Utilizing Virtual Reality for Electromagnetism Instruction

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Work in Progress: Utilizing Virtual Reality for Electromagnetism Instruction

Introduction

The theory of Electromagnetism (E&M) is an essential part of the modern technology. It is the fundamental theory that underpins all electronics and light, and it is completely described by the four equations known today as “Maxwell’s equations.” While these equations provide a correct description of the physical world, E&M education goes beyond just learning how to manipulate these equations. There are numerous canonical examples, scenarios, and approximations that are taught as a base for E&M physics education, and all rely on 2D platforms, such as textbooks, whiteboards, and blackboards, which have limitations in conveying the true three-dimensional (3D) nature of E&M. A true understanding of E&M concepts requires building a physical intuition of how these concepts and examples exist in real space. In this study, we explore the use of Virtual Reality (VR) to improve E&M education by assisting with the creation of physical intuition.

VR consists of head-mounted display technology, providing deeply immersive and interactive real-time digital simulations. These simulations and the learning environment surrounding them can allow students to take full advantage of their learning time. The immersive nature of VR fully engages students in the targeted material[1], while also allowing them to work at their own pace to thoroughly understand the concepts. The most critical aspect of VR for education with respect to E&M is that students are placed into a 3D simulation that allows them to view the digital world they are studying from multiple perspectives[2]. As an example, VR can aid students in getting a better understanding of the interactions of E&M fields and waves in an immersive, realistic, and interactive learning environment, thereby facilitating a more engaging and effective educational experience.

Motivation

Electromagnetism is one of the most difficult subjects for Electrical Engineering students, as it requires building mental models involving structures for which students have no real-life reference for. Magnetic fields surrounding a bar magnet have a canonical illustration presented in classrooms using iron shavings to show the magnetic field lines, which allows students to create a model for how magnetic field lines behave. There is no analogous demonstration for moving magnetic fields, electric fields, or electromagnetic waves. There have been many attempts to create such models, as the work done by Dori *et al.*[3]. However, our group aims to develop VR applications that provide students with interactive models that can be employed to address problems involving electromagnetism concepts.

Methodology

The VR experiences are developed using the Unity game engine. The process begins by defining an experiment and the associated learning outcome. This paper presents an example of a VR experience for an E&M application that demonstrates the concept of electromagnetic wave polarization. Figure 1 shows 3D representations of electromagnetic waves with different polarizations.

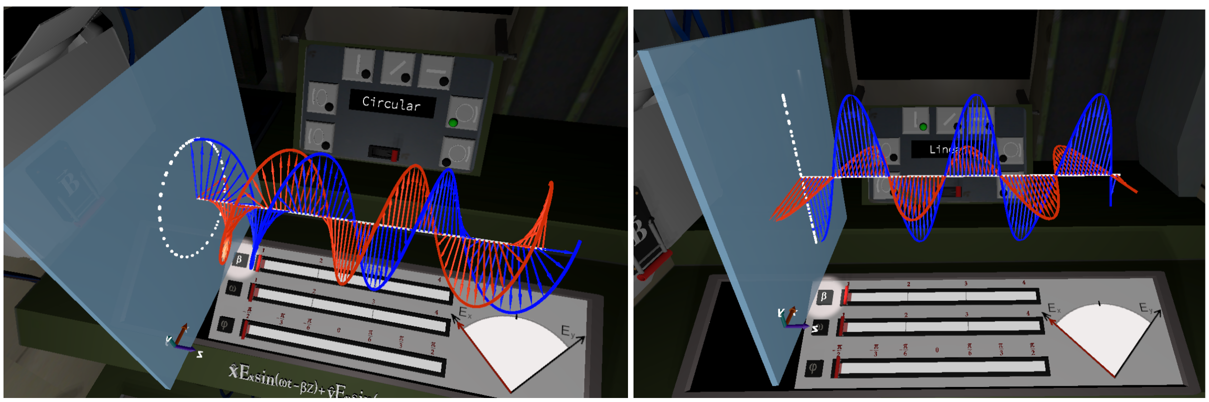

Figure 1: An in-lab representation of circularly polarized wave (left) and linearly polarized wave (right).

The VR experience involves a dynamic experiment space, allowing students to actively engage with the experiment and adjust the wave parameters such that they observe in real time the resulting polarization of the wave. To engage students in the learning process, the interactive visualization is set on the International Space Station, a setting where electromagnetic waves are extremely relevant, both for observation and communication with Earth, as well as a danger from the sun. One of the big advantages of using VR technology for education is that it is immersive; however, one of the largest challenges in constructing VR applications is maintaining that immersion. For the latter, our VR experience has been enhanced by a gamified narrative, as interesting and immersive worlds can intrigue students and cause them to give more time and attention to the material[4]. Figure 2 provides a snapshot of the experiment set.

The student plays as an astronaut that has just arrived aboard the ISS, and needs to be trained in the particulars of wave polarization. After their training, the station navigation breaks and the student has to use their knowledge of wave polarization to save the station. The last part of designing the lab is coming up with a knowledge test. The student has had a chance to play around with the material, now they get to test their knowledge of it. In the wave polarization lab, when the ISS “breaks,” the student has to correctly identify the polarization of incoming waves in order to save the station. If they succeed, the station is saved and they can keep exploring. If they don’t succeed, the student is given a thematic “game over” view of the ISS falling out of orbit, and encouraged to try again (Figure 3).

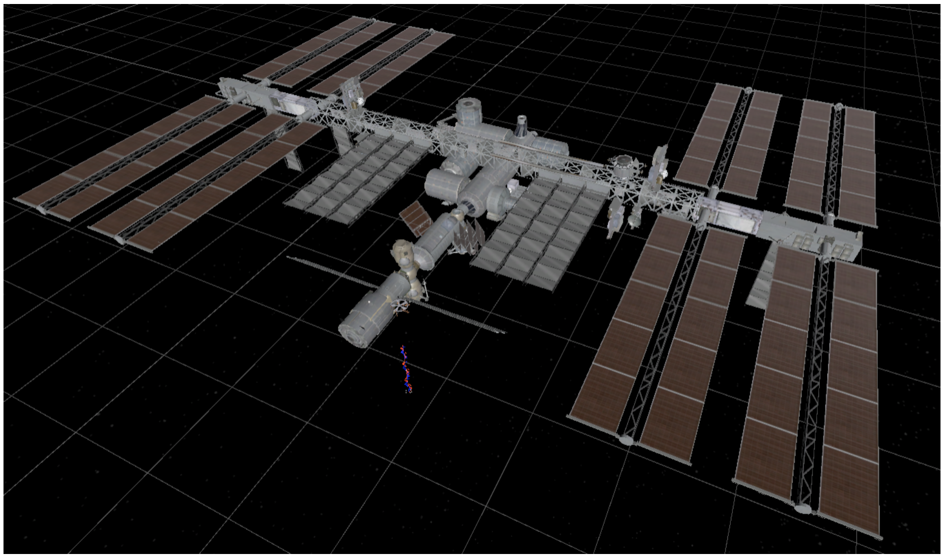

Figure 2: The ISS as the set of the wave polarization laboratory experiment.

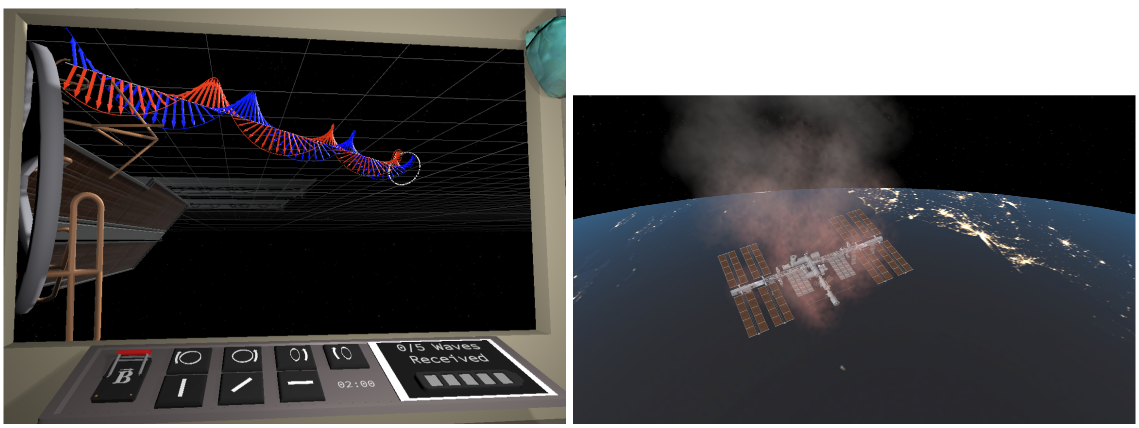

Figure 3: View of incoming polarized waves (left) and the game over scene (right)

The design of the lab often gets interwoven with the implementation of the lab. A team of undergraduate students worked on the development of these VR experiences. These students come in with varying knowledge of Unity and programming, and are trained to use Unity and develop software. Multiple participants have also reported that working on the development of a VR lab has helped them understand the material they are working with better.

Once the labs are completed, students taking E&M classes have the opportunity to use them to master the material. At the University of Illinois at Urbana-Champaign, students can sign up for a lab course that is designed to be taken concurrently with the E&M lecture course. The 1 credit hour laboratory course meets once a week to work through the VR lab experiment. The students enrolled in this course get card access to the physical room where the computers and headsets are kept, and can come in on their own time to additionally engage with the material. Evaluation of our methods is currently underway using knowledge check questions, self-reported learning results, and in-game behavioral tracking data. Each VR experience features a multiple-choice quiz to check their understanding, and a short exit questionnaire after the experience. Quiz questions are designed to encourage conceptual understanding over utilizing equations. Post-experience questionnaires gather student feedback, which also allows the labs to be tuned and improved. Finally, we gather data from the VR headsets to find what objects and game features students pay the most attention while playing, to assess and tune how learning occurs in the VR environment. Using headset tracking software, heatmaps can be generated and used to inform where attention is focused in VR, allowing the developers to streamline the experience by reducing distractions.

Results

Students that engage with the labs appear to experience positive outcomes regarding their understanding of the E&M material. For the wave polarization lab, we have an qualitative questionnaire that reports that the students that used the lab feel that they better understand the concepts of wave polarization after taking the lab. Our results agree with prior work in virtual learning environments such as Gonzalez *et al.*[5]. The team is in the process of obtaining IRB approval to disseminate these results.

Discussion

Virtual reality is an incredible technology with potentially great applications in education. There are however a few difficulties that need to be addressed. First, is accessibility. Our lab currently uses a computer room with Oculus Rift headsets for the students to use. This hardware works well but represents a significant overhead on the cost and space needed to use virtual reality to teach. We are currently working on porting the VR experiences labs to untethered headsets, such as the Oculus quest, a standalone headset. This could cut the cost of setting up a lab for students by a factor of five or more. This introduces a new problem, as standalone headsets have less computation power than desktop computers, and electromagnetic visualizations often involve costly computations. Optimizing these VR experiences is a priority, to ensure that they run at a comfortable frame rate for users [6].

Further information regarding the development and use of these VR applications, as well as how to download and use them for educational purposes, can be found at https://www.ilie.ece.illinois.edu/immersive-learning-lab.

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