Juggling in the Vive - Alex at Owlchemy*. [Online]. Available: https://www.youtube.com/watch?v=O3WGbe-5Mdc

[29] Byford, Sam, “Valve shows off new VR controller prototypes - The Verge.” [Online]. Available: https://www.theverge.com/2016/10/12/13264950/valve-vive-vr-controllers-new-prototype.