“Enlightening”: An Interactive AR Educational Application

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Abstract

We built an educational application for the Meta 2 Augmented Reality headset for our Spring 2018 EE267 final project. The application allows one to view, interact with, and better understand the basics of electrical circuits and their building block components. In this report, we explain the application we built, explore the reasons we believe AR has promising educational and training applications and how our project reflects those, and discuss the advantages and challenges of extending our learnings from this course to building an interactive AR application.

1. “Enlightening”: Our Application

1.1. Overview

Our project was an educational interactive AR electrical circuit application for the Meta 2 headset. The simple circuit example we built includes a battery that discharges and can be toggled to charge, wires, switches, resistors with changeable resistance values, and LEDs.

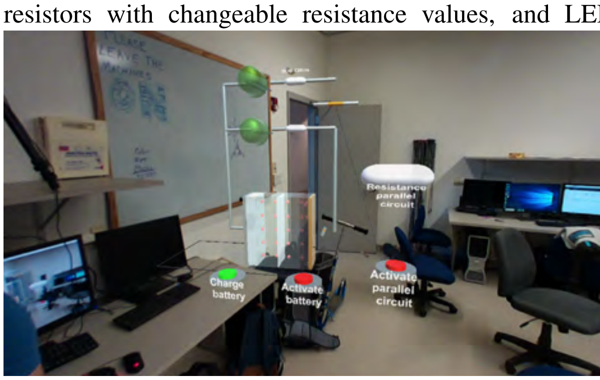

Figure 1. Simple charging state of the circuit.

When the main circuit switch is turned on, current flows through the circuit component. The blue spheres flowing through the wires in this state represent electrons, and the LED is on and emitting light to reflect the current flowing through it.

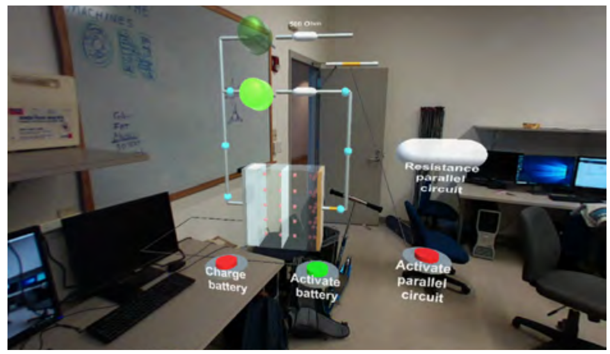

Figure 2. Simple on state of the circuit, one switch is connected and the battery is discharging.

Our circuit also has a parallel subcircuit with its own resistor and LED that can be switched off independently of the main circuit switch. When the parallel circuit is on with finite resistance (more on this below), the current in the remainder of the circuit reflects this.

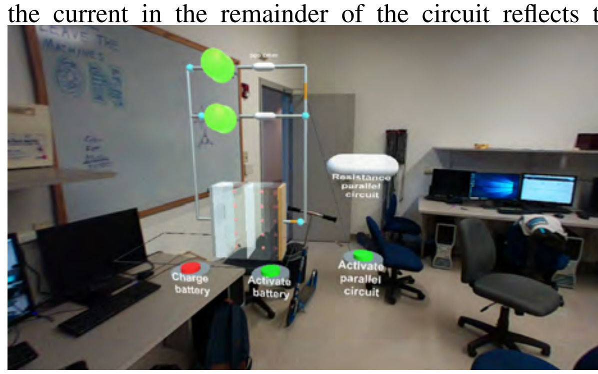

Figure 3. Parallel on state of the circuit, both switches are connected and the battery is discharging.

1.2. Functionality and Interactivity

There is a small control panel of 3 buttons and an external resistor that define much of the interaction a user can have with the circuit. As summarized above, the circuit’s battery can be toggled to charge (by touching the “Charge Battery” button) or discharge (by touching the “Activate Battery” button and turning on the main circuit switch), and can temporarily run out of charge. The switch to turn on the parallel circuit is controlled by the “Activate Parallel Circuit” button.

Figure 4. Benjamin hitting the control panel button to turn on the main circuit switch.

The external resistor that begins near the user and the rest of the control panel but is not a part of the circuit can be used to control the resistance in the parallel circuit’s resistor, and that resistor displays its resistance value. Making the external resistor larger increases the resistance in the parallel circuit, and making it smaller decreases the resistance. As the resistance and therefore the current in the parallel circuit changes, the user can visually see that in the speed of the electrons through the entire circuit, and especially in the parallel circuit. The current change is also visualized by a change in the LEDs’ brightness, if the current increases the LEDs’ will shine brighter.

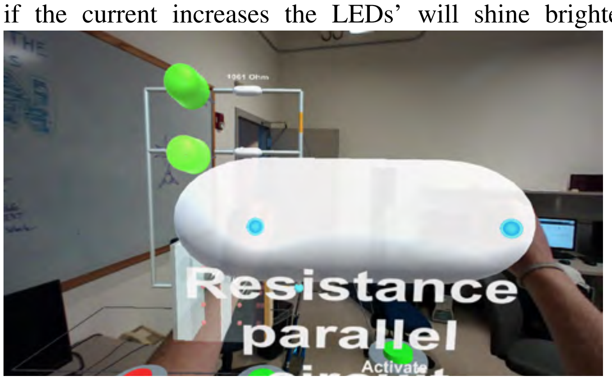

Figure 5. Therese increasing the resistance in the top resistor. The higher resistance of the top resistor is displayed textually (the scene begins with 500 Ohm), the LED is visibly less bright than the lower LED, and the electrons flow through the top subcircuit more slowly than the rest of the circuit.

If the resistance is decreased enough that the current is too high for the LED in the top subcircuit to handle, that LED burns out, and is unusable until the scene is reset (no current flows through the top subcircuit in this case, regardless of the state of the switches and battery).

Figure 6. Benjamin making the external resistor smaller by grabbing it with both hands and moving his hands together, reducing the resistance enough to burn out the top LED. The monitor behind him shows (approximately) what he is seeing in the headset.

1.3. Visualizations

In addition to the abovementioned electrons flowing through the wires to visualize the current and Ohm’s law and the LED emission levels, our circuit being in AR also allows a user to visualize the inner workings of the battery and LED components of the circuit.

The bulb of the LED can also be made invisible, and the user can see the emissions from the chip inside the LED in close proximity while the LED is emitting.

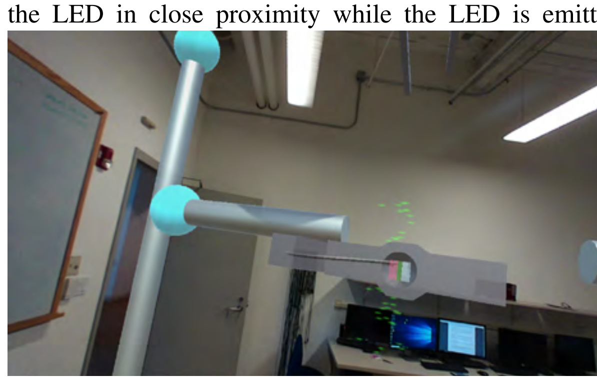

Figure 7. The view of the inner workings of an emitting LED at close range.

The outer shell of the battery can also be made invisible, and the user can see Lithium ions flowing from the cathode to the anode while the battery is discharging, and from the anode to the cathode while the battery is charging.

1.4. Methods and Acknowledgements

We built this using the Meta 2 SDK that extends the Unity game development platform. Most of the circuit components were constructed out of primitive Unity GameObjects, with the exception of the detailed LEDs, which were first constructed in Blender and then imported to Unity. The scene is constructed in Unity, with special Unity components defined by the Meta 2 SDK to make the scene's camera be the Meta 2 headset and to track features of the user's hands. The scripting to define the behavior of the components and the circuit as a whole is written in C#, and utilizes the Unity API and the Meta 2 SDK API.

Headset orientation and position tracking and corresponding translation and rotation of the scene relative to the camera is provided by the Meta2 SDK and Unity API. Basic hand tracking (object collision detection and visual feedback, triggering the collided GameObject, grab gesture detection) and basic hand interaction functionality (one-hand grabs to translate, two-hand grabs to scale equally on all axes) is provided by the Meta 2 SDK. We extended that basic interactive functionality with our own scripts for all of the custom circuit-related behaviors (e.g., all components of the circuit knowing and reacting to their currents, buttons triggering specific components of the circuit, the scale of the external resistor changing the resistance of the resistor in the circuit).

2. Educational AR Applications

We view this specific project as a proof-of-concept of many of the advantages interactive AR (and cooperative AR, which the Meta 2 headset is meant to be compatible with but which we were not able to explore in a project with one headset) applications can have for educational and training purposes.

2.1. Intuitive Visualizations

We believe that AR and VR can make educational concepts that are difficult to grasp concretely and view visually in the real world much more intuitive, engaging, and memorable. We reflect that in our project with a few specific aspects:

- Current as the flow of physical electrons, including the Ohm's law relationship between voltage, resistance, and current, and the ability to change an aspect of the circuit and visually see that reflected real-world visual aspects (brightness of the LED) and the invisible-in-the-real-world mathematical relationship between resistance and current.

- Charging and discharging of the battery: how anions and cations within the battery interact with electrons throughout the circuit.

- Emission of the LED: Visualize how the LED works by making it possible to hide the bulb to see details on the inside of the LED such as the cone that directs the emitted light as well as the electric connection between cathode and anode. The inner workings of the LED is shown by a semiconductor chip with a P-N junction, in which it can be seen how free electrons recombine with positive holes in the middle region and emit energy in form of light. The light is visualized by photons emitted from the LED-chip.

2.2. Interactivity and Experimentation

Building an educational application with digital objects in AR or VR also allows the application designers to untether the interaction with components of the application from reality to the extent the designers wish. Designers can maintain the critical realistic parts of interactions and abstract away distracting details. Our project reflects some relatively simple exploration with this concept:

- Users can scale the resistance of one of the resistors in the circuit in a way that reinforces the intuitive understanding of the resistor (by scaling another one larger for more resistance or smaller for less).

- Users can toggle on and off invisibility of outer layers of the LED and battery components to view the inner workings of those components.

- Users primarily use simple button presses to perform actions that would in reality require multiple steps (e.g., disconnect the battery from the circuit, move it, and plug it into a charger).

We believe that an educational application that fully realizes the potential of this aspect of AR and VR could take things much further than we were able to in this project. One could imagine near limitless potential to design intuitive interactions needing no or limited audio or visual cues to prompt the user to know how to use the application, or build arbitrarily complex interactive systems from repeatable building blocks (e.g., extend our defined-circuit project into a fully extensible electrical circuit breadboard), for example.

Another aspect of AR that the Meta 2 headset is designed to support (but that we were not able to explore for this project with one headset) with multiple users interacting with the same digital object while still being able to make eye contact in the real world and collaborate effectively in person. We think the potential for a teacher in an education setting or a more experienced professional in a training setting to supervise and guide a learner's interaction with the digital objects would be a massively important addition to the effectiveness of such an application.

2.3. Safety and Reusability

Working with digital objects rather than physical ones in a way that still teaches learners about the physical world also enables AR applications to be safer for the human trainee and more repeatable than the corresponding training in the physical world might need to be. It also allows for objects that would be rare, expensive, and/or fragile in the real world to be destroyed in simulation and reused by simply resetting the scene or application. This should generally allow training in a wider range of situations than would be prudent using only physical objects.

For example, learning about circuits by interacting with our project's digital versions of normally-potentially-dangerous electrical components should be a safe introduction to these components. Gaining hands on experience with what can happen to electrical components that are exposed to too much current in our project with the simulated LED burnout merely requires a reset of the scene to use that same LED component again rather than destroying a physical electrical component.

3. Considerations for Building AR Applications, and Future Work

Much of the detail of moving from the VR scene and head-mounted display we've been building up in this class to an AR application using the Meta 2 headset (e.g., moving the scene relative to the camera with the headset, tracking hand position and gestures) was abstracted away from us by the functionality provided by the Meta 2 SDK and Unity game development platform. Aside from hardware-related limitations necessary to develop an application for the Meta 2 (system requirements for the PC to run the SDK, propensity of the SDK to crash), we found designing intuitive hand interactions to be among the most challenging and thought-provoking parts of this project that extended our other learnings from this class.

We are not claiming to have achieved the full potential that AR and VR offer on this front in our project, but we were thoughtful about trying to design hand interactions like the one to scale the resistance in the circuit that were simple, intuitive, and took advantage of the advantage of the AR setting. We also tried to explore the amount of flexibility vs. guidance to give the user in terms of how they could interact creatively with the scene, and tried to balance the mix of realism vs. intuitive visualizations of the key concepts we wanted to get across.

We think there is plenty of future work that could be done to further explore these principles and how best to implement them in AR and VR applications for educational and training purposes. We also obviously focused our project on creating a specific proof-of-concept application to simple electrical circuits, but we believe AR and VR, and the advantages we've discussed that those mediums have for education and training over being restricted to the real world, have broadly-ranging potential applications in professional training in many industries and in many academic disciplines.