Gesture Based Light Design System

ECE 445 Design Document

Mateusz Chorazy, Debjit Das, and Ian Fitzgerald
Group 33
TA: Anthony Caton

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Table of Contents

1. Introduction

1.1 Objective

Currently, there are excellent sophisticated lighting systems in place at almost all venues in order to provide proper lighting to design theatrical acts and production for musicians. Unfortunately, the control systems behind these lights can be very expensive, difficult to learn and difficult to transport. Particularly for travelling musicians, lugging around a heavy control board could be problematic, and learning someone else's equipment is time consuming in a field where time of the essence. There are also few current lighting systems which gives those on stage the option to be involved in the process; there is almost always someone in the backroom controlling the set.

Our goal is to streamline the process of learning these complex systems, reduce the cost of travel, and offer a new side of production to all types of performers through our gesture-based light design system. Using this system will be much more intuitive and light, changing the way how lighting design is done in the modern world. Instead of learning a series of button and slider combinations that need to be learned, the user will be able to just point in the direction they want the light to face. Furthermore, past utility our project will offer a new type of flare and design to performers on stage. For the first time musicians and actors will be able to take control of the light themselves in a visually appealing way, adding to the showmanship of the whole performance.

1.2 Background

Nearly every modern entertainment venue uses some form of light design to achieve the best overall look for a stage or theater. As stage lighting become more complex, it is increasingly necessary to design the stage's lights prior to the show, requiring a multitude of expensive control boards. Even with the high expense of the control boards, the complexity of the design system can greatly take away from the creativity of the performing artist.

We plan to make our system one of the most intuitive and user-friendly on the market, allowing better production flow of the artist, while keeping it affordable for an entry-level light design system. No need to learn which buttons do what on an expensive board. Instead, the light designer can take full control of the lights by just gesturing his hand. Additionally, we plan to emphasize the ability of our system to be used while a musician performs. The musician will have the ability to entertain via their music and, with the help of our system, the ability to control the light show as well.

1.3 High-level Requirements

- The user must be able to walk freely with respect to the Control Unit, but within a distance of 30 feet, and be able to control the Stage Lights with gesture movements.
- The user must be able to select or deselect any single or group of stage lights which they wish to control.
- The system must be able distinguish whether the user is gesturing to control the lights, or if the user is gesturing arbitrarily.

2. Design

This system will be composed of two main fragments, the glove subsystem and the main control unit. The glove subsystem is responsible for capturing the information behind how the user wishes to interact with the system and communicating it to the main control unit.

A 9 volt battery and a voltage regulator will ensures the glove is powered safely and reliably by allowing batteries to be swapped when they run out of charge. The glove will feature an ATmega328P microcontroller in order to satisfy the computing needed to process and route the sensor data at a low power consumption of .36 milliwatts [1]. The sensing unit is composed of buttons, a gyroscope, accelerometer, and flex sensor in order to measure the various parameters tied to how a user wishes to interact with the light system. Four buttons will be included on the glove which allow the user to select which lights they would like to control via the main control board. These buttons will be equipped with LEDs in order to let a user know which lights are selected. Furthermore, the buttons will provide a medium for the user to calibrate the glove position. The gyroscope and accelerometer will provide information of how the user is moving the glove to determine where the user is pointing and what gestures they are executing. Lastly, the flex sensor will provide information to determine whether or not a user is pointing his pointer finger. In order to communicate information to the main control unit, the glove will be equipped with an nRF8001 low energy bluetooth chip. This component satisfies our range requirements by allowing wireless data transmission up to 32 feet and consuming a power of 330 milliwatts [2].

The data interaction between sensors, the glove unit, and the control unit are show in the block diagram in Figure 1. It’s important to note that while the glove unit is sending the sensor data to the main control unit, the glove unit is not processing the data. The data processing and calculations for where to point the light sources are solely the job of the main control unit. The main control unit has a more powerful microprocessor than the glove unit and additionally, the main control unit is directly connected to the light module. In essence, the glove unit is merely sending the sensor data to the main control unit. There is some communication to the glove unit from the main control unit, such as whether calibration was successful and whether the Bluetooth connection is fully established.

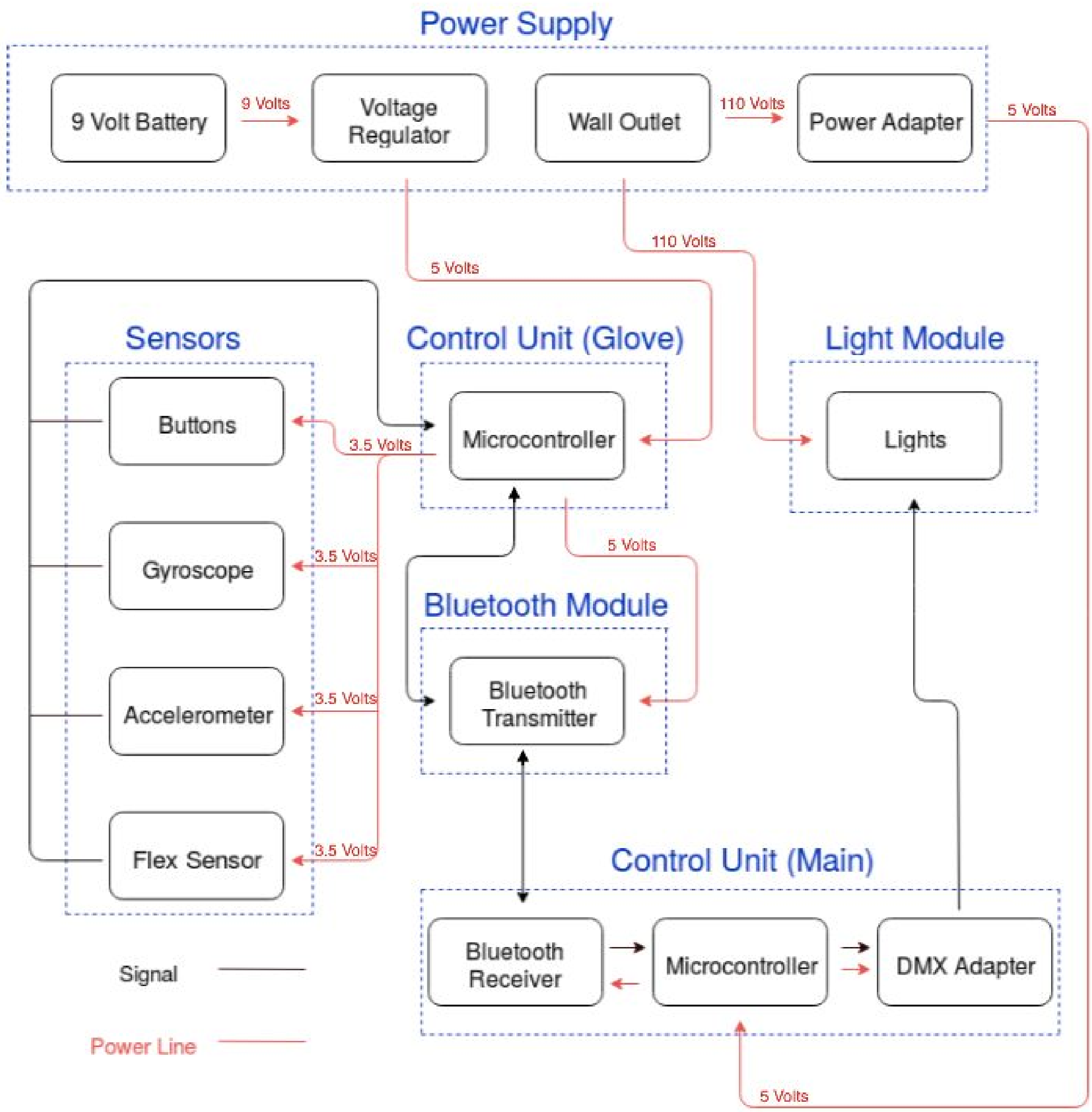

Figure 1: Block diagram.

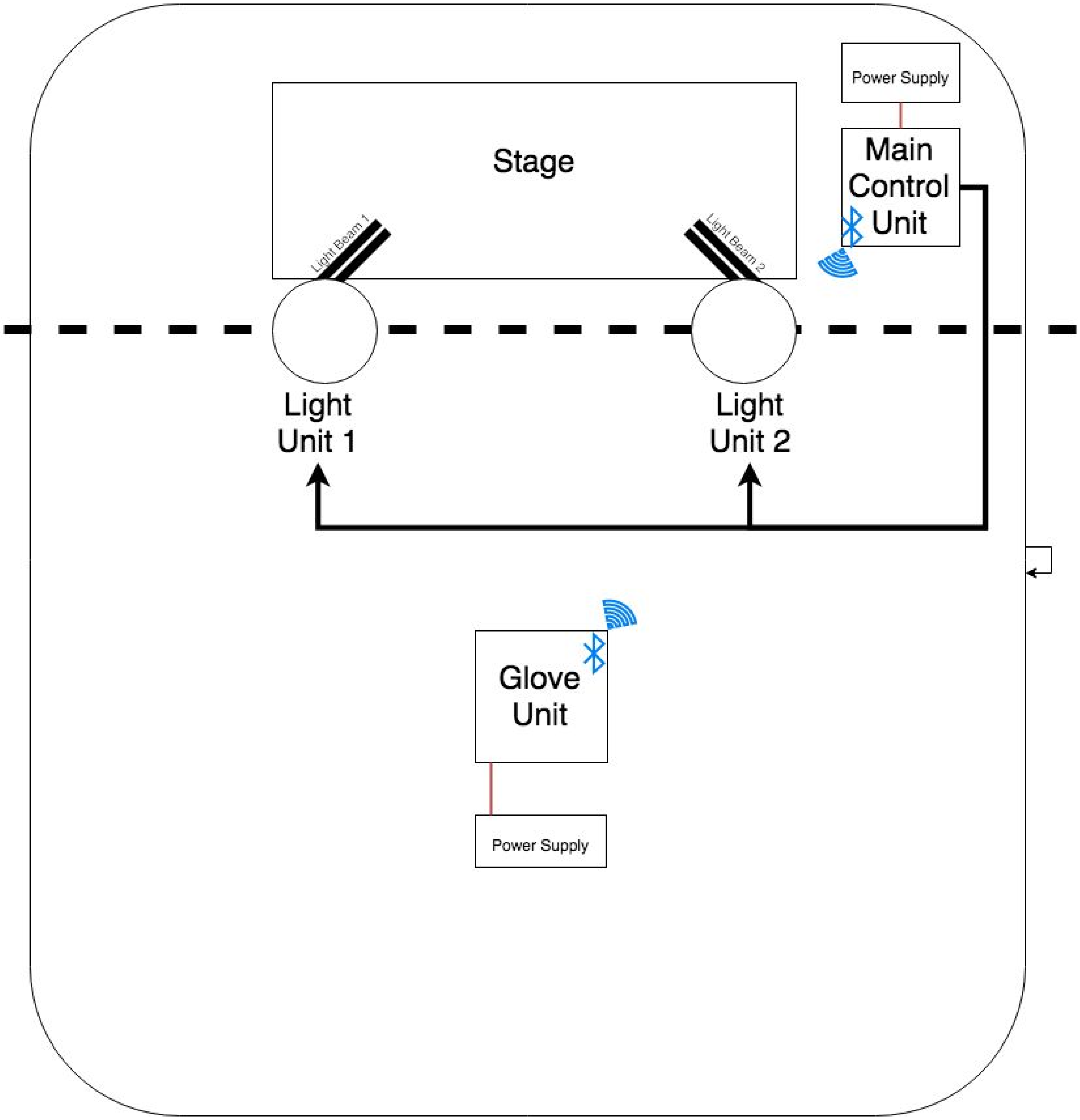

Figure 2: Physical Layout of Light Sources with Respect to the Stage.
It's important to note that the Glove Unit is free moving while all other modules are not.

2.1 Power Supply

In order to fulfill the power requirements while maintaining portability, the glove will feature a 9 volt battery. It is most convenient to power the lights and main control unit through the wall outlet due to their stationary nature. It is of great concern that a standard 9 volt battery satisfies the power requirements of the glove for at least three hours. The microprocessor (100mA, 3.3V) and bluetooth module (12.5mA, 3.3V) will be our greatest power sinks. Energizer's 9 volt battery can supply 610 mAh of energy, which will satisfy the energy demands for over three hours [3].

2.1.1 9 Volt Battery

The 9 volt battery will supply the power required to power the glove circuit without sacrificing portability. The two main power sinks on the glove require an energy capacity of 112.5mA of current at ~3.3V. Allowing a 90mA leeway of additional current draw, the battery must be able to supply 600 mA-hours of current at a maximum voltage input of 3.7V in order to power the glove unit for three hours. We plan on using an Energizer alkaline 9 volt battery.

Requirement	**Verification**
Battery supplies 600 mA-hours of current at a voltage of 3.5 V.	1. Connect a fully charged 9 Volt battery to a power drawing test circuit. 2. Discharge the battery at 150 mA for at least three hours. 3. Utilize a voltmeter to ensure the supply voltage stays above 3.5V throughout the procedure.

2.1.2 Voltage Regulator

The sensors, microprocessor, and bluetooth module take in a supply voltage of ~3.5V. In order to power these components, the battery voltage must be stepped down to within 5% of 3.5V in order to appropriately operate each component. We plan on using a LM317T-DG voltage regulator.

Requirement	**Verification**
1. Voltage regulator supplies ~3.5 V for an input voltage of 6-9 V.	1. Confirm the output voltage operates within 10% of 3.5V over

2. Operates in the current regime of 0-200mA. 3. Maintains a thermal stability below 100℃.	the input voltage range of 6-9V and current range of 0-200mA through the use of an oscilloscope. 2. Ensure the component maintains a temperature under 100℃ through the use of an IR thermometer.

2.2 Sensors

2.2.1 Buttons

The buttons will connect to the glove's microcontroller and will act as an interface which will allow users to choose which lights they would like to interact with. One button will also act as a medium which allows the user to calibrate the device's location shall errors from the accelerometer arise. In order to communicate which button and light combos are active, the buttons will be paired with an LED which will illuminate if the button is active. We plan to use the MPB-43 mini-tactile pushbutton switch.

Requirement	**Verification**
1. Verify the button circuit delivers a high signal when pressed, and a low signal when not pressed.	1. Use an oscilloscope to confirm the output of the button circuit is ~3.5V when pressed and 0V when not pressed.

2.2.2 Gyroscope and Accelerometer

The gyroscope and accelerometer will connect to the glove's microcontroller and will provide information of how the user is moving his or her hand. The IC chip we plan on using contains both a gyroscope and an accelerometer. This information will be rerouted to the main control unit via the bluetooth module. The main control unit will use this information in order to determine which way the user is pointing their hand and which gestures they are executing. Gyroscopes and accelerometers are devices prone to error. Due to this, we will allow the user to calibrate the sensors using a reference shall the error become too large. We plan on using the InvenSense MPU-6050 accelerometer and gyroscope chip.

Requirement	**Verification**
1. The gyroscope and accelerometer must not consume more than 5 mA	1. An oscilloscope will be used to measure the chip's current

of current to ensure low power consumption. 2. The gyroscope and accelerometer should have enough accuracy to track the location differential of the glove without introducing a 5 degree error between the calculated finger pointing vector and actual finger pointing vector.	consumption at a 3.5 V supply input. 2. The gyroscope and accelerometer will be tested with gesture motions and movement to ensure the error between the estimated and actual finger pointing vector stays within five percent through a three hour usage.

2.2.2 Flex Sensor

The flex sensor will connect to the microprocessor and will be placed in the index finger slot of the glove to detect if the user is pointing their finger. This information will be rerouted to the main control unit via the bluetooth module. The main control unit will use this information in order to determine if a user would like to guide any chosen lights in the direction being pointed at. We plan on using the Adafruit Short Flex Sensor (ADA1070). The ADA1070 has a flat resistance level of 25K Ohms [4]. Because it's unlikely that a user will achieve a perfectly flat pointed finger, we are using 35K Ohms as our cut-off level for determining whether or not the user is in fact pointing his or her finger.

Requirement	Verification
1. The flex sensor must change it's resistance if a user is pointing their index finger versus when they are not pointing their finger.	1. The flex sensor will be sown into the glove and wired up to the microprocessor. An ohmmeter will be used to detect if there is a change in resistance when the finger is resting versus when the finger is pointed. 2. A pointed finger corresponds to a resistance level of less than 35K Ohms. 3. An unpointed finger corresponds to a resistance level of more than 35K Ohms.

2.3 Bluetooth Module

The Bluetooth Module covers both the Main Control Unit and the Glove Control Unit. This will be how the two control units communicate to each other. Most importantly, the data that will be transferred via Bluetooth is all of the Glove Unit's sensor feedback. Instead of processing this data on the Glove Unit, we are choosing to only use the Glove Unit to communicate sensor feedback to the Main Control Unit. The Main Control Unit, because of its more powerful processor, will process and decode exactly what the sensors are communicating. For example, when the user gestures in a new direction, the Glove Control Unit will communicate the accelerometer and gyroscope's data to the Main Control Unit where the Main Control Unit will proceed to determine the directional change for the Light Units. The Glove Unit is not calculating the directional updates.

2.3.1 Bluetooth Transmitter

The bluetooth transmitter will be connected to the glove's microprocessor and is responsible for broadcasting signals containing the sensor information. These signals will be picked up by the bluetooth receiver that is connected to the main control board and used to decide how to control the lights. We plan on using the Adafruit Bluefruit LE chip.

Requirement	**Verification**
1. The bluetooth chip must not consume more than 110mA of current to ensure low power consumption. 2. The range of the bluetooth signal must exceed 30 feet.	1. An oscilloscope will be used to measure the bluetooth chip's current consumption at a 3.3 V supply input. 2. The chip will be used to broadcast a test signal which will be received over a range of 20 to 40 feet and tested by matching with the original test signal to determine signal integrity.

2.3.1 Bluetooth Receiver

The bluetooth receiver will be connected to the main control unit microprocessor and is responsible for receiving the signals broadcasted by the glove unit bluetooth transmitter. These signals will be delivered to the main control board to decide how to control the lights. We plan on using the Panda USB Bluetooth Adapter.

Requirement	**Verification**
1. The receiver must receive the	1. The RSSI value of a bluetooth test

bluetooth signals at a strength above -70 RSSI value at a range of 30 feet.	signal 30 feet away will be tested over the course of an hour to determine it remains above -70 at all times.

2.4 Glove Control Unit

2.4.1 Microprocessor

The microprocessor is the unit which will process the information received through the sensors and route it to the main control board through the bluetooth module. Due to the fact that the microprocessor will be powered by a battery, it would be ideal to choose a microprocessor with a low power consumption. However, the microprocessor must be able to have enough computing power to process the information from the sensors and route them to the main control board via the bluetooth module. It is crucial that the sensors and bluetooth chip are compatible. We plan on using the ATmega328 8-bit AVR microcontroller.

Requirement	**Verification**
1. The microprocessor must be compatible with the sensors and bluetooth chips. 2. The microprocessor must not consume more than 15mA of current to ensure low power consumption. 3. The microprocessor must turn on the LEDs when its corresponding button has been pressed.	1. The microprocessor will be tested with the sensors to ensure the microprocessor receives and stores meaningful values. 2. An oscilloscope will be used to measure the microprocessor's current consumption at a 3.3 V supply input. 3. Confirm the LED turns on to the corresponding button when the button is pressed.

2.5 Main Control Unit

2.5.1 Microprocessor

The microprocessor is responsible for using the information from the sensors to control the lights. The microprocessor will receive the sensor information from the bluetooth receiver. The microprocessor will process this information as shown in Figure 7, and send control signals to the lights using the DMX-512 protocol via the DMX adapter. We plan on using the Raspberry Pi as our main control unit processor due to the fact that Debjit has one already.

Requirement	Verification
1. The microprocessor must be compatible with the bluetooth receiver and DMX adapter.	1. The microprocessor will be tested with the components to ensure the microprocessor receives and stores meaningful values.

2.5.2 DMX Adapter

The industry standard with professional grade lighting is to use the DMX-512 communication protocol. In order to control the lights, the control signals will have to be delivered using this protocol. The DMX adapter will be connected to the main control unit microprocessor to enable the signals being sent to the lights to follow the DMX-512 communication protocol.

Requirement	Verification
1. The DMX adapter must output signals using the proper DMX-512 communication protocol.	1. The DMX adapter will be tested by pairing it with the main control unit microprocessor and communicating known control signals to the lights to see if they align with the actions executed by the lights.

2.6 Glove

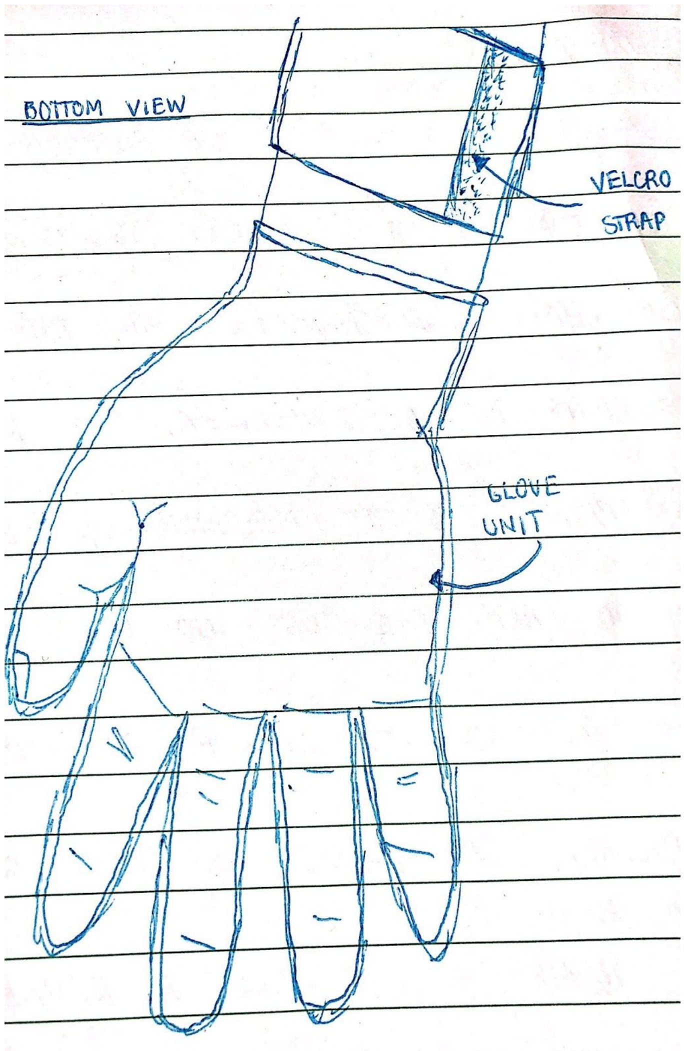

Figure 3: Palm view of glove design.

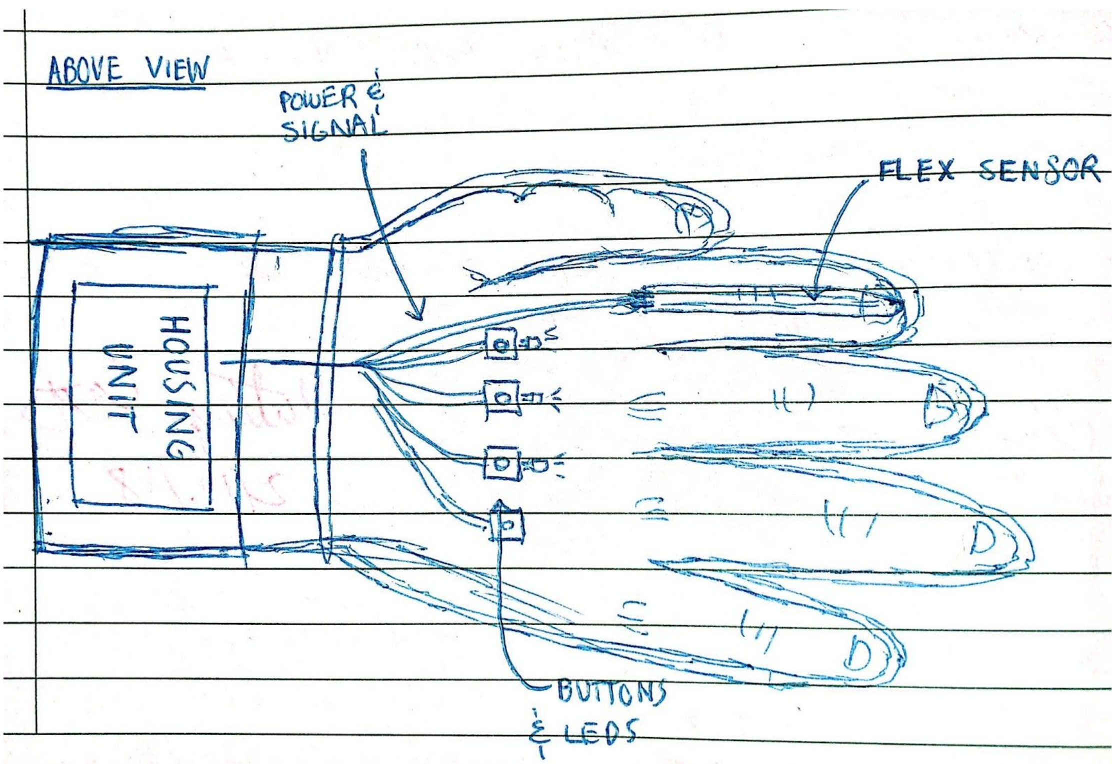

Figure 4: Backhand view of glove design.

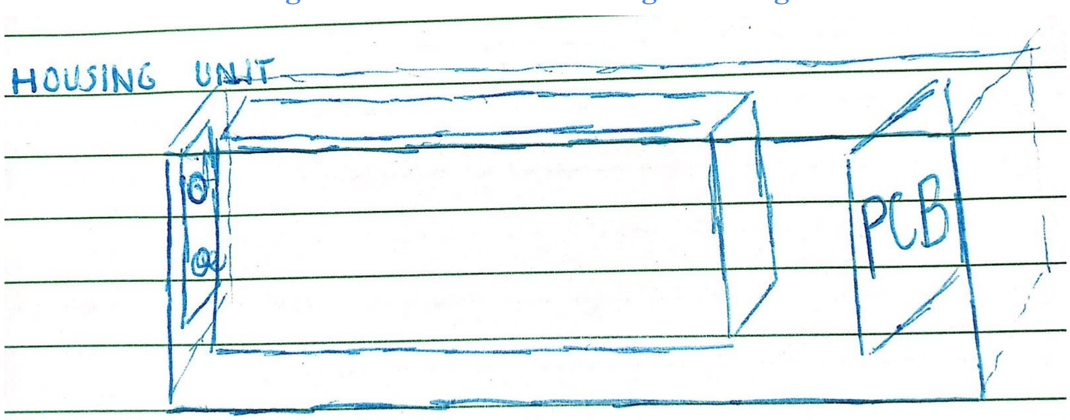

Figure 5: Glove housing unit for PCB board and battery.

2.7 Software

The software component of our project will be twofold. First, we will program the Glove Control Unit to receive all of the sensor data and transmit all of this data over its own Bluetooth Module. Second, we will program the Main Control Unit to receive the Glove's Bluetooth communication, process the sensor data, compute the new coordinates for which the Light Units will point to, and then communicate the new coordinates to the Light Units over the DMX-512 protocol. We will be responsible for creating the exact algorithms for both of these software components, but we will use publicly available software libraries to interpret the data coming from the MPU-6050 (gyroscope and accelerometer), to communicate via Bluetooth, and to send the data to the Light Units over the DMX-512 protocol.

A general decision diagram for both the Glove Unit and Main Control Unit are provided below. Regarding the calibration protocol, the user must invoke calibration. When doing so, for best results it will be recommended that the user is standing centrally in the middle of the two Light Units. This is not required, but will aid the user's perspective in understanding where to point his or her hand when wanting to direct the Light Units. When the user invokes the calibration protocol, the Glove Unit will communicate that the protocol has been invoked to the Main Control Unit. The Glove Unit will continue to transmit all data to the Main Control Unit. The Main Control Unit will use the incoming data from the gyroscope and accelerometer to set a "zero point." This process will take 2 seconds to capture enough data from the gyroscope and accelerometer. During this process the user will have their hand extended parallel to the ground and arm fully extended. Lastly, after the 2 seconds of capturing data from the Glove Unit, the Main Control Unit will set the average of the captured data set to be the 'zero point.' This point is when the Light Units are pointing to the center of the stage and at a height of 5 feet. The zero point for the Light Unit will be manually hard coded to the Main Control Unit during set up of the entire system.

After calibration is completed, the Light Units should not take longer than ½ second to respond to the users directions (i.e. when the user points their finger and gestures, the lights will move to the appropriate position within a ½ second.) We strongly believe this to be a very reasonable time constraint. The Bluetooth module will be communicating new data points at a minimum interval of 12.5 milliseconds [5]. In its worst case, the time it takes for the communication from the Main Control Unit to get to the Light Units over the DMX-512 protocol is 22.67 milliseconds [6]. This leaves us 464.83 milliseconds to process the gyroscope/accelerometer data set and calculate the required information the Light Units need to point in the correct direction. From our own previous software engineering experiences, and based on the power of the Main Control Unit's processor (the Broadcom BCM2837), we have no fear that our algorithm will take less than the 464.83 milliseconds to process the incoming data and compute the data for the Light Units.

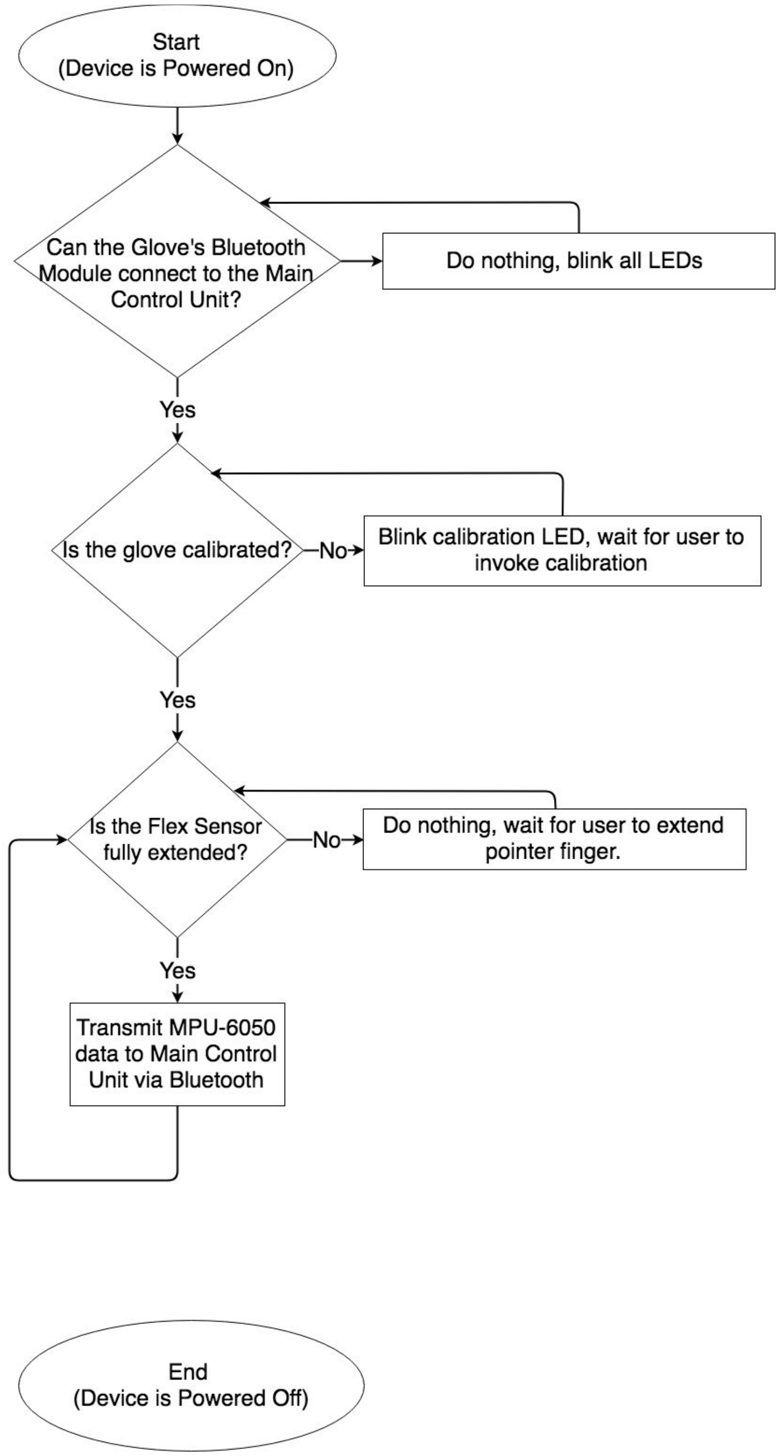

Figure 6: Glove Control Unit Decision Diagram.

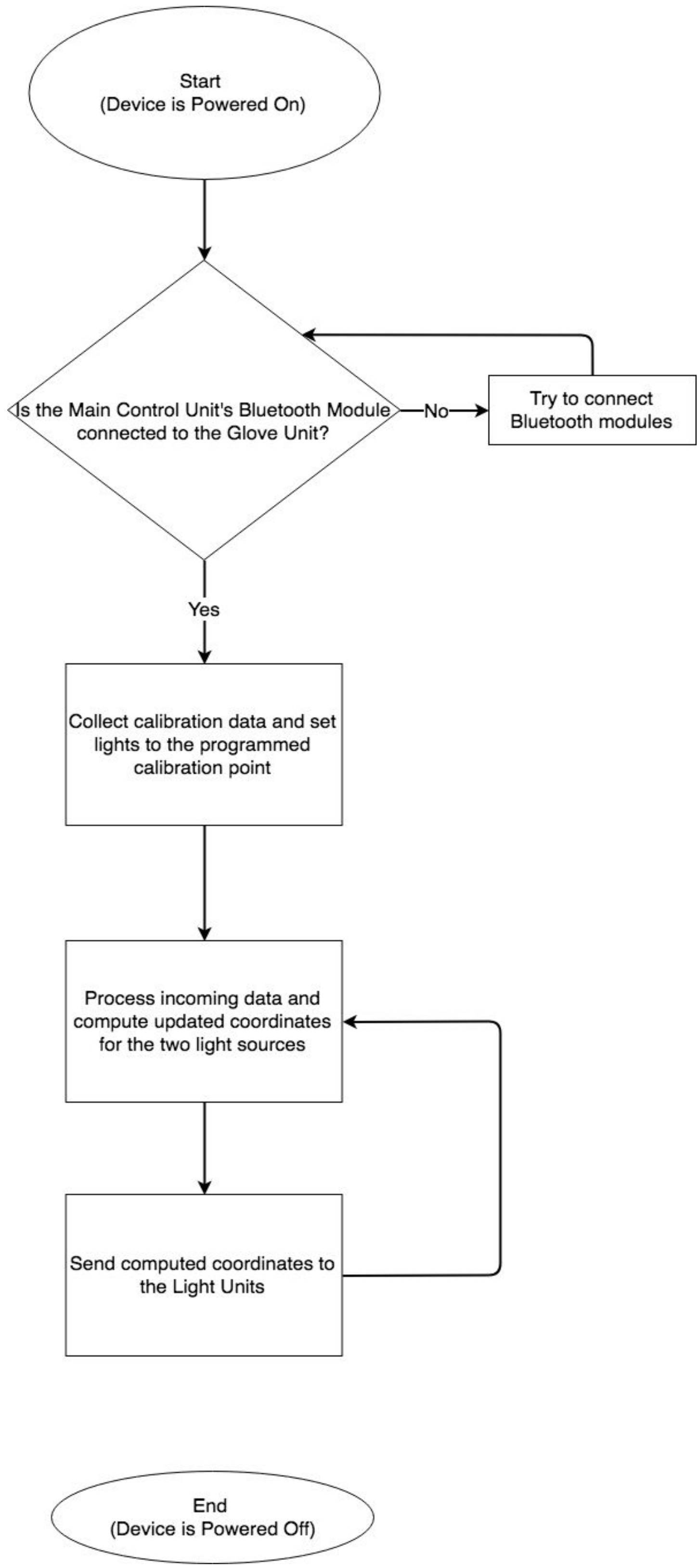

Figure 7: Main Control Unit Decision Diagram.

2.8 Tolerance Analysis

The most important tolerance we must deal with is the degree of error between where the control unit believes the user is pointing versus where the user is actually pointing. Through research, we believe that the MPU 6050 we plan on using is fairly reliable and will not bring about much concern. Our main focus on this would be in the software, how our code handles the data. Unfortunately this means that most of our error testing would have to be done through trial and error.

The areas to consider when mapping this code is how fast the user's hand is moving, the degree of tilt in the glove, how far away they are from the light, and the distance the glove moves. Each of these would map to the movement of the light in a three coordinate plane and how fast the light moves. For testing maximum accuracy, we will be treating the light like a laser with a single point as our reference.

We can find our degrees of error fairly easily as well through some trigonometry. By measuring the length of the room (distance between a and b of figure 8) and how far off the beam is from our desired location, in both the x and y direction, we can find the degree of error by running inverse cosine, sine and tangent operations.

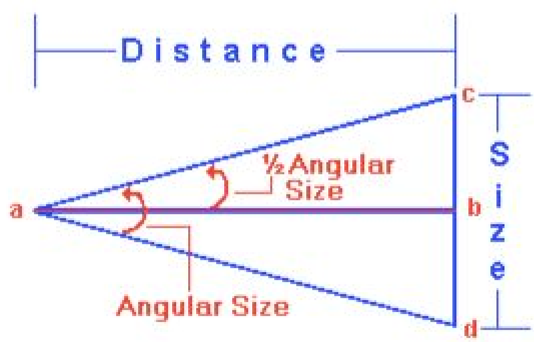

Figure 8: Angular Size Diagram.

It is important too to make sure that latency is as low as possible to maintain the illusion that everything is happening instantaneously with the hand movements. The human eye is particularly good at rendering movement and light in their vision so our threshold would have to be at 40 ms at maximum, and 8.3 ms at its most optimal performance [7][8]. A latency below that time should not be noticeable to the naked eye.

3. Costs

Our fixed development cost will be for 3 people at $40/hr a week, 5 hours/week among 3 people, for approximately 12 weeks:

3 * $40/hr * 5 hr/week * 12 weeks = $7200

Part	Cost (Prototype)	Cost (Bulk)
Glove (Amazon Generic)	$8.00	$4.90
Glove Microcontroller (Digikey)	$25.00 (already owned)	$2.00 (per chip)
Flex Sensor (Amazon)	$13.00	$7.16
Gyroscope & Accelerometer (Amazon)	$4.52	$1.00
Bluetooth Breakout (Amazon)	$20.00	$15.96
3 x LEDS (ECE Shop)	$1.00	$0.27
4 x Buttons (ECE Shop)	$1.68	$1.44
Broadcom System (Raspberry Pi)	$70 (already owned)	$50.15
Bluetooth Adapter (Amazon)	$12.00	$8.77
DMX Adapter (Bit Wizard)	$50.00	$34.82
9-V Battery	$3.74	$1.20
Voltage Regulator (ECE Shop)	$0.77	$0.26
Total	$210.61 (w/ owned $115.61)	$127.93

Since we plan to build upon our prototype, with labor and part costs our total development costs would be $7410.63. We don't plan to order anything in bulk, however if we were a company looking to reach out to venues across the world, we would see a price decrease of $82.68.

4. Schedule

Week	Mat	Debjit	Ian
2/5/2018	Research DMX-512 communication protocol and design Power Supply for both Control Units.	Research and design high-level Main Control Unit	Research and design high-level Glove Control Unit
2/12/2018	Design Document	Design Document	Design Document
2/19/2018	Create schematic for the Power Supply for both Control Units	Create schematic for the Main Control Unit	Create schematic for the Glove Control Unit
2/26/2018	Program Glove Control Unit sensors and Bluetooth communication	Program Main Control Unit for Bluetooth and DMX-512 communications	Order all supplies, begin design for Glove Control Unit PCB
3/5/2018	Physically prototype Power Supply and voltage regulator	Connect the Main Control Unit to Light Units and test DMX-512 Communication	Physically prototype the Glove Unit with sensors
3/12/2018	Verify both Control Units' programs	Glove Control Unit Schematic/PCB order	Glove Control Unit Schematic/PCB order
3/19/2018	Spring Break	Spring Break	Spring Break
3/26/2018	Continue physical prototype	Continue physical prototype	Continue physical prototype
4/2/2018	3D Design and Print the Housing Unit for Glove	Fix any bugs with the program and actual prototype	Resolve consistency issues between programs and the prototypes
4/9/2018	Finish case and	Replace Glove	Solder the PCB

	work with PCB to ensure seamless integration with the Glove Unit	Control Unit prototype with PCB	Board sensors and replace the prototype on the Glove Unit
4/16/2018	Complete all verification tests. Complete and resolve any last minute issues. Work on demo.	Complete all verification tests. Complete and resolve any last minute issues. Work on demo.	Complete all verification tests. Complete and resolve any last minute issues. Work on demo.
4/23/2018	Presentation/Demo	Presentation/Demo	Presentation/Demo
4/30/2018	Final Paper	Final Paper	Final Paper

5. Ethics and Safety

At a quick glance, it seems our project does not have any of the major traditional safety risks that other ECE 445 projects encounter. This is most notably because we are not using a rechargeable battery. However, we have identified areas where ethical and safety questions arise in the following paragraphs.

Although we are not using a rechargeable battery, which are known to explode under improper use, we are using an alkaline battery which still carries the potential to explode [9]. To minimize the risk that any alkaline battery explodes on a user, we will always recommend to follow standard storage and usage procedures for disposable alkaline batteries. To elaborate, there is essentially a nonexistent chance of electrocution by such a small voltage. However, to take full precaution, we will take an additional step and isolate all electrical components of the wearable device from the users skin. No electrical components will be making direct contact with the user.

Next, users of our system may be exposed to high voltages when using standard professional DMX-512 moving-head lights. These lights consume large amounts of electrical power, and are powered directly by the wall outlet. We will communicate this potential electrical hazard to all users of our system through the use of warning labels.

In most cases, the DMX-512 protocol does not include a parity check or an error check [10][11][12]. This means that when using a DMX-512 hardwired system, such as our current approach, there is a potential risk that the wires used to communicate to the lights pick up interference and cause an undesired operation. In the worst case, this means that the moving-head lights move uncontrollably and at incorrect colors/brightness levels until it receives a new correct signal. We will fully disclose this risk to the users of our system and include warning labels. The requirement to use our system will be that all moving lights be in a physical area that gives a full range of movement to the moving-head light with zero possibility of collision or human contact.

We do not suspect interference to be a large problem, but according to IEEE Code of Ethics #1, we must “hold paramount the safety of the public... and disclose promptly the factors that might endanger the public or environment” [13]. We believe we have fully followed this code and all other standards laid forth by the IEEE Code of Ethics.

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