4D Media Jacket

FINAL REPORT

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1. Introduction

1.1 PROBLEM

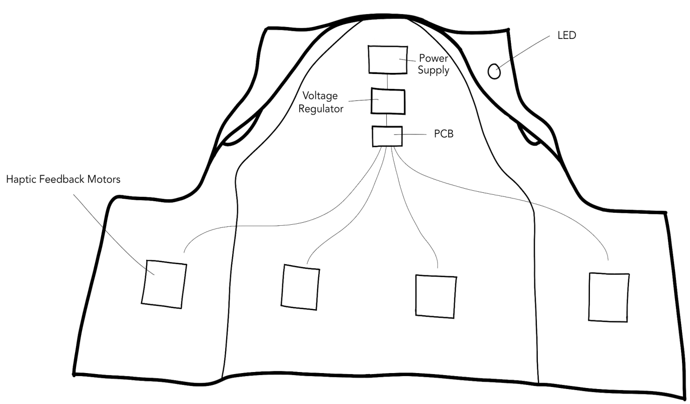
Media has become an integral and pervasive part of the pandemic life. According to Time Magazine, video gaming increased by seventy-five percent in the first week of quarantine [1]. In addition, average weekly gaming increased by twenty-three percent every week since lockdown [2]. According to BBC, streaming services such as Netflix gained sixteen million subscribers within the first month of lockdown [3]. Furthermore, the average weekly Netflix usage rose by seventy-two percent [4].

Thus, amid the COVID-19 pandemic we rely more than ever on media forms to keep us entertained. Movies, music, and video game technology sales are at a peak and new innovations are needed to keep up with the amount that we have come to rely on these media forms. The status quo of these media forms rely on a very 2D experience which after about a year of quarantining has become boring, as well as the fact that this 2D experience is not indicative of the technological innovations of our time today.

1.2 SOLUTION OVERVIEW

Our proposed solution was to create a jacket that provides a 4D experience for various media forms. Specifically, we wanted to focus on movies, music, and video games. Instead of just being able to hear sounds and see visuals, the goal for this project was to develop a more engaging media experience by enabling users to actually feel these media forms through vibrations and shocks from our jacket. For example, in movies we want users to be able to feel the vibrations of sitcom audience laughter or explosions, in music we want users to be able to feel the vibrations of the beats, and in video games we want users to be able to feel the shock of a gunshot and hits. Thus, our goal for this project was to successfully devise a more engaging media experience by upgrading from the current 2D experience to a 4D experience. In addition, we wanted to make this jacket inexpensive to ensure it can be purchasable by most consumers. There are a few similar concept jackets in the market. However, the problem with these jackets is that they are only built and supported by virtual reality based video games. They do not have the ability to utilize haptic feedback for other forms of media such as music and movies. These jackets are expensive as well.

1.3 VISUAL AID



1.4 HIGH LEVEL REQUIREMENTS

- The jacket must be able to create different patterns of haptic feedback based on inputs from the microcontroller over Bluetooth.
- The jacket must be able to last over 4 hours of use on a single charge.
- The app interface should be able to activate the jacket and simulate haptic feedback patterns.
- The Bluetooth module attached to the microcontroller must have a maximum latency of ~70 ms.

1.5 BLOCK DIAGRAM

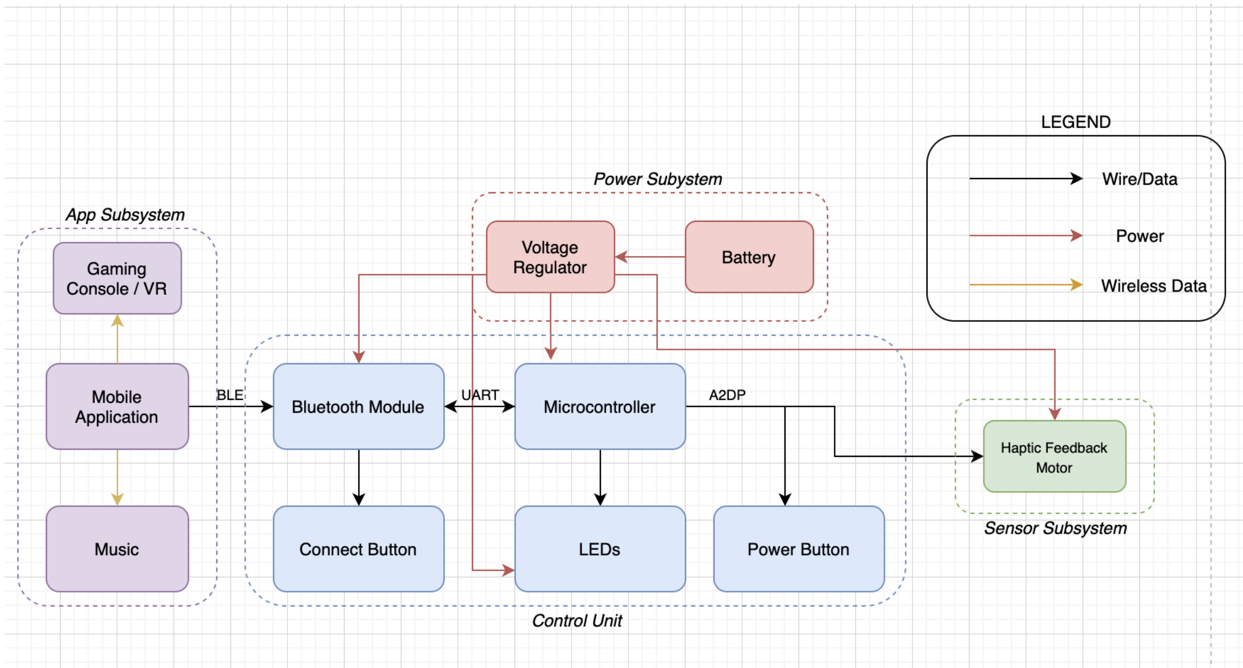


Fig. 2: Block Diagram displaying the required interconnected subcomponents

2. Design

2.1 DESIGN PROCEDURE

2.1.1 POWER SUBSYSTEM

One of our high level requirements is that the jacket must be able to last over 4 hours of use on a single charge. The power subsystem has to supply power to both the control unit subsystem and the sensor subsystem (which includes twelve haptic feedback motors). In addition to this, we had to ensure that the battery would be light-weight and small enough to fit inside the jacket, as well as inexpensive. We were originally going for a Lead Acid battery, which would be very bulky as well as expensive. We switched that to a small rechargeable Li-Ion battery which can fulfill our high current requirements. We ensured that the small rechargeable Li-Ion battery we picked (capacity of 7.8 AH) would be able supply 4 hours of power to the control unit subsystem and the twelve motors (current rating of 100 mA) by performing the following calculations:

$$100\,mA \ * \ 12\,motors \ = \ 1200\,mA \ = \ 1.2\,A$$
$$7.8\,AH \ \div \ 1.2\,A \ = \ 5.2\,hours$$

2.1.2 CONTROL UNIT SUBSYSTEM

The biggest design consideration in the control unit subsystem was selecting a good microcontroller. Our main two contenders were the ESP32 WROOM and the ESP32 WROVER E. Both of these microcontrollers were good choices for us because they have built-in bluetooth modules. We preferred the built-in bluetooth modules over external bluetooth modules because we figured it would entail less wiring, and would additionally take up less space within the jacket. We decided to use ESP32 WROVER E for our final design because the ESP32 WROVER E is much newer, and it has 8Mib of PSRAM which ESP32 WROOM does not.

2.1.3 SENSOR SUBSYSTEM

There were three main design considerations that were needed to determine the most ideal haptic feedback mechanism for the project. The first consideration was the amount of haptic feedback motors we wanted to implement in our jacket. Our initial estimate was to have twenty motors - fifteen motors for use and five motors as back-up. However, the cost for this was too high. We decided to have fifteen motors - twelve motors for use and three motors as back-up. This was a cost-effective solution that would not affect the 4D experience of the jacket too much. The second consideration for the haptic feedback motors was that of physical safety. Since the jacket is a wearable item, it was important to consider how much vibration and shock we want to emit from the jacket onto the user's skin. If the motor was too strong it would potentially be detrimental to the user's health. After some research we found that the ideal skin receptors for safely transmitting vibrations through the jacket are the Pacinian Corpuscle sensory receptors. These sensory receptors respond best to a frequency range from 125 Hz to 300 Hz, peaking at 250 Hz. The third consideration was about displacement of the haptic feedback motors within the jacket. An increase in frequency is directly correlated with an increase in displacement.

$$v \ = \ \frac{displacement\ (\Delta s)}{change\ in\ time\ (\Delta t)}$$

This means that the faster the motor, the more the motor would move within the jacket. Having the motor out of place would defeat the purpose of the jacket, as we do not want vibrations and shocks to be emitted to the user at incorrect locations. Thus, because the ideal sensory receptors present us with the frequency peak of 250 Hz, in addition to the fact that we want to lessen the potential of motor displacement, we decided to use the NFP-7C-FS0725 haptic feedback motor in our jacket. These motors have a rated speed of about 14,000 ± 15% rpm.

$$1 \text{ rad/s} = \frac{1}{2\pi}\text{Hz} = \frac{60}{2\pi}\text{rpm}$$

This rated speed converts to 233.33 Hz.

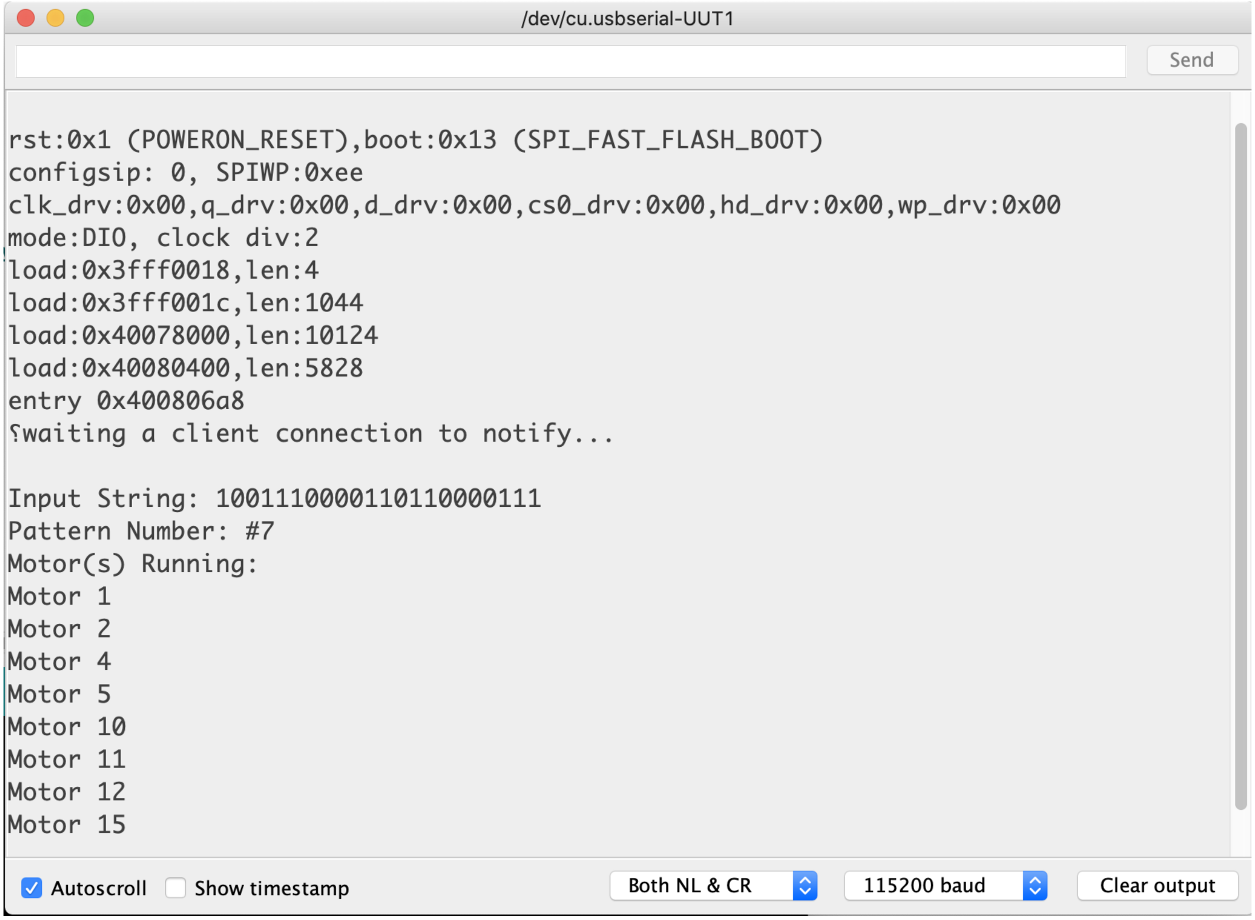
2.1.4 APP SUBSYSTEM

One of the main design considerations for the app subsystem was that it would be easy to use and intuitive. The native iOS application uses Apple's CoreBluetooth framework to establish a BLE connection with our ESP32 Bluetooth module. Once users have scanned for bluetooth devices and connected to the ESP32, they can pick a haptic feedback pattern from several modal lists. The next step involves selecting the motors they want to feel the selected feedback pattern on. Once this is done, the user can send this information to the ESP32 module. We were able to design a linear and intuitive interface for our app subsystem in this manner.

Utilized Bluetooth Low Energy (BLE) which is a built in bluetooth module in our ESP32. BLE is a power conserving variant of Bluetooth that is ideal for transmitting low bandwidth data. Steps for programming BLE in the Arduino IDE:

1. Create a BLE server
2. Create a BLE service
3. Create a BLE characteristic on the service
4. Create a BLE Descriptor on the characteristic
5. Start the service
6. Start advertising (this enables other devices to find it)

After data is transmitted from the iOS application through BLE, we decode the string via the Arduino IDE. The bottom 7 bits correspond to the desired vibrational pattern The top 15 bits correspond to the desired motors to be turned on (0 indicates off, 1 indicates on). We can see the output on the serial monitor



2.2 DESIGN DETAILS

2.2.1 LITHIUM - ION BATTERY (L37A78-3-2-2WX)

Battery chemistry: Lithium Ion (ICR/CGR/LIR)
Capacity: 7.8 Ah
Voltage: 3.7 V
Measurements: 2.1" x 0.07" x 2.7"
Weight: 6 oz
Termination style: Wire leads with connector

2.2.2 ESP 32 WROVER E

Category: RF/IF and RFID
RF Family/Standard: Bluetooth, WiFi
Memory Size: 16MB Flash, 8MB SRAM
Voltage: 2.3 V - 3.6 V
Mounting type: Surface mount

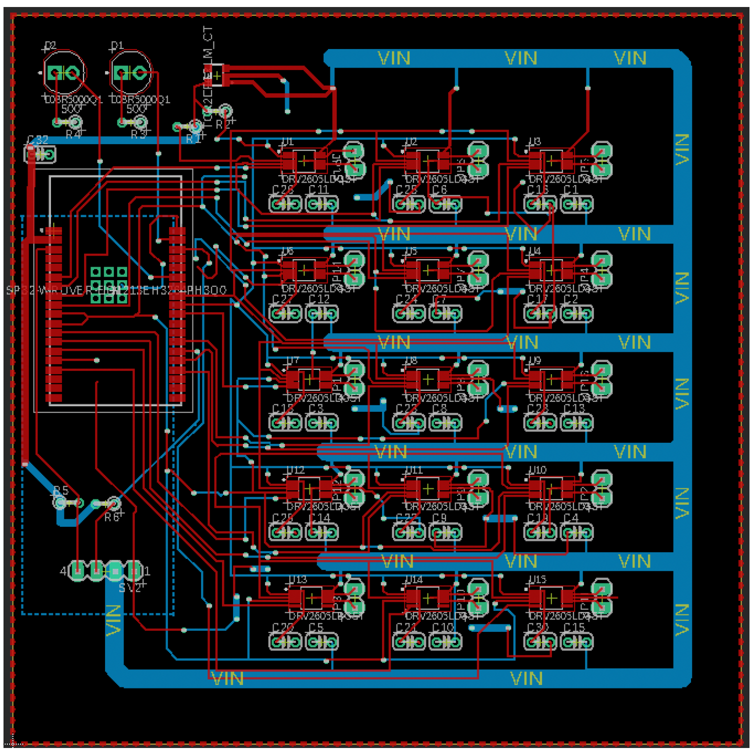
2.2.3 ENCAPSULATED SMALL VIBRATION MOTORS (NFP-7C-FS0725)

Rotation: CW/CCW
Voltage: 3.7V DC
Speed: 145000 +/- 15% rpm
Current: 100 mA
Nominal amplitude vibe force: 2.60 G

2.2.4 IC MOTOR DRIVER (DRV2605LDGST)

Motor type: ERM, LRA
Technology: Power MOSFET
Interface: I^2C
Voltage: 2 V - 5.5 V
Mounting type: Surface mount

2.2.5 PCB Design



PCB Design - ESP32:

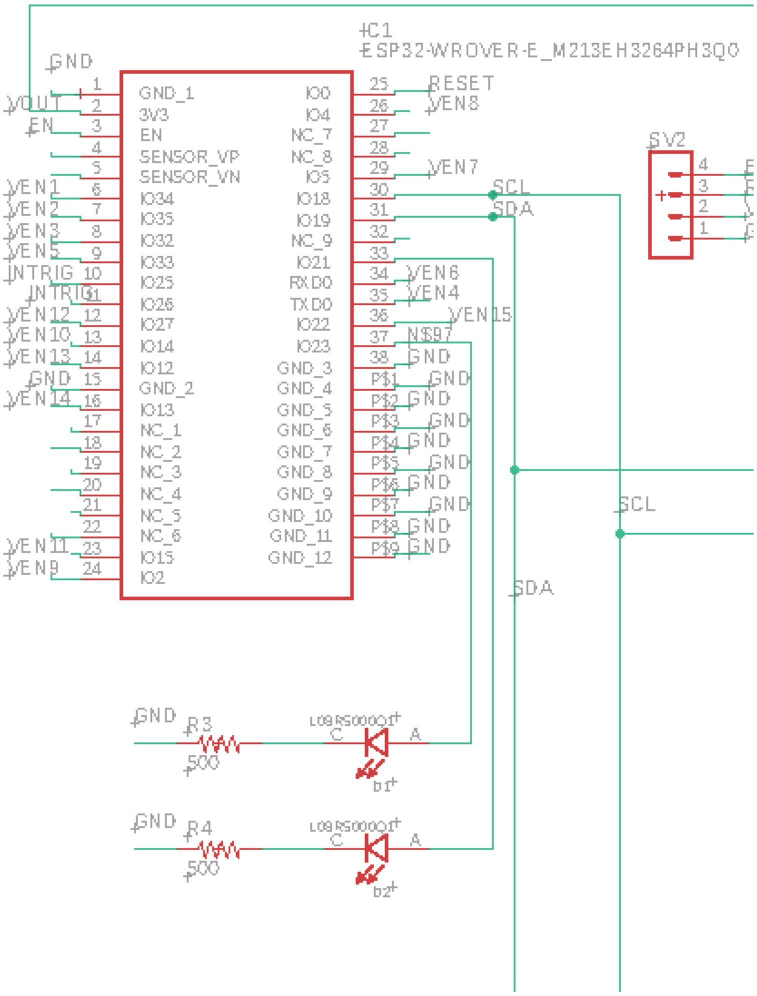
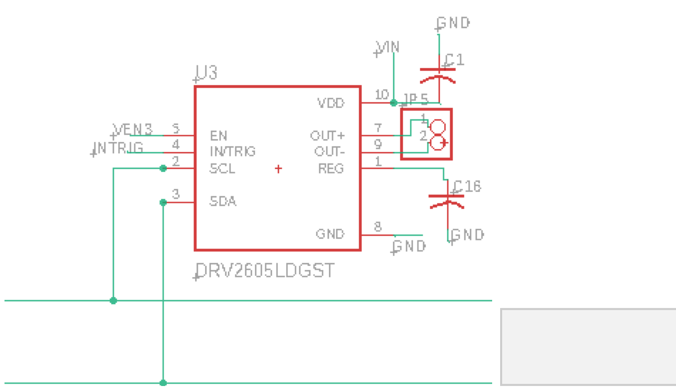
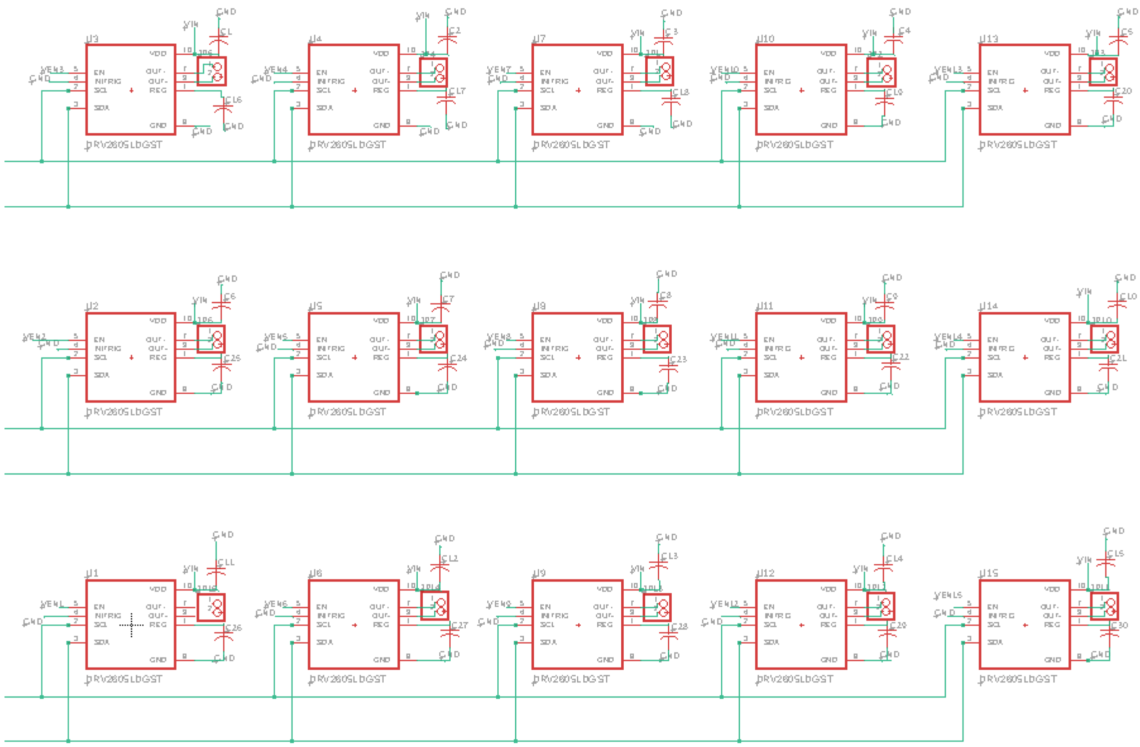


Fig. 5: ESP32 Schematic

PCB design (1 motor driver):



PCB design (15 motor drivers):



3. Verification

The main risks for this project are latency and power. The Bluetooth module we have chosen is not the fastest way of communication, but it is more energy efficient than a WiFi module. Thus, latency will play a major factor in user experience. The second risk is power. We need a reasonably small and relatively lightweight power supply, but the haptic feedback motors have significant energy consumption in large numbers. Thus, we need to balance the power consumption of the feedback motors against their effectiveness.

3.1 Power Subsystem

The power supply will supply power to all components of the jacket. The power supply must be able to power the suit for over 4 hours on a single charge and has a voltage regulator attached to it to prevent damage to the circuit.

3.1.1 Li-Ion Battery

Requirement	Verification
1. Must store more than 6Ah in charge	1. Connect a fully charged battery (6 V) Li-ion battery with positive terminal at Vdd and negative terminal at GND. 2. Discharge at a rate of 350 mA for 20 hours. 3. Connect a voltmeter in parallel to the battery and ensure the voltage is greater than 5.25 V

3.2 Control Unit Subsystem

The control unit subsystem will consist of a PIC microcontroller and a Bluetooth module. This microcontroller will interact with the haptic feedback motors in order to create around different haptic feedback patterns, with each pattern corresponding to a different stimulus. The control unit will interface with the game/audio and send signals to the haptic feedback motors to generate a “4D” experience.

3.2.1 Status LED

Requirement	**Verification**	**Verification Status(Y/N)**
1. LED light is visible to user while wearing the jacket	1. Connect the LED to PCB 2. Supply LED with 10 mA of current 3. Wear the jacket and turn the jacket on by pressing the ON switch 4. The user should be able to see a green light emanating from the LED	Yes

3.2.2 Power Button

Requirement	**Verification**	**Verification Status(Y/N)**
1. Must be easily accessible and pressable	1. Wear the jacket 2. Try to press the power button 3. Ensure this can be done without significant stress	No

3.2.3 Connect Button

Requirement	**Verification**	**Verification Status(Y/N)**
1. Must be easily accessible and pressable	1. Wear the jacket 2. Try to press the power button 3. Ensure this can be done without significant stress	No

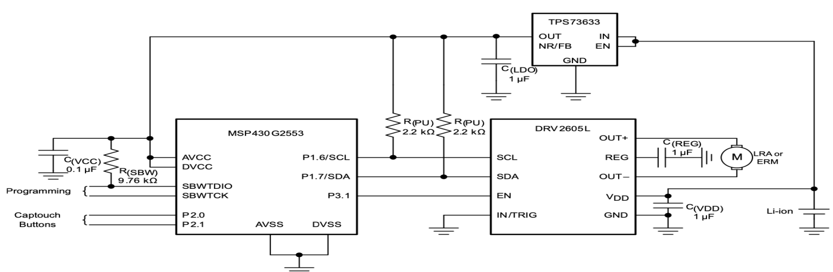
3.2.4 Microcontroller

Requirement	Verification	Verification Status(Y/N)
1. When the device is in standby mode, i.e it hasn't been used for over 10 minutes and it does not have any active bluetooth connections, the microcontroller puts it in standby mode. 2. Jacket to consume under 50mW of power in standby mode	1. Disconnect any bluetooth devices from the jacket. 2. Wait for 10 minutes 3. Check if the LED is showing a yellow light 4. Measure the power consumption and verify if it meets our requirement	No

3.3 Sensor Subsystem

Our sensor subsystem consists of haptic feedback motors. This motor will be used to generate the vibrations needed to create the "4D" experience for our jacket. For example, in video games the sensation of shots will be implemented by the haptic feedback motor generating very high impact vibrations.

3.3.1 Haptic Feedback Motor



Requirement	Verification	Verification Status(Y/N)
1. Different vibration patterns should be created in the haptic feedback motor through the driver chip	1. Connect power source to DRV2605 with capacitors and NFP-7C-FS0725 haptic feedback motor as shown in diagram 2. Use the provided library code for the haptic driver to program two patterns to the captouch buttons. 3. Both buttons should produce different feedback patterns	Yes

3.4 App Subsystem

Our mobile application subsystem consists of a native iOS app that can communicate with the ESP32 bluetooth module. This app will be used to link with music streaming apps and playback the songs with haptic feedback on the jacket. It will also let users control the feedback patterns of the haptic motors for demonstrative purposes.

3.4.1 iOS App

Requirement	Verification	Verification Status(Y/N)
1. App must be able to connect to ESP32 bluetooth module and produce different haptic feedback patterns in the jacket	1. Power on the jacket 2. Press the connect button on the jacket to establish a connection with Bluetooth 3. Connect to the ESP32 module on the mobile phone settings screen 4. Navigate to the app and press the buttons corresponding to feedback patterns 5. Verify that the patterns are being simulated on the jacket, and that all motors are responding in the same amount of time.	Yes

4. Cost

4.1 LABOR

According to statistics from the Electrical and Computer Engineering Department at UIUC [6], the average salary of Computer Engineer graduates is 84,000 dollars. All 3 of our team members are computer engineers so we will use that to estimate the average hourly salary. Workers in the US average 260 days of work per year as well. So:

84000 / 260 = 323 dollars/day / 8 hours/day = ~40 dollars/hour * 3 = ~120 dollars/hour
120 * 2.5 (overhead multiplier) = 300 dollars/hour

So, to employ our team, it would cost an employer approximately 300 dollars per hour. Estimating 15 hours per week of work and 16 weeks in the semester, the total would come out to $72,000 to provide the average cost to employ a team of engineers of our caliber.

4.2 PARTS

Parts	**Cost (Prototype)**	**Cost (Bulk)**
Haptic Motor (NFP-7C-FS0725)	$5.00	$3.00
Haptic Driver (MAX1749EUK+T)	$2.85	$2.55
Microcontroller + Bluetooth Module (ESP32-WROVER-E)	$3.90	$3.90
Battery (L37A78-3-2-2WX)	$14.99	N/A
Miscellaneous (Wires, Connectors, Cloth/Stitching, Casing)	$25	N/A
Total:	**~$52**	**$9.45**

4.3 TOTAL

The prototype will cost around 52 dollars, for the actual jacket, we only need to order extra motors/drivers and one extra microcontroller in case there is a problem, or we burn out the other one. For the motors and drivers at 5.50 bulk cost at 15 pieces each will come to around 75 dollars of expense plus 4 dollars for the ESP, bringing it to approximately 80 dollars. So the total cost of the project should be around $130, plus $72000 of salary.

5. Conclusion

5.1 EXECUTIVE SUMMARY

In summary, we were not able to complete all the goals we set out to achieve at the beginning of this project. There were many bumps in the road as will be outlined later in this report. However, we were still able to get one motor to work and the scalability from there should be simple modification of the PCB design. We really enjoyed working on this project and learned so many valuable things such as PCB Design, design specification, hardware skills, soldering, and so much more invaluable knowledge. We hope to continue working on this project after this class and into the future.

5.2 SUMMARY OF ACCOMPLISHMENTS

We were able to accomplish most of our initial goals in terms of establishing Bluetooth connectivity between the bluetooth module and the iOS app. This enabled us to correctly transmit data through BLE and control the haptic motor drivers, which in turn were responsible for driving the motors correctly. The other aspect of our project focused on the playback of music from mobile devices, and creating a corresponding haptic feedback in the jacket. We were able to accomplish this using a different bluetooth protocol, namely A2DP. We were also able to achieve most of our high level requirements, and had minimal latency for bluetooth communication.

5.3 PROBLEMS / FUTURE WORK

Throughout this project, we had many problems and uncertainties along the way. Our biggest problem by far was the continuous breakdown of the ESP32. We only diagnosed this problem in the final weeks of the semester and so unfortunately, it was hard to get ahead of it. The problem originated when multiple I2C devices used the same SCL/SDA lines. Unfortunately, the ESP32 does not support multiple addressing and therefore each I2C slave requires its own individual address for SCL/SDA. We were not the only team with this issue as well. We have found multiple reports on github of the ESP32 malfunctioning after multiple I2C devices are connected. This was the major problem in our design, and something we did not account for. The solution is very simple however. All we need is a SCL/SDA multiplexer, that will create multiple SCL/SDA addresses for each I2C slave. It copies the address given by the ESP32 and replicates it such that it does not corrupt the microcontroller. Because of these problems, we were only able to have 1 motor being driven at a time.

Other problems we ran into during the design process included the placement and choice of capacitor for the ESP32 as well as the ESP32 browning out. According to our TA, the capacitor between power and ground on the microcontroller needs to be placed as close to the microcontroller as possible. On our second round PCB, this was not the case, and although remedied for the third round, we never received our third round PCB. Another huge issue was the ESP32 browning out, this meant it was not receiving enough voltage to function properly. This happened for quite a few reasons, one of them being the capacitor issue. Another one was the improper supply of power to the board. Although we supplied 3.3V, which was the recommended voltage, it was not enough. We then changed to a 3.7V battery and used the 3.3V voltage regulator which seemingly fixed the problem.

In the future, we would like to incorporate the multiplexer into our PCB design and allow the design to support more than 1 haptic driver and motor. Once the design works with multiple motors, we would like to implant into a jacket or vest to create the 4D experience we envisioned. We would also like to get A2DP and BLE working together to allow the user to choose either a musical vibration or vibration choices through the app. Finally, we would like to integrate VR games or even console games if they offer the data needed to simulate gunshots.

5.4 SAFETY AND ETHICS

For our power supply unit we are using a 7.8 Ah lithium-ion battery to keep all 15 haptic feedback motors running for a period of 4 hours. The problem with these batteries is that they can easily overheat. This can happen either by overcharging the battery, overusing the battery, or bringing the batteries to extreme temperatures. This is especially risky in our project because the batteries are placed inside of the jacket which will actually be worn by a person. To mitigate this, we will make sure to not overcharge, overuse, and bring the jacket/battery to extreme temperatures. In addition, we will replace the batteries every couple weeks to make sure that the batteries are not being overused.

Another possible concern for this project is that the haptic feedback for certain video games (particularly those where we will be simulating gunshot hits) may be too upsetting for certain people, especially those with pre existing heart conditions. To resolve this, we will conduct a lot of research regarding how much stimulation is safe over the parts of the body that the jacket covers, and pay close attention to the rules and regulations of other high stimulation activities such as roller coasters to ensure that the ride is safe for everyone. This aligns with the IEEE Code of Ethics, #9, which states that technologies should not injure people [7].

It is evident that the media plays a large role in our society today. It is responsible for not only learning but also the mental well-being of many young people. Status quo is that there is concern that violence from video games make young people more prone to violence in real life. Questions may arise regarding whether enhancing the video game experience from 2D to 4D will make matters worse. Although these concerns exist, there is no scientific evidence correlating video games to someone becoming more violence prone. Facts are based on quantitative methods and scientific calculations, and not opinions or anecdotes. This aligns with IEEE Code of Ethics, #5. In order to be “honest” and “realistic” in stating claims and concerns, we have to look at the available evidence which explicitly does not correlate playing video games and increased violence [7]. Thus, since there is no actual evidence linking the two together, we contend that enhancing the video game experience through our project does not provoke any ethical risk.

6. References

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