The Educational Entanglement Device

By

Andrew Situ

Benjamin Kassel

Ian Skirkey

Final Report for ECE 445, Senior Design, Fall 2021

TA: Josephine Melia

Abstract

The Educational Entanglement Device is an intuitive and interactive device which is intended to assist the public in understanding the basic principles of quantum entanglement and their potential for use in real-world applications. The basic functionality of the device is to send pulses of light, representing photons, down a tube which users can interact with through touch. When the user touches a photon, the photon reacts as though the user were making a measurement of either its position or its color and undergoes an animation representing that measurement. Additionally, a binary value is assigned to that measurement and subsequently displayed on a monitor for viewing by the user. The result of this project was a fully functional, small-scale prototype of the Educational Entanglement Device.

.

Contents

1. Introduction

1.1 Problem

Quantum entanglement is a physical phenomenon that occurs when a group of photons or particles interact in a way such that the quantum state of each photon/particle of the group cannot be described independently of the state of the others [1]. For example, say two objects are entangled where both objects can either be a square or a circle and have a color of red or blue. If a person decided to try and measure the shape or color of both the objects, they would find that there is a correlation between these two entangled objects no matter the distance between them. However, if one person decided to measure the shape of an object and another person tries to measure the color of the entangled object there would be no correlation between them. This property of entanglement is difficult to display in a classical fashion and there is currently no commercially available product to illustrate this phenomenon.

1.2 Proposed Solution

We will create an 'entanglement simulator' for public demonstrations and outreach. Since this demonstration is built in the real world everything needs to follow classical physics because there is no real way to visually demonstrate entanglement classically. This demonstration will emulate two entangled photons moving in two different directions through the two different LED strips. Each photon will be simulated using two LED lights on each strip which are separated by a 6-inch difference to represent the superposition of the photon's time state and initially have the same color (purple, a mix between blue and red) to represent the superposition of color as shown in Figure 1. A user can emulate measuring the photon's time state by pressing on the capacitive sensors on the two LED strips which would cause one of the lights to disappear, illustrating that the photon is no longer in a superposition since it has been measured. The user can also choose to measure the color of the photon by touching the area between the two LEDs which would change the lights to either red or blue. The two separate photons would have correlated outputs if both users decide to use the same measurement on the photon otherwise the results would be random.

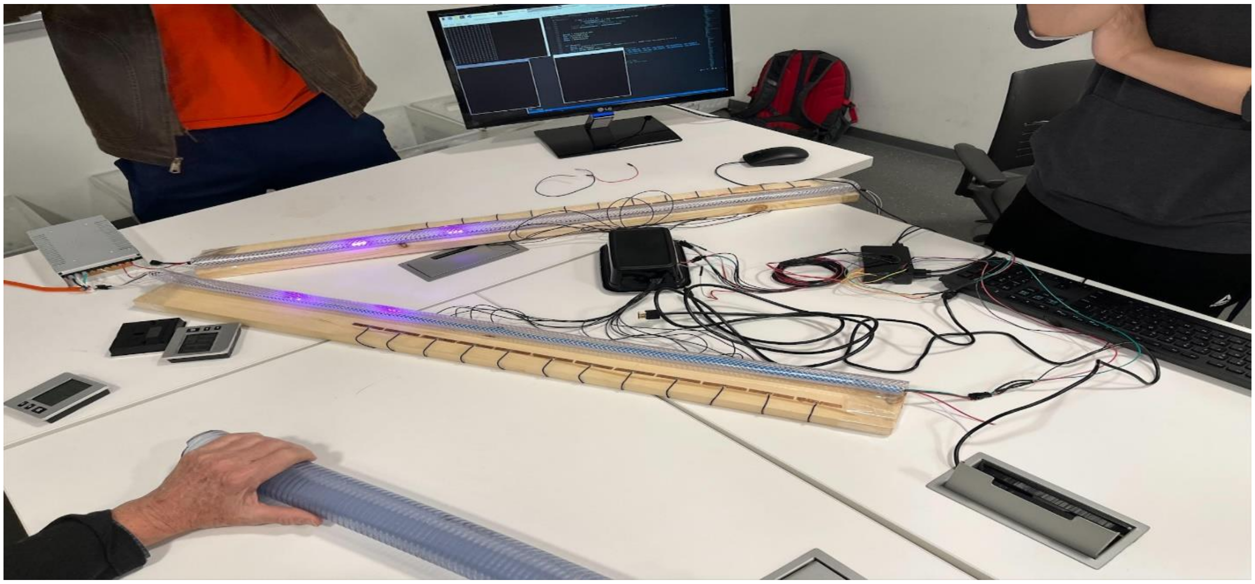

Figure 1: Photograph of Educational Entanglement Device Prototype

2. Design

2.1 Design Overview

The design features a central source, out of which come two LED strings, in opposite directions. Correlated light pulses travel down each string (visible to the observers). The participants can then measure the pulses in one of two ways, either by touching between two LED pulses, or touching the two LED pulses directly, yielding a color measurement or a position measurement, respectively.

2.2 Block Diagram

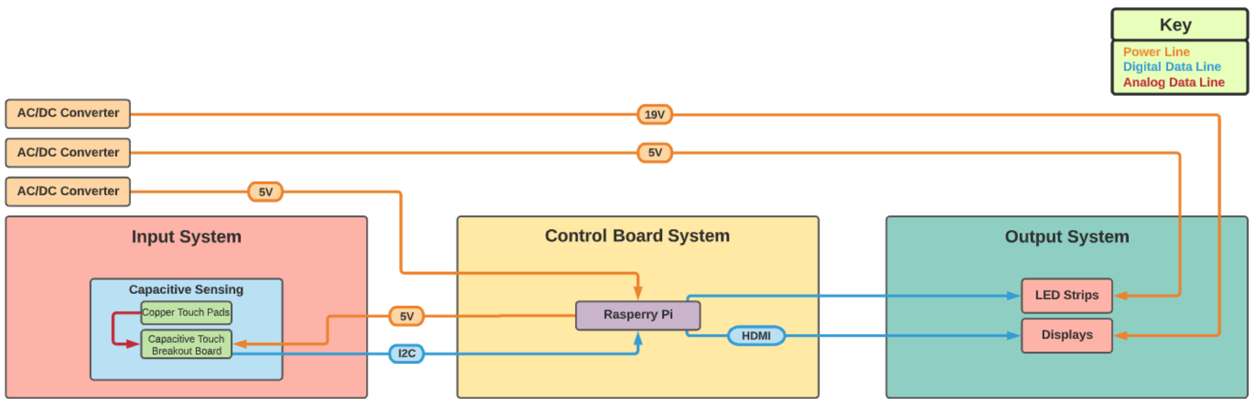

Figure 2: Block Layout of Final Project Implementation

2.3 Subsystem Overviews

2.3.1 Power System

The power system for this device is primarily comprised of three AC to DC rectifier units, all of which are off-the-shelf components. One of the units powers the Raspberry Pi at 5V, which then relays that power to two capacitive touch breakout boards, each also at 5V. Another unit supplies power to two LED light strips at 5V, and the final unit powers a monitor at 19V.

The power supply that we chose for the LED strips is capable of supplying 300 Watts at 5V. We chose to use this power supply because the sponsor of this project planned to use 6 meters of high-density LED strips that run on 5V. The strips had a density of 144 pixels per meter which means the entire system would have 864 pixels. Each pixel consumes roughly 0.3 Watts, so theoretically if all the LEDs were turned on at maximum power draw, the total system would consume 259.2 Watts by way of the LEDs alone.

2.3.2 Input System

The input system is comprised of two capacitive touch breakout boards, each of which is equipped with twelve touch sensing input lines, wired directly to individual 2" strips of bare copper film which act as "buttons" that users may press. These boards each receive power at 5V from the Raspberry Pi and send touch data to the Raspberry Pi through a shared I2C bus, made possible by the breakout boards each having their own unique I2C identifier addresses.

2.3.3 Control Board System

The control board system is solely comprised of a Raspberry Pi, where the totality of the project software is contained, all the input signals are processed, and from which all the output signals are sent. Further details of these signals are outlined in sections 2.3.2 and 2.3.4.

2.3.4 Output System

The output system is comprised of two LED strips in addition to a monitor which is connected to the Raspberry Pi through HDMI. The LED strips each receive power at 5V from a shared AC to DC rectifier. Furthermore, the strips both receive digital data signals from the Raspberry Pi which address each LED in the two strips individually, controlling their hues and luminance independently at any given point in time. The HDMI display is simply used to interface with the Raspberry Pi operating system, from which, two output windows are subsequently launched through the project software, each displaying a single large digit at a time, representing the binary results of measurements made on their respective LED strips, by way of the capacitive touch sensors.

2.4 Design Alternatives

Since this was a sponsored project, we simply wanted to make sure that we could get a rudimentary design implemented for testing and demonstration purposes. The final physical design that we chose for our prototype was mainly limited by a lack of parts. Our sponsor had bought 2” diameter tubing for the final product as well as longer lights and a container to house all cables/parts. We did not have this luxury for our prototype, so we just used some wood, tape, and tubing we were able to get at our local hardware store. As for the physical design, we would redo it with all the final parts to make it look a bit more polished. As for the technical aspect of this project. The only thing that we would change is to use a Raspberry Pi from the beginning for all functions. This will make everything a lot easier to debug and run, as we had many issues with the Raspberry Pi communicating with the microcontroller consistently.

3. Design Verification

3.1 Original Block Diagram

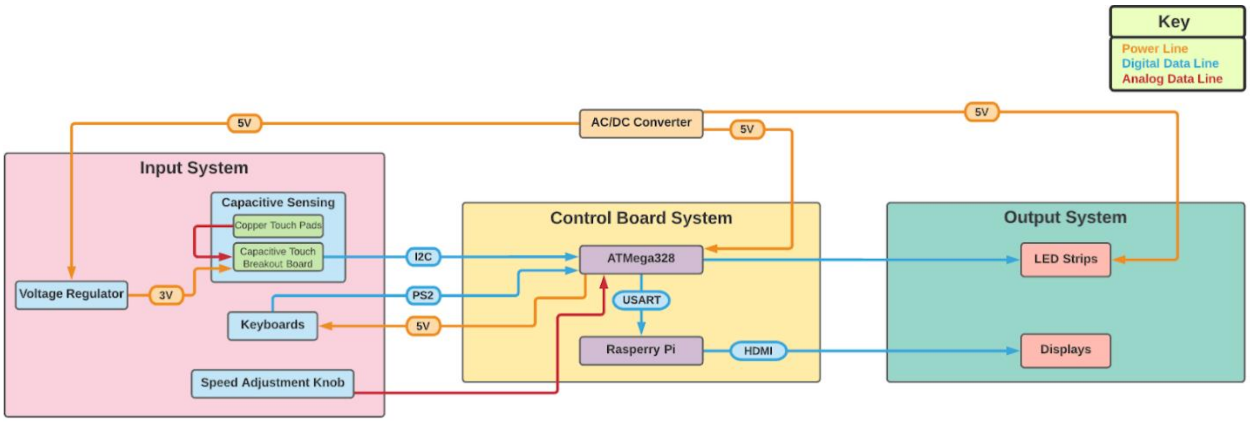

Figure 3: Block Layout of Original Design Plan

3.1.1 Explanation of Original Block Diagram

The design [3] presented in the block diagram contains a power system, control board system, input system and output system. The power system will convert AC power from the wall to DC power for the various modules after regulating the voltage. The control board system takes input from the input systems which allows users to interact with the entanglement device and cryptography demo. Once measurements have been made the control board system then outputs the data to the output system to display the resulting measurement and encrypted message.

3.1.2 Original Design PCB Schematic

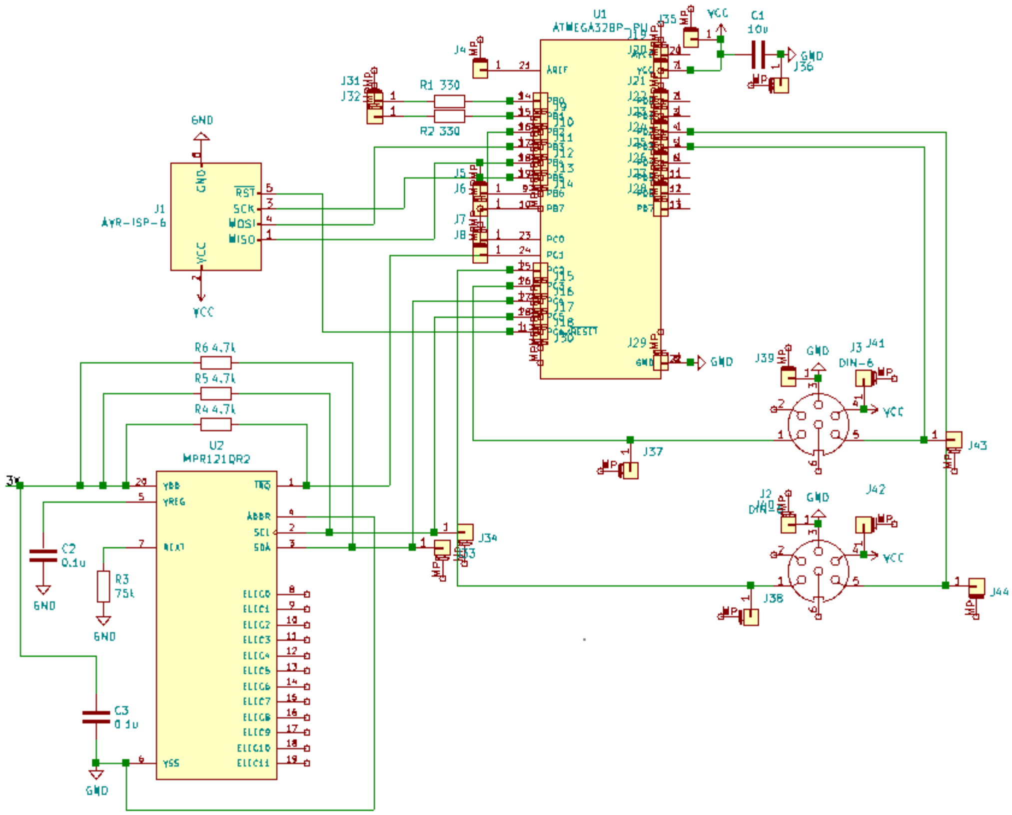

Figure 4: PCB Schematic

Figure 4 shows our original plans for using the microcontroller to connect to two PS/2 keyboard interfaces and using an I2C bus for the capacitive touch breakout board. Then we would use the UART transmit and receive pins on the microcontroller to communicate with the Raspberry Pi so that it could signal a change in the display.

3.2 Requirements & Verifications

Table 1: System Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
The copper touch pads, along with the capacitive sense breakout boards should be able to deliver touch flag data to the microcontroller with at least 97.5% accuracy.	Touch all the pads 100 times and check the number of state changes within the software comparing them with the number of times we touch all the pads	Y
The microcontroller must be able to output two UART signals to the LEDs	Plug in the two different addressable LEDs and send signals from the microcontroller to the LEDs to see if they change states.	Y
The resolution of the LED display must be able to display a letter with such clarity that each letter and number can be easily distinguished from one another from 10 feet away	We will display an image of a letter onto the screen and walk 10 meters away and see if the image is still recognizable	Y
The keyboard should have a latency of < 200ms between the keyboard stroke and the microcontroller. It should be able to send a signal 99% of the time when a key is pressed.	We will be estimating the scan rate of the keyboard using an online website [4] and determine the pull rate from the keyboard protocol to estimate the latency of the keyboard	N
• With the knob turned to 100%, the velocity of the lights should move at the full speed of 5 m/s ± 0.1. • When the knob is turned to 0%, the velocity of the lights should move at the minimum speed of 0.1 m/s ± 0.1. • With any other setting between 0 and 100% be within 0.1 and 5 /s.	We will time how long it takes for one LED light to move from one end to the other in software. Using that time measurement and the length of the LED strip, we can convert that measurement into m/s.	N

3.2.1 Quantitative Results

Obtaining quantitative results which verify the functionality of this project is an intrinsic difficulty given the hands-on, visual nature of this project. The functionality of the project can be completely verified based on the visual tactile perception of a user alone. Nevertheless, we may begin with the results obtained when testing the capacitive touch sensors. In this test, we cycled through twelve capacitive touch pads a total of nine times and monitored a console output window on the Raspberry Pi which indicated the index of the touch sensor triggered. If the index given in the console matched the index of the pad touched, then the test was successful. This amounted to a total of 108 total probes, all of which passed the test, yielding better than our minimum requirement of 97.5% accuracy.

In order to verify the functionality and readability of the display unit, we stood at a distance of ten feet from the unit and displayed a single character on the screen, in the same dimensions to be used in the final project implementation. Each member of the team was able to discern the characters displayed with ease from a distance of ten feet, indicating the effectiveness of our display method. The results of our testing of the communication between the Raspberry Pi and the LED strips are evidenced by our ability to animate the LEDs in accordance with our project vision. There were no results obtained from the testing of the keyboard input, as well as the speed adjustment knob due to the fact that there was not enough time to include either one of them in the final project implementation.

4. Costs and Labor

4.1 Cost

We have estimated that an engineer would be making around $50/hr, and with there being 3 people working on this project at an average of 20 hours/week for 15 weeks with 2.5 times overhead, our project has an estimated building cost of $112,500.

Table 2: Parts Costs

Part	Retail Cost	Quantity	Final Cost
Raspberry Pi 4 Starter Kit	$109.99	1	$109.99
Microcontroller ATMEGA328-PU	$2.58	1	$2.58
Capacitive Touch Sensor Breakout	$7.95	4	$31.80
5m Copper Tape	$4.95	3	$14.85
3’ LED Strips	$17.99	2	$35.98
PS2 connectors	7.95	2	$15.9
Knob	$5.18	1	$5.18
AC/DC Converter	$29.99	1	$29.99
DC/DC Regulator	$0.70	1	$0.70
36” Frosted Acrylic Round Tubes	$9.00	2	$18.00
Resistors and Other PCB parts	$1.00	10	$10.00
Heavy Duty Clear Tape	$8.47	1	$8.47
Clock oscillator	$1.24	1	$1.24
Total			$270.26

4.2 Scheduling

Table 3: Schedule of tasks

Week	Benjamin	Andrew	Ian
Week of 9/27	Find parts and finish up Design Document	Find parts and finish up Design Document	Start work on PCB schematic
Week of 10/4	Help Ian with PCB Schematic and order parts	Help Ian with PCB Schematic and order parts	Finish working on PCB Schematic
Week of 10/11	Start compiling a list of online references for LED interfacing	Start compiling a list of online references and libraries that we plan on using	Start compiling a list of online references for RPI interfacing
Week of 10/18	Begin software implementation of LED lights	Begin software implementation of LED lights	Begin soldering parts to PCB board
Week of 10/25	Finish LED light implementation and help with RPI implementation	Received most of our parts and began testing the RPI	Begin software implementation of RPI
Week of 11/1	Finish software implementation of RPI	Finish software implementation of RPI	Finish software implementation of RPI
Week of 11/8	Testing for mock demo with prototype	Testing for mock demo with prototype	Testing for mock demo with prototype
Week of 11/15	Mock Demo	Mock Demo	Mock Demo
Week of 11/22	Fall Break	Fall Break	Fall Break
Week of 11/29	Demo and begin work on Final Paper	Demo and begin work on Presentation	Demo and begin work on Presentation
Week of 12/6	Presentation and final paper	Presentation and final paper	Presentation and final paper

5. Conclusion

5.1 Accomplishments

Overall, we are satisfied with the final result of this project. We were able to complete the most important parts that were tasked to us by our sponsor. These include getting the touch capacitive sensors to interact with the lights, having two displays that could run two different programs, and having full customizability when it came to the speed, color, separation, and hold time in the software. We were able to meet all three of the high-level requirements set by our sponsor, and during our closing meeting with him, he expressed satisfaction with the outcome of the project.

5.2 Uncertainties

There are very few uncertainties, as we have been in close contact with our sponsor every week consistently sending videos of updates and changes as he has requested. The only uncertainties currently are the exact configuration of the wires and capacitive touch board on the final product. We have had a meeting already discussing and brainstorming, and we will be a part of the team that makes these decisions in the future.

5.3 Ethical considerations

Since we are creating an educational device to be used in a public building for anyone to use, we wanted to make sure that our device can be operated correctly so that everyone who uses our device will learn about Quantum Entanglement in a fun, safe way. It is important that we follow the 7.8 IEEE Code of Ethics [4], specifically in code I.1 which states that our project must "hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment", and I.2 which states that our project must "improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies". We will be inspecting our device frequently, mainly the keyboard and monitor, to make sure they are well maintained. This project will be open to all individuals who have a curious mind and wish to see a simple display which shows a much more complex element. We will make sure that these ethics are upheld before, during, and after the construction of this device so that there is no one that will feel unsafe or uncomfortable using it.

We also need to make sure that we have the proper safety warnings so that there are no instances of public endangerment. We will be using proper insulation and grounding everything using electricity so that there is no danger of anyone being on the end of any electric shocks. In addition, there can be some sharp edges on the copper tape used, so we will be covering any sharp edges with clear tape so that they cannot harm anyone. Due to the ongoing pandemic, we also plan on having a cleaning station available to all those who wish to disinfect the display after each use to stop the spread of germs.

5.4 Future work

As previously mentioned, we will be handing this project off to Professor Kwiat and a couple of students he will be working with next semester. He had given us a brief rundown of new modules he wanted to add to our already working design. First, he wanted to implement a module that related to Quantum Memory. While he did not give us too much information, he showed us a 16x16 grid of LEDs that would be slowly light up as photons reached the end of the device arms. He also wanted to add a quantum cryptography demonstration to the project, something we had planned on doing, but failed to finish in time. He also wanted to add a physical switch that could send more pulses down the strand of lights. Additionally, he wanted to clean up the physical design so it would look polished. This finished demo would then be used in Lab Escape, a physics-based escape room which Professor Kwiat is a part of, as well as being used for display in Loomis Laboratory, where students may learn about quantum entanglement in an interactive way.

References

[1] F. Wilczek and substantive Quanta Magazine moderates comments to facilitate an informed, “Entanglement made simple,” *Quanta Magazine*, 23-May-2019. [Online]. Available: https://www.quantamagazine.org/entanglement-made-simple-20160428/. [Accessed: 19-Oct-2021].

[2] “1.3 introduction to Capacitive Touch Sensors,” *Fieldscale*. [Online]. Available: https://fieldscale.com/learn-capacitive-sensing/intro-to-capacitive-touch-sensors/. [Accessed: 11-Sep-2021].

[3] *Drafting for electronics--block diagrams*. [Online]. Available: http://www.industrial-electronics.com/drafting-for-electronics-12.html. [Accessed: 11-Sep-2021].

[4] *Keyboard Scan Rate Tool*. [Online]. Available: https://blog.seethis.link/scan-rate-estimator/. [Accessed: 30-Sep-2021].

[5] “IEEE code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: 13-Sep-2021].