Visualizing Fundamentals of Electric and Magnetic Fields in Virtual Reality

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1 Introduction

In the first half of the 19th century, Michael Faraday studied electricity and magnetism. He hypothesized that a changing magnetic field can generate a current. He tested his hypothesis by conducting numerous experiments, most notably the coil and magnet experiment. He created a coil by wrapping a paper cylinder with wire, connected the coil to a galvanometer, and moved a magnet back and forth inside the coil. He noticed that the galvanometer showed there was a current induced when the magnet was in motion.

Faraday theorized that a current was induced because there were magnetic lines of force around the magnet. He demonstrated the existence of these lines of force by conducting the iron filings experiment. He poured tiny pieces of iron filings to coated sheets of paper placed on top of bar magnets. The iron filings were attracted to form a shape that resembles that of the magnetic lines of force. The iron filings' formation showed that the magnetic lines of force were curved and not straight as Newton conceptualized. After this experiment, Faraday began to visualize magnetic field lines as a collection of lines, each of which has a certain direction. These visualizations have transformed Faraday's ideas into more precise mathematical and physical concepts that provide more insights to people who study magnetic and electric fields.

There is one problem that new learners face in learning magnetic and electric fields. They are presented with two-dimensional visualizations when, in fact, these fields are three-dimensional. These visualizations are not only confusing but also prone to misinterpretation. I aim to tackle this problem by creating immersive experiences in visualizing electric and magnetic fields in Virtual Reality. I harnessed the power of GPU, computer graphics, and virtual reality technologies to create a new way of learning the two fields that make use of physical movement and gestures in a fun and engaging way. I developed four experiences, each illustrates magnetic and electric fields in different scenarios. **The Simple Moving Magnet Experience** visualizes the magnetic and electric fields around a bar magnet as it moves back and forth. **The Interactable Magnet Experience** allows users to directly interact with the magnet by holding it and seeing the magnetic and electric fields generated by the magnet. **The**

Coil and Magnet experience is a recreation of Faraday's experiment in which users can move a magnet inside a coil to generate a current that will turn on a light bulb. The last experience, **The Two Magnets Experience**, visualizes the magnetic and electric fields between two bar magnets.

In the next four sections of my paper, I describe the details of each of the four experiences as well as the process of designing and developing them. In the following section entitled **Game Instructions**, I walk through how one can engage in the virtual experience using the HTC Vive VR headsets. In the next section entitled **Creating the Virtual Environment**, I explain the algorithms used to render the fields and the XR Interaction toolkit that allows users to move and interact with various game objects. Finally, I reflect on my learning experience in working on this project and share my future visions on how this project can be improved.

2 The Simple Moving Magnet Experience

2.1 Description

The Simple Moving Magnet Experience is the first experience that a user encounters when entering the virtual experience. The purpose of this experience is to give the user a first dive into the theory of magnetic and electric fields. In this experience, the user is presented with a magnet that oscillates in the x-axis based on a cosine function. As the magnet moves, the user can see a dynamically-rendered field that is computed based on the position of the magnet. The key concept illustrated in this experience is how and why the vector at a certain point in three-dimensional space around the magnet change its direction and magnitude when the magnet moves from one point to another.

The user is provided with a mini tablet and a panel to help them study the key concept. The user can choose to see either the magnetic field or the electric field by pressing a button on the tablet. The mini tablet has a pause button which, if pressed, stop the magnet. This feature allows the user to observe the field more closely as they can pay attention to the vectors that are away from the magnet which may not be visible when the magnet is in motion. The mini tablet is also equipped with a slider that the user can use to position the magnet as they wish. If the slider is slid to the left, the magnet will move in the same direction. This feature is implemented to immerse the user in the experience, allowing physical movement to see changes in the displayed field.

While a field is displayed, the user can go to a nearby panel to have a read on the fundamentals of the displayed field. The panel has two buttons that can be used to navigate through the pages. One can think of the panel as a text book containing two short chapters on magnetic and electric fields. The panel is placed in front of the moving magnet so that the user can identify the name, definition, and formula of the displayed field. The panel minimizes the need to take off VR headsets to read about the fields and wear them again to see the visualizations. The benefit of having such a panel is that the user can have the various learning resources they need to study the two fields in one place.

2.2 Fundamentals of Magnetic and Electric Fields

In this section, I will present a brief introduction to the fundamental concepts of magnetic and electric fields. These fundamentals motivated the emergence of the study of vector field in mathematics about 60 years after 19th century scientists started drawing field lines to visualize forces around magnets.

2.3 Development

I began the development of this experience by creating a magnet prefab.

Definition 2.1. A prefab in Unity is a special type of component that allows fully configured GameObjects to be saved in the Project for reuse.

I created two cubes, colored one cube red and the other blue, and stick them together as a prefab. I decided to make a magnet prefab so that I can reuse the prefab instead of making a magnet from scratch for future virtual experiences. Prefabs reduce time spent on not only creating objects from scratch but also modifying objects. If the prefab is modified, the modification is applied to all of the prefab instances across all scenes. Once the prefab is created, adding a magnet into the scene can be done by dragging the prefab into the hierarchy window.

The second step in developing this experience is adding a game object of type *VectorField* into the scene. The *VectorField* object reads the charges and positions of the two poles at each frame. nd renders a collection of arrows based on the positions of the poles. It also each vector in the field based on these I decided to configure the field to appear large enough because I believe that larger visualizations are easier to understand.

3 The Interactable Magnet Experience

3.1 Description

The purpose of the Interactable Magnet Experience is to allow the user to interact with the magnet in a way that gives much more freedom than the first experience. In this experience, the user can move the magnet in any direction they wish as opposed to moving it along the x-axis only. The idea behind the creation of this experience is once the user have a basic understanding of magnetic and electric field, they can try to move, rotate, and flip the magnet to see the different visualizations of the magnetic or electric field.

3.2 Development

4 The Coil and Magnet Experience

4.1 Description

4.2 Development

5 The Two Magnets Experience

5.1 Description

The Two Magnets Experience presents a scenario in which the north pole of a magnet and the south pole of another magnet generate a magnetic field. The purpose of this experience is to visualize the changes in the field when a magnet is moving into or away from the other magnet. The visualizations of a magnetic field between two magnets in text books can be misleading. One can interpret that there is a constant number of magnetic field lines between two magnets. A key concept this experience illustrates is that the number of magnetic field lines is not constant.

The user is presented with three game objects in this experience: a dynamic magnet, a static magnet, and a panel. The dynamic magnet can be moved along the z-axis using a slider attached to the panel. When the dynamic magnet is moved away from the static magnet, more arrows will be rendered to fill in the space in between the magnets. The increase in the number of arrows illustrates that magnetic field lines are continuous and exists at any point in space.

This experience introduces the user to the concept of electrostatic force.

Definition 5.1. Electrostatic force is the force between two point charges.

In this experience, the positive point charge is represented by the north pole, and the negative point charge is represented by the south pole. The magnitude of the force is quantified by Coulomb's Law that states that

> The magnitude of the electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them.

5.2 Development

6 Game Instructions

In this section, I provide instructions on how to move around the virtual space and interact with the game objects inside it. These instructions will use the HTC Vive controllers as an example. I developed my virtual reality using the OpenXR platform to reach various kinds of hardware. The following instructions should apply to other kinds of controllers.

6.1 User Movement

There are two kinds of movement in my virtual reality: position and rotation. Position refers to the position of the virtual character at a specific frame whereas rotation refers to the virtual character's head rotation. The position movement is implemented to enable users to play in a relatively small space in reality whereas the rotation movement is implemented to minimize the need to rotate the user's head when looking at an object in the virtual reality.

The left controller's trackpad can be used to move the virtual character. To move forward, one can touch the upper part of the trackpad. Similarly, touch the bottom part of the trackpad to move backwards. The benefit of implementing this movement is that the user can "walk" about the virtual world without actually walking in the real world.

The right controller's trackpad can be used to rotate the head of the virtual character. To rotate right, one can touch the right part of the trackpad. To rotate left, touch the left part of the trackpad. The character's head can only rotate right or left. To rotate the head upwards and downwards, the user needs to rotate their own head. In designing the virtual reality, I placed all of the game objects at eye level, minimizing the need to move the user's head up and down.

6.2 Grabbing Interaction

There are two game objects that the user can grab with their virtual hands: the mini tablet and the interactable magnet in the second experience. Both of these objects are designed in a way that makes learning more engaging as they motivate the user to move their own hands and be more active. In designing the grabbing interactions, I decided to enable either hand to grab game objects from within arm's reach but only use the left hand to grab objects from afar.

The mini tablet can be grabbed from within arm's reach and from afar. To grab from within arm's reach, the user can move closer to the tablet and press the trigger button on the desired hand controller. To grab from afar, the user can lift their virtual left hand up and point it towards the tablet until a blue ray appears. The blue ray indicates that the tablet can be pulled into the user's left hand. While the blue ray is in display, press the trigger button on the left hand controller twice to grab it from afar.

The interactable magnet can only be grabbed from within arm's reach. T

6.3 UI Press interaction

7 Creating the Virtual Environment

8 Conclusion