E-Remote: Inclusive Video Game Controller

Team 24: Seok Young Choi, Nicholas Gutierrez, Eunhye Kwon, and Yumin L. Wei

Executive Summary (Lisa and Eunhye)— With the growth of the internet, human connection is not only limited to those physically present. Online communities are growing and the gaming community is an example of an upcoming space for people from all over the world to meet. But joining a gaming community is not as easy as switching the on button. The barriers of entry still exist in this new social platform, especially for those with disabilities. Other companies have tried to create inclusive video game controllers to lower these barriers, but those controllers come with their own problems as well. The final deliverable of our project is to have a working video game controller compatible with PC through Bluetooth connectivity. The controller should have full functionality with at least four different genres of video games: arcade, puzzle, racing, and shooting. The user should play with minimal to no pain reported after 30 minutes. We will also provide a programmed Arduino Micro that handles inputs from the controller buttons and sends the proper signal over Bluetooth to the PC and a user manual that details the operation of the controller and how to easily connect it to a PC. Our product, E-Remote, will have innovative features such as palm-controllable joysticks, touch sensor buttons, and Bluetooth connectivity. These features will eliminate problems of conventional video game controllers and provide a fun and comfortable gaming experience for individuals with rheumatoid arthritis.

Index Terms—Channels and controllers, Combinational logic, Data communication devices, Portable devices, Real-time and embedded systems, Wireless systems

1 Introduction (Lisa)

In the last few years, it seems like more people than ever have realized the importance of being able to share experiences online. One of the most popular ways to connect with others online is video games. Unfortunately, the handheld controllers required for most games can act as a barrier to entry for those with physical disabilities. Individuals with rheumatoid arthritis form 14% of the disabled gaming community and have reported to face problems using modern controllers for PlayStation, Xbox, etc. that require the player to have a high level of dexterity [1]. To increase accessibility of playing video games, we propose an inclusive video game controller designed to fit the needs of individuals with rheumatoid arthritis. Our product, the E-Remote will be able to provide a fun and intuitive gaming experience for individuals with rheumatoid arthritis. The E-Remote is an inclusive video game controller, rated E for everyone!

Within the ever-growing gaming community, 20.5% of that population are individuals with disabilities [1]. In Fig. 1, researchers ask disabled and non-disabled gamers, "In the last 12 months have you purchased any in-game add-ons or subscriptions?" It was found that those with disabilities are reported to be more engaged with purchasing adjacent gaming content, such as add-ons, Twitch streams, Reddit posts, etc. [2]. With such a large community of actively engaging consumers, it is a disservice when companies are slow to create inclusive video games, and even slower to create specialized controllers.

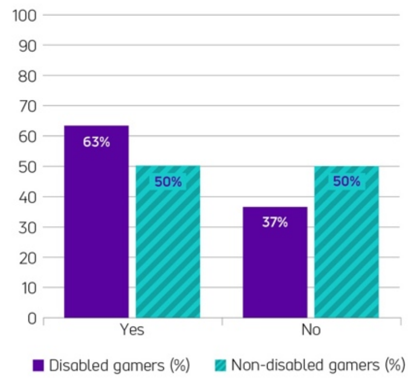

Fig. 1. Bar graph showing the survey results of "In the last 12 months have you purchased any in-game add-ons or subscriptions?" [2]

The most common physical disability that gamers face is rheumatoid arthritis, standing at 14% of the disabled gaming community. Rheumatoid arthritis (RA) is "a chronic inflammatory disorder affecting many joints, including those in the hands and feet" [3]. Studies have shown that for people with RA, gaming allows the player to take their mind off of their chronic pain, but extended use is painful [4]. In an interview with a RA patient, they criticized many problems with the standard controllers and even some inclusive controllers that already exist. The main problem is that people with RA cannot hold a flexed hand position for a long time, especially when holding something too heavy and rigid.

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Small and intricate movements, such as pushing buttons that are close together, cause unnecessary pain.

E-Remote will address these issues with current controllers by creating a prototype of a portable inclusive video game controller, along with all the embedded hardware, specialized for customers with rheumatoid arthritis. It should be compatible with at least a PC and four popular video games in the market. Lastly, it should create a unique and fun gaming experience for each gamer.

The main problems that they face at the moment include heavy weight, uncomfortable buttons, painful repetitive motions, a steep learning curve, and a high price point. All of these problems can be seen in Fig. 2, where the largest barriers faced were affordability, knowledge or time to set up and technology. In contrast, our design will be an inclusive video game controller that will allow users to forgo these problems and play games effortlessly. To eliminate the weight problem, the product will rest on a flat surface, therefore, allowing a longer playtime. Significant features of our product are the palm-controllable joysticks and touch sensor buttons. We would replace the standard buttons with light-up, touch-sensor buttons. The joystick will also be replaced with a ball-in-socket component allowing a relaxed hand position. The design should also be intuitive, allowing the player to fully understand the controller after five minutes of use. The price point we are aiming for is less than $99.99 which is the cheapest price on the market right now [5]. These are all the features that we hope to include in our final project in order to make the gaming community a little more accessible.

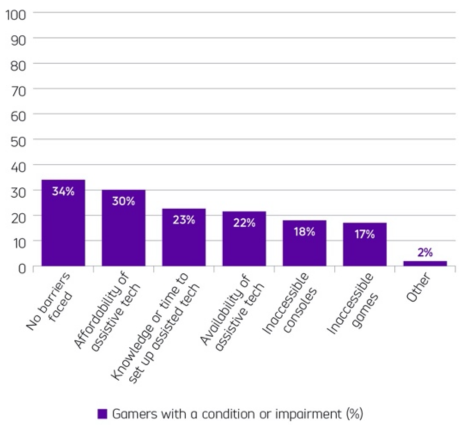


Fig. 2. Bar graph showing the survey results of "What poses a barrier or issue to gaming for you?" [2]

2 Concept Development (Seok Young)

The overall goal of the design process is to minimize the movement of hands and fingers while using the controller and allow users to be able to control the device effortlessly because people with RA are having pain coming from making elaborated motions. In addition to avoiding the shape that should be held with both hands, an interviewer mentioned that they most feel comfortable and have less pain when they are resting their hand and arm, just like naturally putting them on a table. Hence the controller is designed to be used while placed on a horizontal platform, having buttons and joysticks on the same plane of the controller so that the user is not necessarily moving or reaching their hand far away but a simple movement during the game.

2.1 Joysticks

The controller is mainly constructed with two palm-controllable joysticks, and they are linked to the rectangular casing where both hands can be placed on the top. Basic mechanism of the palm joystick is identical to the conventional joystick using the ball-and-socket joints which enable movement and rotation to all directions. Our joystick design has a wider and bigger surface area that can be controlled easily without applying forces or moving a certain part of the arm frequently. Final shape of the controller resembles the pancake, which has a low profile and smooth slope angle so that it could fit a wide range of shape and size of hands. As shown in the Fig. 3, each joystick has a diameter of 3.36 inch and height of 0.88 inch including 0.30 inch of a vertical bottom edge to provide a grip for users if needed.

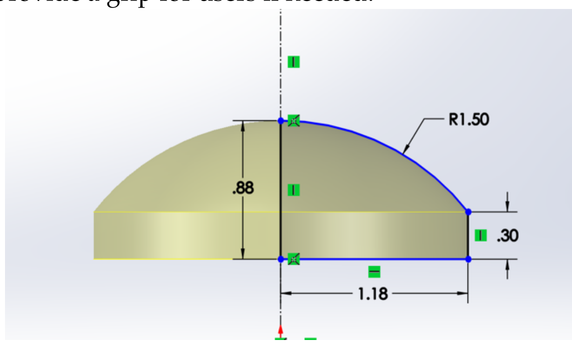


Fig. 3. Sketch of the joystick with dimensions

One of the initial ideas was the roller ball joysticks that are implemented inside of the casing, and detecting the movement of the joystick by gyroscope sensors which are placed inside of the spheres. This method might aesthetically be a better option; however, it has limitations that will exceed the price because of its complex mechanism, compatibility with the microcontroller, and most importantly, this design requires players to use their wrist to control the joystick, which is not ideal for people with RA.

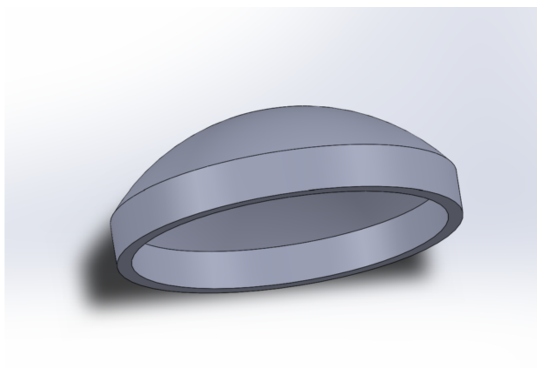


Fig. 4. 3D modeling of the joystick

2.2 Buttons

Total of eight buttons are located on the upper side of the joystick, which can be easily reachable with four fingers - index, middle, ring, and little fingers - when controlling joysticks with palms. The most important specification for the buttons is that it has to be pressed easily and effortlessly to avoid applying significant force. Rather than implementing physical, push down buttons, capacitive touch sensors were used which detects a change in capacitance on an area so that even a small amount of touch or contact will make an input [6].

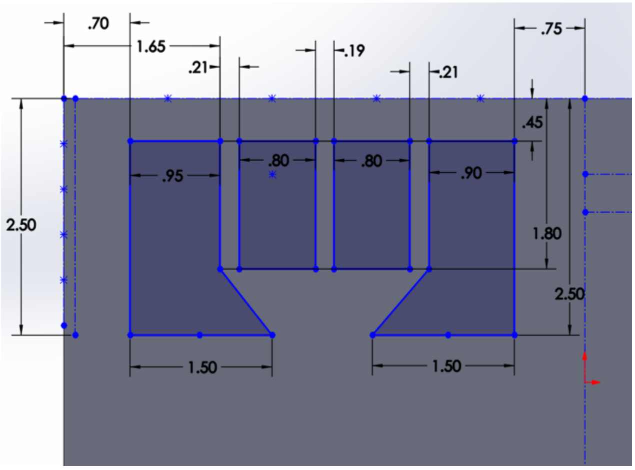


Fig. 5. Shape and dimensions of the buttons

2.3 Convenience Features

The controller has convenience features that will allow users to have a better experience while using the product. To enhance visibility while playing games, LED lights are mounted around the buttons. LEDs are initiated as user inputs and gradually diminished in a second. Brightness can be adjusted using one of the slider knobs on the side of the controller, and the other slider is for changing the sensitivity of the capacitive touch sensors.

As the controller is designed to be placed and used on a surface, detachable base filters are included, and possible material options are memory foam, suction cups, rubber, and velcro.

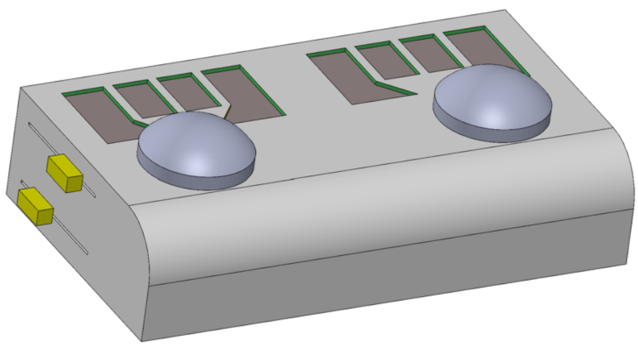


Fig. 6. Visualization of E-Remote Casing

The edge of the casing that faces the users is smoothed for wrist support; soft padding is provided for users who play games for a long time. On top of the wireless Bluetooth connectivity, a case that covers the upper part of the controller will also be provided for increased durability and protection of the device. Fig. 6 shows a visualization of final packaging of E-Remote and the current prototype we have is in Appendix 4.

3 System Description (Nick)

3.1 Hardware

The hardware for the system is powered by four 1.5V Rechargeable Batteries which are connected to a TP4056 Lithium battery charging board. The charging board is wired to an on/off switch which can be used by the customer to power the controller. The controller itself is driven by several inputs and outputs taken from the user and the PC. The first set of inputs is two joysticks, each with a 5V input pin, a ground input pin, an X-axis analog output, a Y-axis analog output, and an SW push button digital output that allows the user to press down on the joystick and send a button input.

Next, the controller uses the Adafruit 12-Key Capacitive Touch Sensor Breakout MPR121 chip to read inputs from eight capacitive touch buttons made from copper sheets. These touch sensors remove the need to press a button, as they send a high signal when tapped. The final inputs are two 10K logarithmic potentiometer sliders used to adjust the sensitivity of the capacitive touch buttons and LED brightness.

Outputs from the controller consist of eight LEDs, each one controlled by a corresponding capacitive touch button, and the game action signals are mapped from the user inputs. The system is controlled by an ESP32-DevKitC-32E microcontroller which takes in all user inputs and translates them into the correct signals needed by the PC to register a game action. The ESP32-DevKitC-32E was chosen for its embedded ESP32-WROOM-32E chip which allows for Bluetooth capabilities and allows our controller to wirelessly connect to any PC with Bluetooth support.

3.2 Software

The Arduino IDE is used to write the software for the controller and uses the standard Arduino setup and loop structures as the foundation for the program (Note that ESP32 is compatible with the Arduino program structure). Upon startup, the program will declare and initialize all I/O pins required by the LEDs, sliders, and joysticks. Next, it will verify that the Capacitive Touch Sensor Breakout has been connected. If the chip is not connected, then the program will turn on the Onboard LED and loop until the chip is connected.

After the setup section is completed, the program enters the loop section which will continue until the device is powered off. In the loop, the microcontroller will read the current state of every input device and determine if the state has changed since the last poll. If there is a change in state, the program will send a new signal to the PC indicating the change in in-game action and change the state of the corresponding LED. The program will also detect any changes in the slider values and adjust the sensitivity of the LEDs/touch buttons which should take effect in the next loop. The average input lag from user input to an in-game action being performed should be less than 15 ms. The following is high-level pseudocode of how the controller will operate.

```
Setup {
        Assign I/O
        Initialize I/O
        while (CapacitiveButtonChip Not Connected) {
                Start Onboard LED
        }
        Stop Onboard LED
}

Loop {
        For (Input in Inputs) {
                If (Input Has Changed) {
                        Send new game action signal to PC
                        Set Outputs (Input)
                }
        }
```

3.3 System Diagram

The system diagram (Fig. 7) illustrates the flow of the system once powered on. The ESP reads slider values, polls the user inputs, and then determines if there is a change in state for any input. It then changes any LED states that had their corresponding input state changed and prepares to send the game action signal. Before sending the new signals, the ESP needs to translate the input states to the correct Bluetooth signals that can be properly identified by the PC. Finally, the PC receives the new set of signals and completes game actions accordingly.

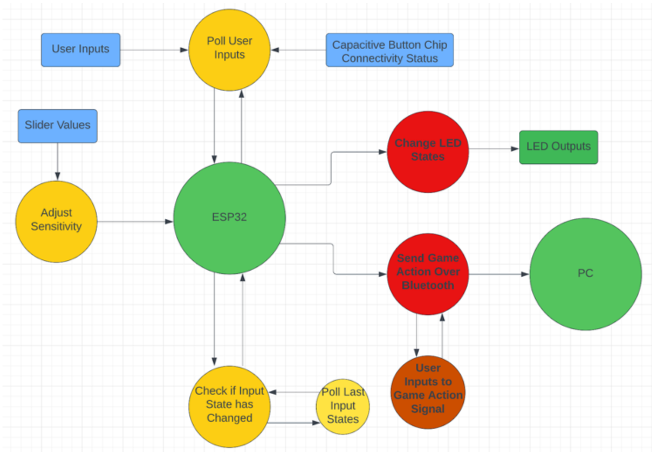


Fig. 7. Level 2 System Diagram of E-Remote after being powered on

4 First Semester Progress (Lisa)

The first action we took was researching the inclusive video game market and audience to brainstorm designs that solved the specific problems we found. To investigate these problems, we researched a casual gamer with RA. After the interview, we created an ergonomic design that solved the physical problems mentioned before. We took that drawing and turned it into a 3D model on solid works and printed the first iteration. Since it was the first print, we revised the sizes and distances of the buttons. The specific adjustments can be seen in Appendix 5.

Since that first print, we have printed two more revisions, changing the buttons and adding sections for specific electronic parts.

In parallel, we also focused on the hardware portion of this project. Starting by making a hardware block diagram (seen in Fig. 8), we mapped out all the electronic components necessary for each section of the block diagram. From there, we order some of the electronic components to start testing: Arduino Micro, tactile buttons, joysticks, potentiometer sliders, and LEDs.

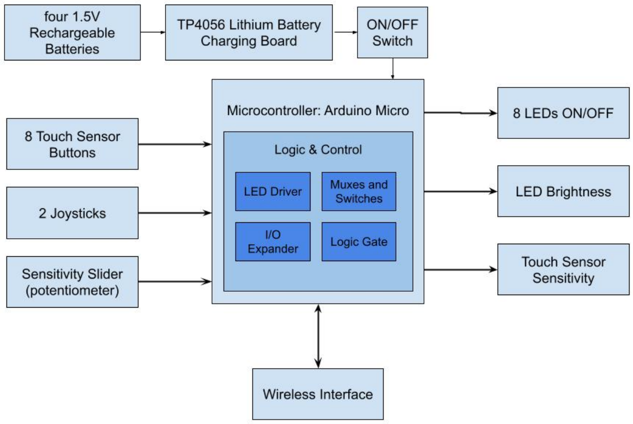


Fig. 8. Hardware Block Diagram of Controller

Using these parts, we started to build the circuit in sections. First were eight tactile buttons, eight LEDs, and an Arduino. We wrote a simple code that turned on the LED once the corresponding button was pressed. They replaced the eight tactile buttons with a touch capacitive board with eight touch buttons. In order to understand the touch capacitive board, we tested different materials and their compatibility with the board. These tests can be seen in Appendix 6. The purpose of this test was to determine the material(s) that could be used as touch sensor pads for E-Remote.

At the moment, we have a working breadboard controller with eight touch buttons, eight LEDs, two joysticks, and an Arduino Micro. The schematic of these components can be seen in Appendix 7.

We also worked extensively with the software necessary for this project. We started by creating a software flow diagram in order to map out the logic of the code. As you can see in Appendix 8, the block diagram loops through each input to make sure there is not a state change; if there is a change in state, the output will then be activated.

Next, we used the Arduino library to write a code that reads inputs from push buttons and maps them to controller inputs which are then sent over USB to the computer. The code can also read push button inputs and turns on/off the corresponding LED. In order to test the system, we wrote a testing procedure to confirm the functionality of these inputs and outputs. Appendix 9 shows the functionality of buttons and joysticks will be tested through LED outputs, gaming controller outputs, and game action performances. From our tests, the system was working well.

5 Technical Plan (Eunhye)

We have made substantial progress in our current prototype but there are still more tasks to be done to complete our proposed solution of an inclusive video game controller. To complete this project, the next steps will be divided into three phases: hardware requirements, integration and test, and finalization. A Gantt chart summarizing the project schedule from December 11, 2022, to May 1, 2023, is in Appendix 2. The following sections will discuss specific tasks to be completed in each phase.

5.1 Phase I: Hardware Requirements

Task 1: Potentiometer

Two 10K logarithmic potentiometer sliders shall be implemented within the circuit architecture and tested. They shall have an operating region of 3.3 - 5V and output a range of 0 - 5V. The resulting output depends on the slider's location. Each potentiometer slider shall utilize one analog pin on the Arduino Micro and control LED brightness or touch sensor sensitivity. The circuit should be tested with a dummy voltage of 4V. Lead: Eunhye, Assisting: Lisa.

Task 2: Touch Sensor Design

Eight touch sensor pads shall be designed, fabricated, and tested. It shall be made with conductive material, such as aluminum, have laser-cut holes for LED light to shine through, and be covered by clear conductive material. The touch sensor pads shall be connected to the MPR121 capacitive touch sensor breakout board by soldered wires. The design should be tested by MPR121 touch sensor input signals and LED light visibility. Lead: Seok Young; Assisting: Lisa.

Task 3: LED Lighting Design

Eight LED lights of different colors shall be designed and implemented in touch sensor architecture. They shall be compact and placed under the touch sensor pads and implemented in the circuit to turn on/off based on touch sensor input. Lead: Seok Young; Assisting: Eunhye, Lisa.

Task 4: Rechargeable Battery Supply

Four 1.5V rechargeable batteries connected to a 5V, 1A MakerFocus TP4056 Lithium Battery Charging Board shall be implemented within the circuit architecture and tested. It shall be rechargeable and meet specifications for weight, battery life, and heat dissipation. The rechargeable battery should be tested with a dummy load of 500 ohms. Lead: Lisa; Assisting: Eunhye.

Task 5: Bluetooth Connectivity

A microcontroller with Bluetooth capabilities shall replace the Arduino Micro in the current circuit architecture. The ESP31-DevKitC-32E microcontroller with embedded ESP32-WROOM-32E chip which allows Bluetooth capabilities shall provide wireless connectivity to any PC and control the video game controller system. All electronic components such as joystick modules, a capacitive touch sensor breakout module, LED lights, and rechargeable batteries shall be transferred onto the ESP31-DevKitC-32E microcontroller. The design shall be tested by 30 minutes of gameplay via Bluetooth connection to a PC and input lag calculations. Lead: Nick.

5.2 Phase II: Integration and Test

Task 6: Solder Breadboard Design

A solder breadboard shall be designed, fabricated, and tested. It shall have all electronic components and wires soldered onto the breadboard for proper circuit connections and meet specifications for weight and durability. It shall be tested for all electronic components, connections, and I/O ports. Lead: Lisa; Assisting: Eunhye.

Task 7: Final Software Design

The final software of the controller system shall be developed and tested. It shall connect all electronic components of the controller and send information to the PC. It should be tested that the average input lag from user input to an in-game action being performed is less than 15 ms. Lead: Nick.

Task 8: Packaging Design I

An initial controller packaging shall be designed, fabricated, and tested. The 3D printed controller packaging shall hold all electronic components such as breadboard, joystick, buttons, LEDs, and batteries, and meet all specifications for dimensions, weight, and cost. The controller packaging should be tested for comfort and durability by clients with rheumatoid arthritis. Lead: Seok Young.

Task 9: Client Testing and Feedback

A group of clients with rheumatoid arthritis shall test and provide feedback on the first packaging design. The group size shall be 10 - 20 individuals with rheumatoid arthritis and they shall complete a survey and provide feedback on the user interface and overall usability of the product. The feedback from clients should be used to revise the packaging design. Lead: Eunhye; Assisting: Lisa.

5.3 Finalization

Task 10: Final Prototype Test

All electronic components and software shall be implemented in controller packaging and tested. They should be tested for input lag and 30 minutes of gameplay of four different game genres. The prototype shall meet all specifications for requirements and functions. Lead: Lisa, Nick; Assisting: Eunhye.

Task 11: Final Packaging Design

Final packaging of the controller shall be designed, fabricated, and tested. The packaging shall be revised from the first design following feedback from clients. The 3D-printed packaging shall hold all electronic components, eight touch sensor buttons and lighting, two palm joysticks, and detachable bases. The packaging shall be tested for functionality and durability by carrying it around in a backpack for a day. Lead: Seok Young.

All of these tasks will help complete our proposed solution by the week of April 1, 2023, for the functional testing of the product. The month of April 2023 will be dedicated to product revision (if needed), customer installation, and preparation of the final report due by the end of April 2023 and ECE Day on May 5, 2023.

6 Budget Estimate (Lisa)

The most expensive component so far is the Arduino Micro which was $55.24 for two. In addition, we bought four Touch Capacitive Boards for $60.65 because we accidentally made soldering errors with the first batch we bought. Besides those big purchases, the majority of our materials have been donated by members through past projects or from the Boston University ECE department. Table 1 includes the list of items used so far.

Table 1. Total Budget Estimated (Last Updated: 12/9/22)

Item	Cost	Origin
3 Potentiometer Sliders	$14.41	Online
2 Arduino Micro	$55.24	Online
1 ESP-32	$16.99	Online
4 12-key Capacitive Touch Sensor	$60.65	Online
2 Electrical Tape, 1 Aluminum Tape, 1 Superglue	$15.90	In-Store
2 Threaded rod (12X8-32, 24X10/24), 1 Pack of LOCK NUT #8-32, 1 Pack of ROD COUPLING NUT #10-24	$6.73	In-Store
3D Printer PLA Filament	$19.99	Donated
2 Joysticks	$9.00	Donated
8 LEDs	$0.61	Donated
8 Tactile Buttons	$6.99	Donated
Breadboards	$12.99	Donated
Solder Breadboards	$11.98	Donated
Copper Sheets	$4.21	Donated
Wires	$15.00	Donated
Total Cost	$250.69	
Total Spent (excluding donated items)	$169.92	

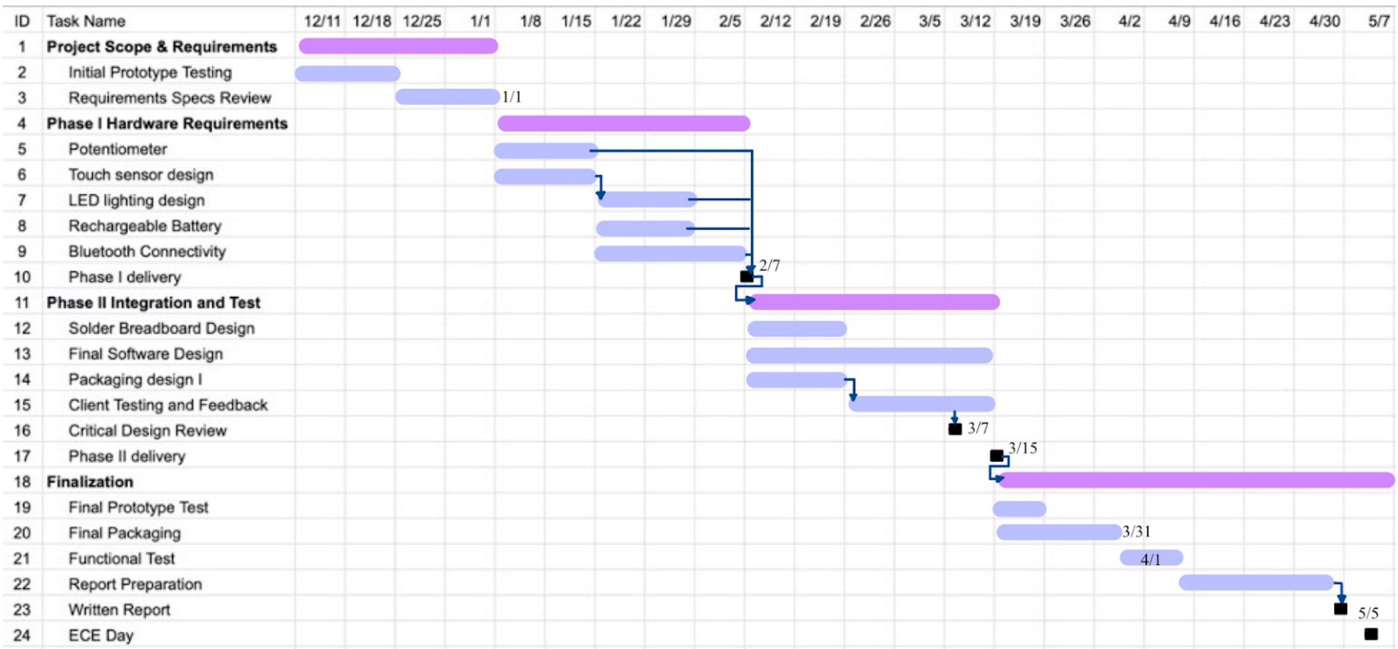
7 Attachments

7.1 Appendix 1 – Engineering Requirements (Seok Young)

Team # 24 Team Name: E-Remote: Inclusive Video Game Controller
Project Name: Inclusive video game controller

Requirement	**Value, range, tolerance, units**
Case dimensions	11 inch × 6 inch × 2.5 inch
Joystick dimensions	⌀ 3.36 inch (diameter) × 0.88 inch (height)
Buttons	User programmable capacitive touch sensors
Input lag	< 15 ms
Power	Rechargeable 3.3V lithium-ion batteries 24-hour runtime / charge
Bluetooth sync time	< 30 secs
Connection range	< 10 m (33 ft)
Weight	< 1.33 lbs
Constraints	Able to carry, fit in a 22 inch × 14 inch × 9 inch size backpack
Cost	< $99.99

7.2 Appendix 2 – Gantt Chart (Eunhye)



7.3 Appendix 3 – Team Information (All)

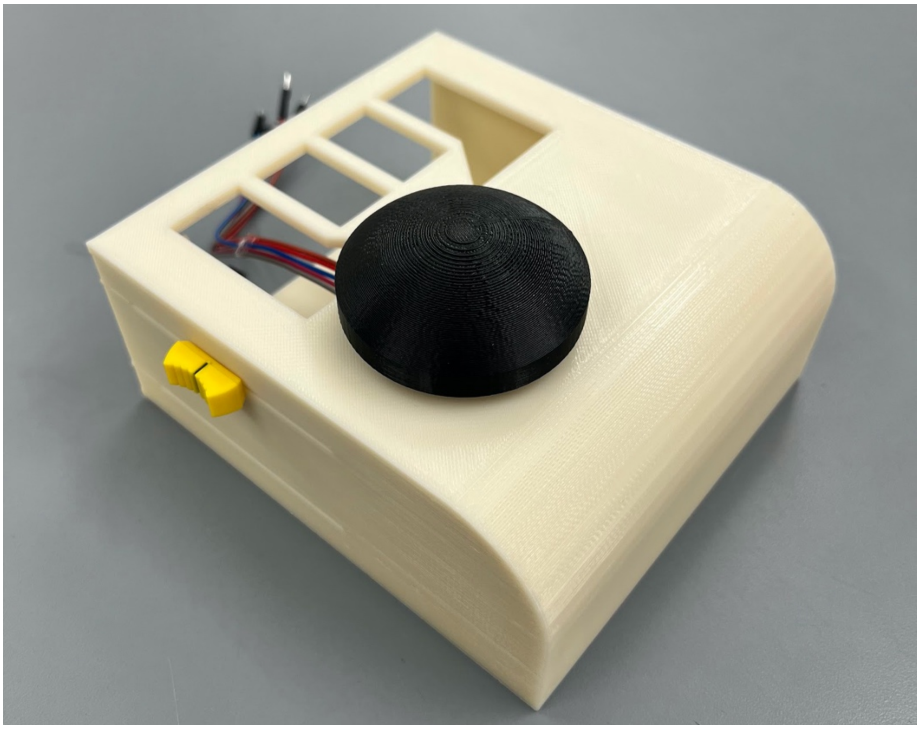
Seok Young Choi is a senior at Boston University graduating in Fall 2023. He is pursuing a degree in Computer Engineering (B.S.) and a minor in Mechanical Engineering. Seok Young has interest in computer architecture, digital design, as well as product design and development. While taking computer engineering courses for his major, he discovered his interest in mechanical engineering when he joined the Terrier Motorsports team and acquired knowledge of 3D modeling and mechanical design. Upon completion of his undergraduate studies, he intends to apply his experience and knowledge into practical applications. He can be contacted by email: schoi11@bu.edu, or by phone: 857-361-2236.

Nicholas Gutierrez is a senior at Boston University graduating in Spring 2023 with a B.S. degree in Computer Engineering. Prior to attending Boston University, Nicholas had never taken a programming course and found his passion for programming after taking his first class. He has since had two consecutive internships with Amazon Web Services and has completed several personal projects. He has a special interest in algorithmic design and hopes to continue learning after graduation. He can be contacted by email: nickgutz805@gmail.com or by phone: 615-557-3141.

Eunhye Kwon is a senior graduating from Boston University in Spring 2023 with a B.S. in Electrical Engineering. Eunhye has a special interest in control systems, renewable energy, and power distribution. With experience working on control systems at Kulicke and Soffa Inc. and energy distribution at National Grid, Eunhye has a well-rounded understanding of all aspects of electrical systems. Eunhye can be contacted by email: ekwon23@bu.edu, or by phone: 484-682-9222.

Yumin Lisa Wei is a senior at Boston University graduating in Spring of 2023 with a B.S. in Electrical Engineering. Yumin has an interest in circuit design/prototyping, fabrication of integrated circuits, and VLSI. While working at Signify (formerly Phillips Lighting), she learned her love for building prototypes and debugging circuits while also leading a personal project on power savings. There she learned many technical skills required for soldering surface mount and through-hole PCBs. Upon the completion of her undergraduate studies, she intends to apply her knowledge into the semiconductor industry. She can be contacted by email: ylisawei@bu.edu or by phone: 857-222-1758.

7.4 Appendix 4 – Controller Prototype (Left Half)



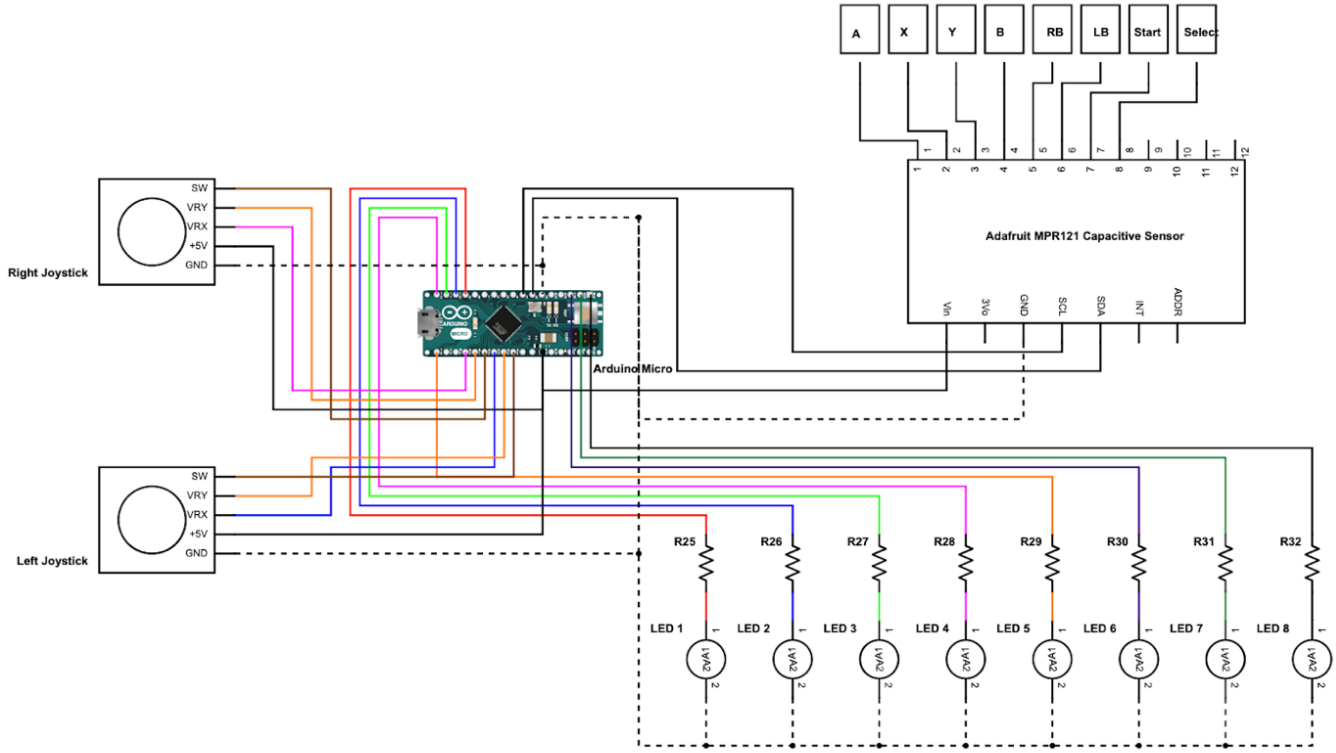
7.5 Appendix 5 – Dimensional Revisions and Feedback (Eunhye and SeokYoung)

Button #	Length/Width/Distance from Joystick	Revision: Length/Width/Distance from Joystick	Feedback
Button 1	2.50/0.95/0	2.50/0.95/0	• Interchangeable joystick mount sizes to fit user's hand size • Buttons should be longer/ increase controller width by one or two centimeters • Decrease controller height
Button 2	1.23/0.7/0.8	1.70/0.80/0.8	
Button 3	1.23/0.7/0.8	1.70/0.80/0.8	
Button 4	2.50/0.7/0	2.50/0.90/0	

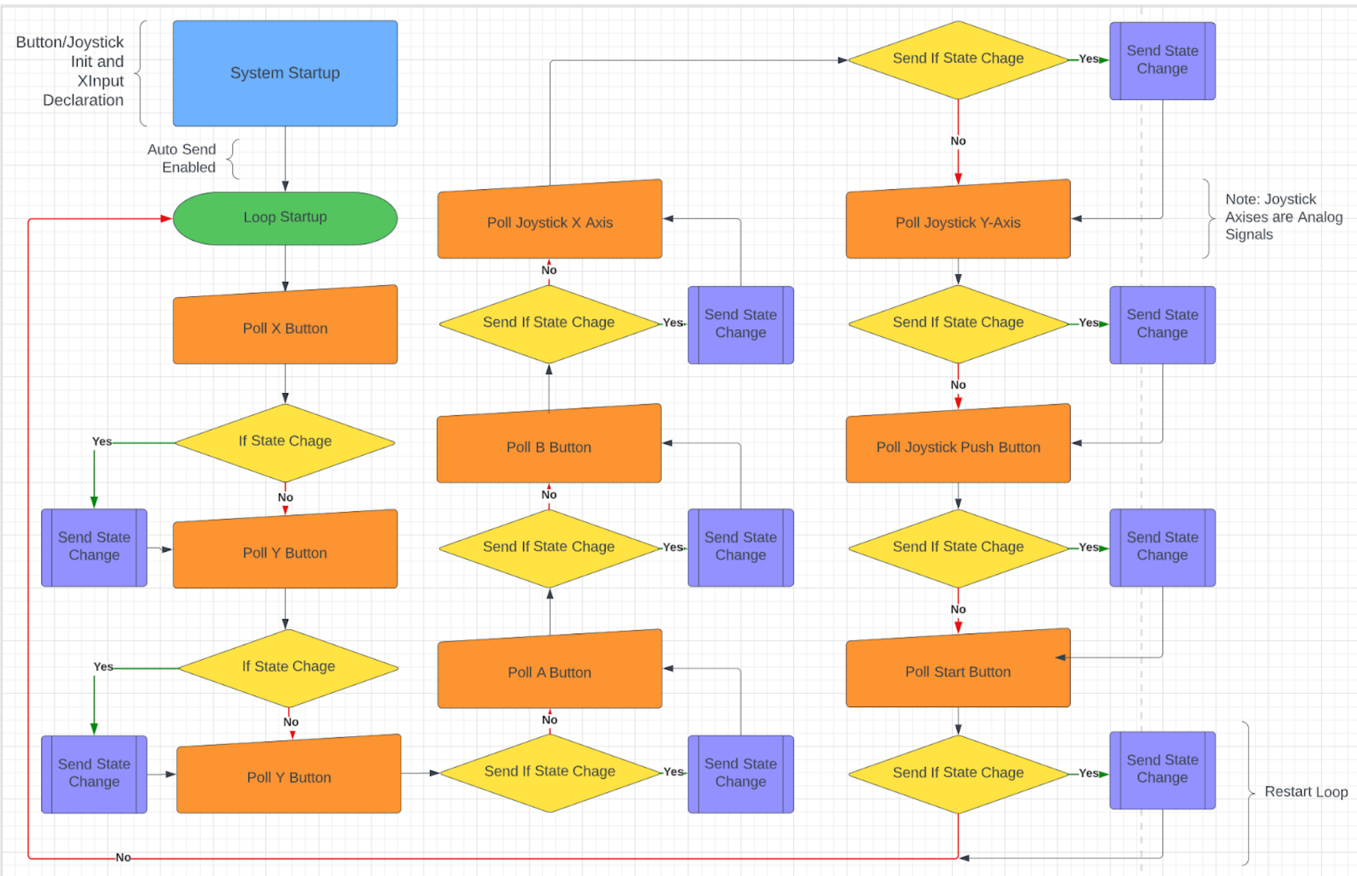
7.6 Appendix 6 – Results of Adafruit MPR121 Sensor Material Conductivity Testing (Eunhye)

Material	Conductive? Y/N
Plastic bag	N
Surgical Glove	Y
Cloth	N
Aluminum Metal	Y
3D printer plastic filament	N
Paper	N
Plastic	N
Metal clip	Y

7.7 Appendix 7 – Hardware Schematic (Eunhye)



7.8 Appendix 8 – Software Flow Diagram of Controller (Nick)



7.9 Appendix 9 – Score Sheet of Controller Buttons and Joysticks Testing Result (Nick and Lisa)

Button	Led On/Off?	Correct Controller Output?	Game Action Performed?	Total Score
1	Yes	Yes	Yes	100
2	Yes	Yes	Yes	100
3	Yes	Yes	Yes	100
4	Yes	Yes	Yes	100
5	Yes	Yes	Yes	100
6	Yes	Yes	Yes	100
7	Yes	Yes	Yes	100
8	Yes	Yes	Yes	100
Left Joystick Push	N/A	Yes	Yes	100
Right Joystick Push	N/A	Yes	Yes	100

7.10 Appendix 10 – References

[1] Victoria. "'Disabled Gamers' Comprise 20% of Casual-Video Game Audience." Marketing Charts, June 12, 2008, https://www.marketingcharts.com/industries/media-and-entertainment-4920. [Accessed: October 12, 2022].

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[3] "Rheumatoid arthritis," Mayo Clinic, May 18, 2021. [Online]. Available: https://www.mayoclinic.org/diseases-conditions/rheumatoid-arthritis/symptoms-causes/syc-20353648. [Accessed: October 12, 2022].

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