

Electromagnetics Education with VR

Team member: Zhewen Fu, Zhanyu Feng, Daosen Sun and Han Hua

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TA: Xinyi Xu

1.Introduction

1.1 Objective:

Current college electromagnetics courses rely heavily on advanced calculus, which is good for quantitative analysis of electromagnetics problems. However, it has little help in giving students an intuitive understanding of electromagnetics. Students may lose the concept of electromagnetics quickly after finishing the course. Unlike rigid body objects, we cannot interact with the electromagnetic field in our daily life. It's fundamentally harder to understand the electromagnetic field that we cannot directly perceive. The current experiment in electromagnetics courses can only use the device to transform the invisible electromagnetic field into data or graphs. We want to visualize electromagnetics in the virtual world, and students can use controllers to directly interact with those charged objects and see the influence on the electromagnetic field.

1.2 Background:

There is a lot of discussion about the challenges for electromagnetics teaching and education. They all point out the requirements in mathematics are much strict compared to other courses. Professor Ari argues that” one further expectation in educating students into a mature relation with electromagnetics is that they clearly understand the connection of the electromagnetic concepts to real-world phenomena.” [1] The current solution in building intuitive connections in real-world phenomena and electromagnetic concepts is using some visualizing tool such as a 2D image or 3D model that draws the Magnetic Induction lines and the electric field lines. [2] However, those visualizing tool is usually static or pre-scripted. Students and users cannot interact with it. Besides, with the rise of covid-19, many Labs have to be performed online. As a result, there is a strong need for students can do interactable electromagnetism experiments in the virtual world.

1.3 Physical Design:

Our project will be heavily on software development. We will use mature commercial VR headsets and equipment as our hardware basis. As a result, we do not have a physical design.

1.4 High-level requirements List:

1.Four interactive(users can use controllers to manipulate the objects in the scenes and see the corresponding electromagnetic field) labs each demonstrates one of four Maxwell equations (Gauss's Law, Gauss's law for magnetism, Ampere's Circuital Law, Faraday's Law)

2.Each Lab should run smoothly which means each frame should use less than 16.66ms to render.

3.The GPU acceleration should provide 5X objects simultaneously simulation compared to traditional CPU simulation.

2.Design

2.1 Block Diagram:

Since we will accomplish the demonstration of the four Maxwell equations in different lab scenes, we have four distinct systems designed to achieve the high-level requirements. We will give more details of how these systems will achieve the functionality of the experiments in the block subsystem requirements part.

Gauss's Law

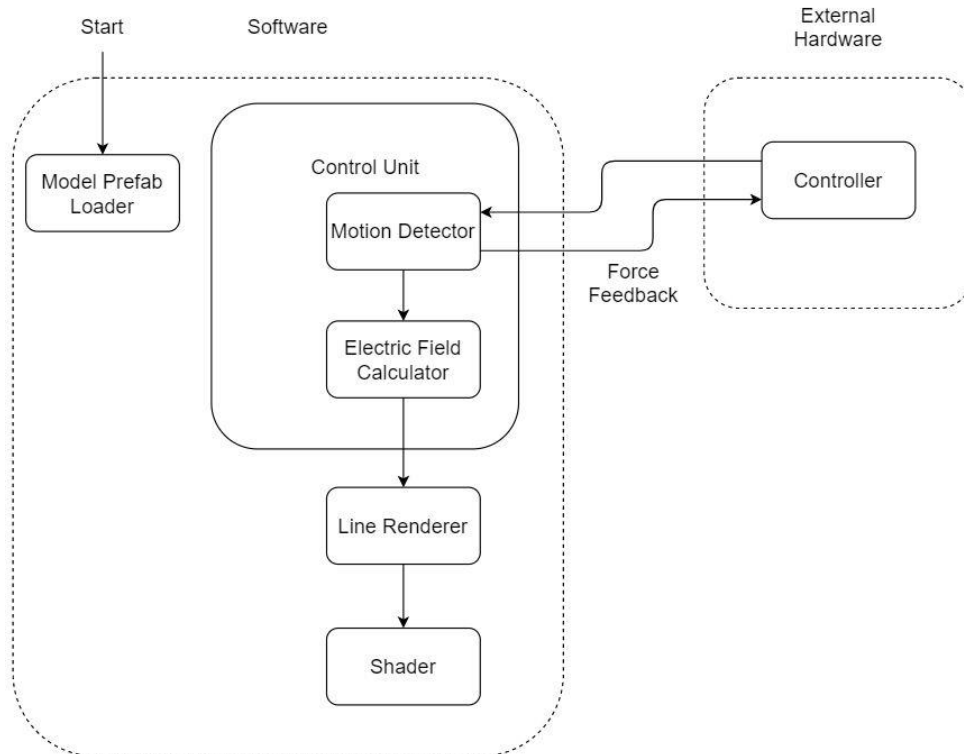


Figure1, block diagram for Gauss's Law lab

Gauss's Law for Magnetism

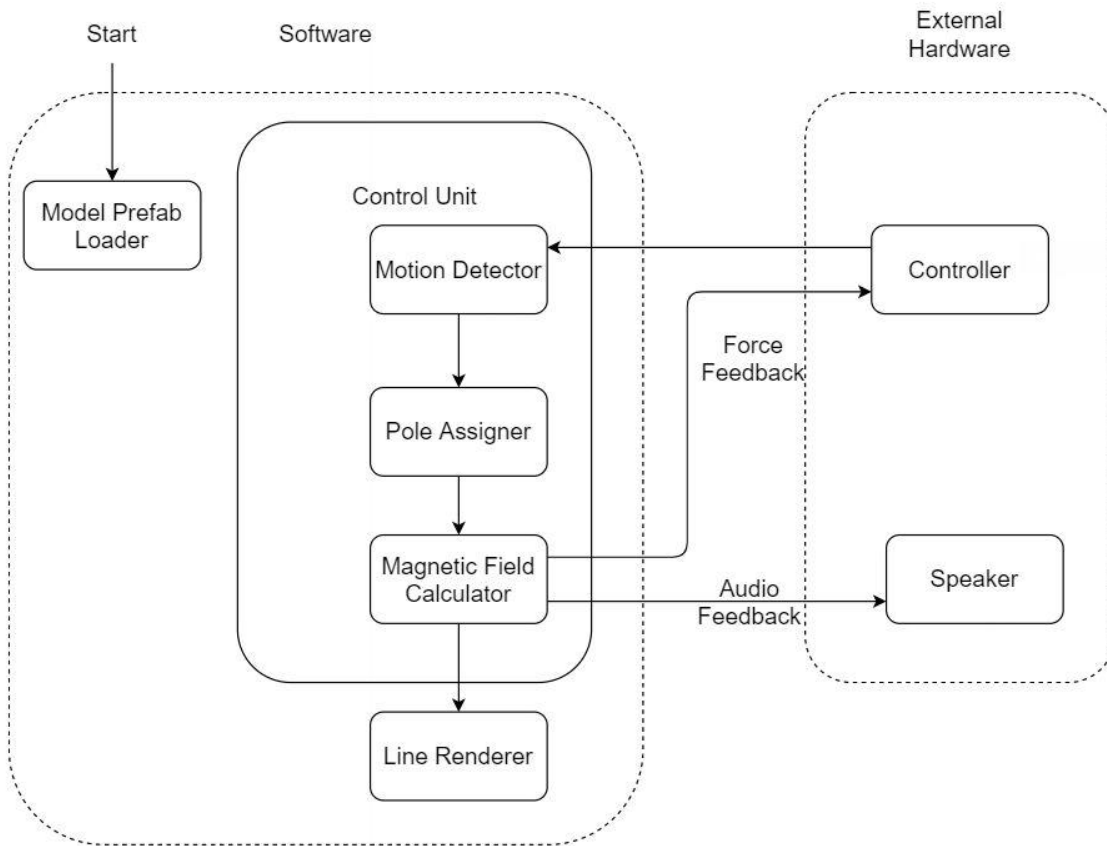


Figure2, block diagram for Gauss's Law for Magnetism lab

Faraday's Law

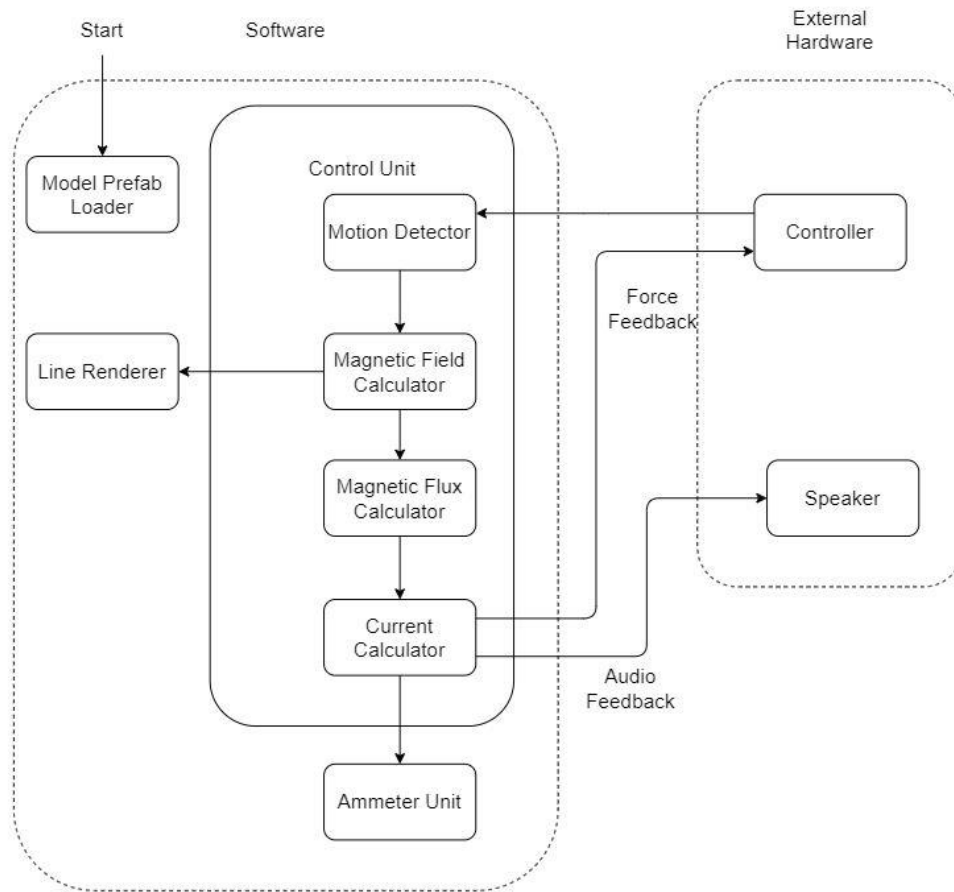


Figure3, block diagram for Faraday's Law lab

Ampere's Circuital Law

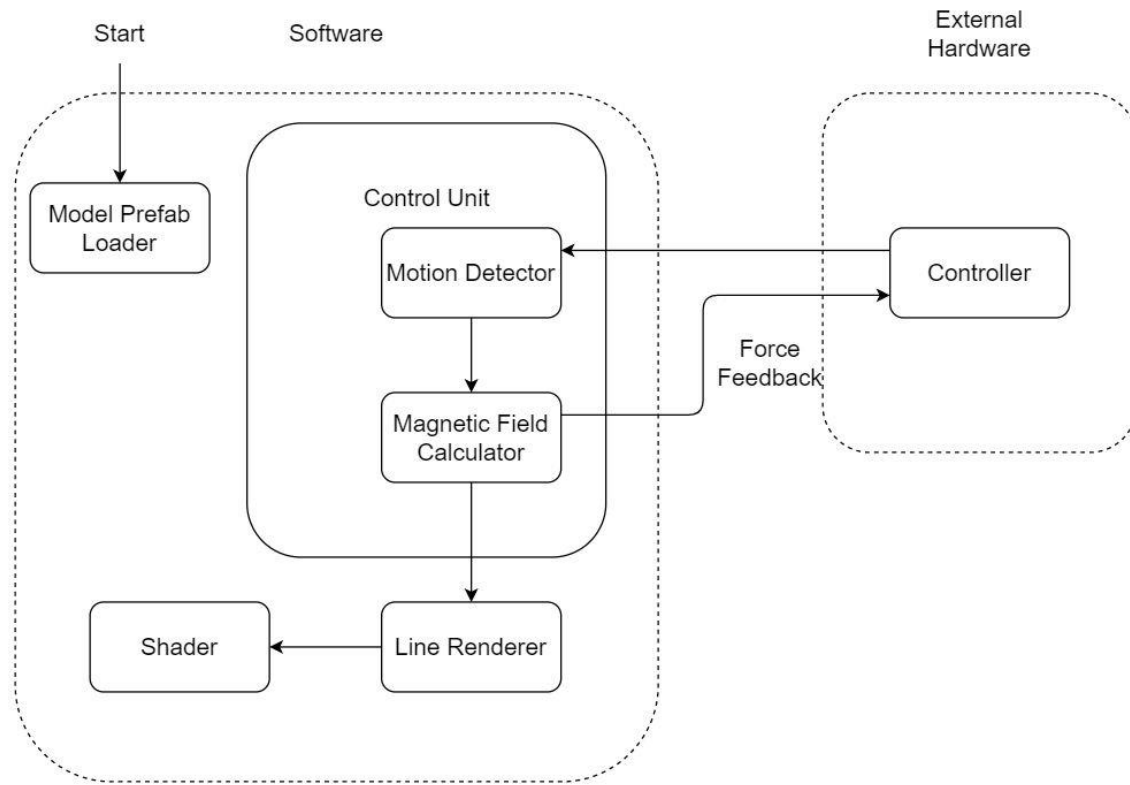


Figure4, block diagram for Ampere's Circuital Law lab

2.2 Functional Overview:

2.2.1 Scene 1: Gauss's Law for Electric Fields Lab

This block will be responsible for using VR to show Gauss's law in the electric field, which will be integrated with other blocks to build a complete teaching system. In this block, we will large-scale, complex, and interactive visualization for the electric waves. Compared to some already existed visualization projects, we plan to use shader to do the calculation and make higher speed and accuracy by GPU programming. Except for visualization, we will add some force feedback in this block, you may feel the strength of the electric field through the vibration frequency of the controllers.

2.2.2 Scene 2: Gauss's Law for Magnetism Lab

This block will be responsible for using VR to demonstrate Gauss's law for magnetism. Gauss's law for magnetism states that no magnetic monopoles exist and that the total flux through a closed surface must be zero. This scene visualizes Gauss's law for magnetism by showing the magnetic field around a magnet. In this scene, the user will be able to divide the magnet into two parts and both parts have an N pole and an S pole after division. Both parts will have continuous magnetic fields to show the poles. There will be force and audio feedback to demonstrate the strength of the magnetic field and give users a more interactive and immersive experience.

2.2.3 Scene 3: Faraday's Law Lab

Faraday's Law of induction is a basic law of electromagnetism stating that the electromotive force around a closed path is equal to the negative of the time rate of change of the magnetic flux enclosed by the path. [3] Our scene demonstrates the law through the visualization of unseen current induced by the changing magnetic flux through the ring collector on the ammeter. The user will be allowed to move the solenoid and see the real-time changing field while moving. The changing of flux through the collector will induce current which will be reflected through the waving pointer of the ammeter. The comparing of the visualization of flux through the collector with the amount of current induced illustrates the correlation between the changing magnetic flux and the electromotive force.

To fully construct the lab scene and achieve the functionality of the experiment, we would need to implement several subblock systems including the control unit, line renderer unit, model prefab unit, sound/force feedback unit, and ammeter visualization unit. The control unit manages all the logic of scene states and all the required massive computations. It can be divided into four subunits: motion detector, field calculator, flux calculator, and current calculator. The motion detector detects the movement of the solenoid and passes the data to the calculators. The field collects data from the motion detector and calculates the field at specific points, then transfers the field data to the line renderer and the flux calculator. The flux calculator will collect the field data around the collector and pass it to the current calculator. The current calculator calculates the amount of current flowing through the ammeter and passes the data to the ammeter visualization unit and sound/force feedback unit.

2.2.4 Scene 4: Ampere's Law for Magnetic Fields Lab

This block will be responsible for using VR to show Ampere's Law in the magnetic field, which will be integrated with other blocks to build a complete teaching system. In this block, we will large-scale, complex, and interactive visualization for the magnetic fields created by currents. Compared to some already existed visualization projects, we plan to use computation shader to do the calculation and make higher speed and accuracy by GPGPU(General-purpose computing on graphics processing units) programming. Except for visualization, we will add some force feedback in this block, you may feel the strength of the magnetic field through the vibration frequency of the controllers.

2.3 Block Subsystem Requirements:

2.3.1 Scene 1: Gauss's Law for Electric Fields Lab

- the user should feel the strength of the electric field through the vibration frequency of the controllers.
- In this block, we should use controllers to set up different types of charged objects and operate the orientation of them. After that, according to the types of objects, the user will see the different electrical field in VR to get a full understand of how it works.
- We should achieve high frame rates in the VR, fasten the process of computation by GPU programming. Besides that, we can also save computation time and get much smoother curves in VR.
- We should create a cube area in unity where objects can display electric field lines in order to reduce meaningless computation.

2.3.2 Scene 2: Gauss's Law for Magnetism Lab

- The magnetic field of the magnet will be visualized for users to have intuitive feelings.
- Users can feel the strength of the magnetic field through the vibration frequency of the controller and the sound intensity of the speaker.
- The magnet can be separated into two magnets and after separation, each magnet still has both N pole and S pole, and their magnetic fields are visualized.
- The real-time magnetic field changes as the position and orientation of the magnet change.

2.3.3 Scene 3: Faraday's Law Lab

- When the experiment starts, the model prefab unit will load all the models and prefabs to the scene.
- The line renderer collects the data and visualizes the real-time magnetic field lines around the solenoid.
- Upon successfully collects the data from the current calculator, the ammeter will move the pointer to the corresponding position.
- The sound/force feedback unit will generate real-time feedback to the speaker and the controller according to the magnitude of the current induced.

2.3.4 Scene 4: Ampere's Law for Magnetic Fields Lab

- In this block, we should use controllers to set up different types of currents (line and solenoid) and operate the orientation of them. After that, according to the types of objects, the user will see the different magnetic field in VR to get a full understand of how it works.
- The user should feel the strength of the magnetic field through the vibration frequency of the controllers.
- We should achieve high frame rates in the VR, fasten the process of computation by GPU programming. For magnetic fields created by lines, we should see the interaction between multiple lines and their overall effect on the magnetic fields. Which should be heavily used in parallel programming.

2.4 Risk Analysis:

2.4.1 Scene1: Gauss's Law for Electric Fields Lab

- We aren't so sure that we can use shader in unity to do the calculation in high speed and convenient way, which may lead to much harder work than CPU computation.
- The laboratory controllers may not adapt to different frequencies of vibration and can't show the force feedback.

2.4.2 Scene 2: Gauss's Law for Magnetism Lab

- The separation of a magnet into two parts requires recalculation of the magnetic fields and frame drop may appear.

- The controllers may not be able to vibrate at different frequencies and force feedback may not be achieved.

2.4.3 Scene 3: Faraday's Law Lab

- The computation of the field around a charged solenoid is complex and may lead to low frames during the experiment.
- The controllers may not be able to vibrate at different frequencies and force feedback may not be achieved.

2.4.4 Scene 4: Ampere's Law for Magnetic Fields

- A little experience and little resources on GPGPU programming on Unity engine. We may have trouble in transfer our knowledge in CUDA program development to computation shader programming.
- The laboratory controllers may not adapt to different frequencies of vibration and can't show the force feedback.

3.Ethics and Safety

3.1 IEEE Codes:

In the IEEE Code of Ethics, it sad that we should hold paramount the safety, health, and welfare of the public. [5] Our project requires the use of the VR helmet, and the surrounding objects cannot be seen during the process of testing or use. At the same time, we use the handlers to manipulate the direction and place objects, it's likely that the users of the device will collide with surrounding objects during the process of operation, which leads to physical injury. To avoid this, we should set the device in some open place and make sure no sharp objects or passers-by. In order to protect the safety, health, and welfare of the public, we should clear the playing field. Playing VR without supervision and in a crowded space is a risky business. While wearing the product's headset, the users are blind to the world around them and we shouldn't rely on the product's chaperone system for protection. They can trip and hit their head or break a limb and get seriously hurt, so someone needs to watch over the users when they are using VR. That's mandatory.

Because our project mainly uses one VR helmet, two controllers, and some force feedback sensors, except for the surrounding situation, we should pay attention to safety when we are using these devices

3.2 Keep an eye on it:

One of the major health concerns about virtual reality involves the eye. [6] Myopia is a growing problem around the world. Looking at tablets, phones, and the like, there's pretty good evidence that doing near work can cause lengthening of the eye and increase the risk for myopia. We are all worried that virtual reality might make things worse. In a virtual environment, the way we look and interact is changed because we may be projecting onto the eyes something that looks far away, but in reality, it's only a few centimeters from the eye. Most of us look at cell phones and tablets for a short time before looking up, which minimizes their negative effect on the eye. But with VR, it's all too easy to become immersed in that out-of-body experience. So when the user experiences these devices, we should Strictly control the time of use and avoid damage to the user's eyes. Maybe we will ask users to take a 10 to 15 minutes break every 30 minutes, even if they don't think they need it.

3.3 Pre-existing conditions:

Most devices include a warning to see a doctor before use if you are “pregnant, elderly, or have pre-existing conditions that may affect your virtual reality experiences such as vision abnormalities, psychiatric disorders, heart conditions, or other serious medical conditions.” That warning includes implanted medical devices, such as cardiac pacemakers, hearing aids, and defibrillators, as well as anyone with epilepsy or a history of seizures and blackouts.

3.4 Children at most risk:

Children may not know how to communicate discomfort of any sort, such as visual discomfort or motion sickness, so you don't want prolonged exposure on screen. Most major manufacturers have set a cutoff age: no use of the device for children under the age of 13. As our project is mainly for teaching, we should beware of improper use by children.

References

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