Final Report for Project Lab 2 at Texas Tech University

Mason Marnell

Justin Sims (group member)

Colbi Maurer (group member)

Jack Kays (group member)

Taylor Moore (group member)

Andrew Stelluti (group member)

R# 11617302

Texas Tech University

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Abstract

This paper describes the workings, mechanics, and technical information regarding an animatronic 3D printed pumpkin system. This pumpkin system must be able to use multiple Raspberry Pis that communicate via the Mosquito MQTT protocol. The system must track individuals that walk by using three different methods of detection, play occasional sounds, and play a larger singing routine when there is a large group of people present. The system should ideally be weather resistant, use a single charge per event day, and have power saving features. The system was originally designed for use during Halloween but has since been repurposed with a holiday aesthetic and sound profile.

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1. Introduction

The Lubbock Pumpkin Trail is an event that the City of Lubbock hosts every year. It is located at Clapp Park where participants walk a trail to see all the donated pumpkins. The pumpkin system referenced in this document attracted much attention due to the thermal tracking and recognizable design.

Due to time limitations, the design of the system as a whole needed to be modified very close to the start date of the pumpkin trail to at least have a working product. By demo day however, the project satisfied effectively every requirement from the original project description. The system also has the “twist” requirements (which were making the system “holiday-ified” and adding a visual camera in addition to the other sensors) incorporated and fully functional.

2. Block Diagram

The block diagram is a comprehensive layout of every physical component used in the pumpkin system. This is both a high-level component overview and a power input diagram.

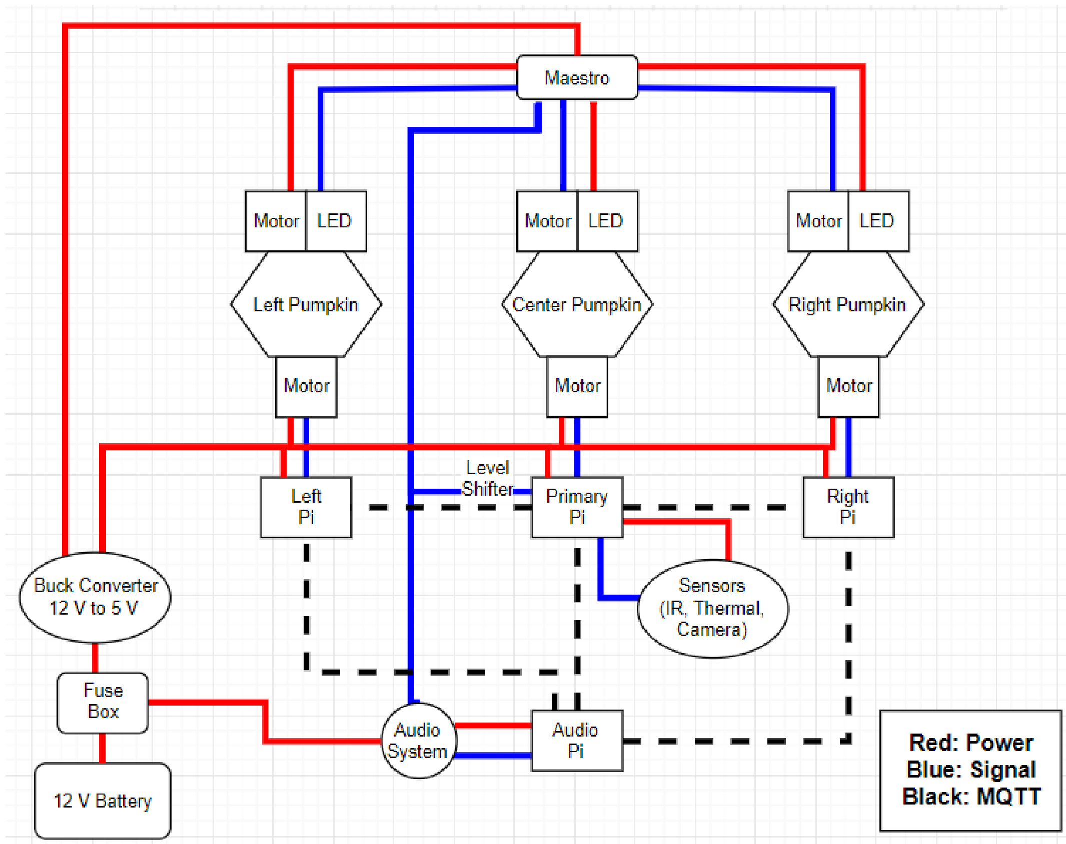

Figure 1: Block Diagram [12]

3. Chassis Design and 3D Printing

For the main chassis, a 40-inch-wide plastic tote was originally chosen. Later, a custom-cut wooden box was made to house the project. A large sheet of ¼ inch plywood was bought from the Architecture building on TTU campus, and eventually turned into a 40-inch wide by 18-inch deep by 6.5-inch tall housing.

On top of the box, three stands for the pumpkins were created. Each stand has a tall PVC cylinder attached to a Lazy Susan style spinning plate to allow for the pumpkins to rotate. Figure 2 demonstrates these spinning plates, as well as the finished project.

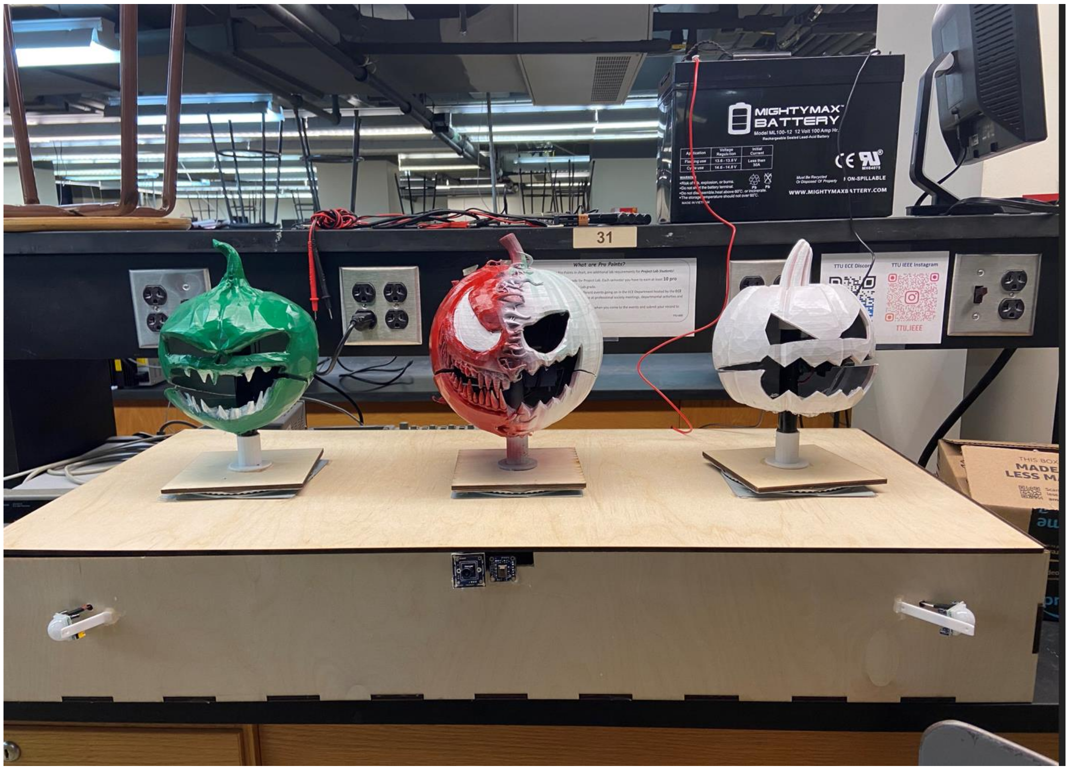

Figure 2: Chassis and Finished Project [12]

Three unique pumpkin designs were chosen for the system. All pumpkins were printed by Andrew Stelluti using his own printer. The print files used were found on Thingiverse and were printed using PLA filament. The middle pumpkin has a diameter of approximately 22.5cm, while the outer pumpkins are approximately 18cm in width [10]. Figure 3 also shows the additional 3D printed parts used to help stabilize the pumpkins as well as allow the vertical movement to take place.

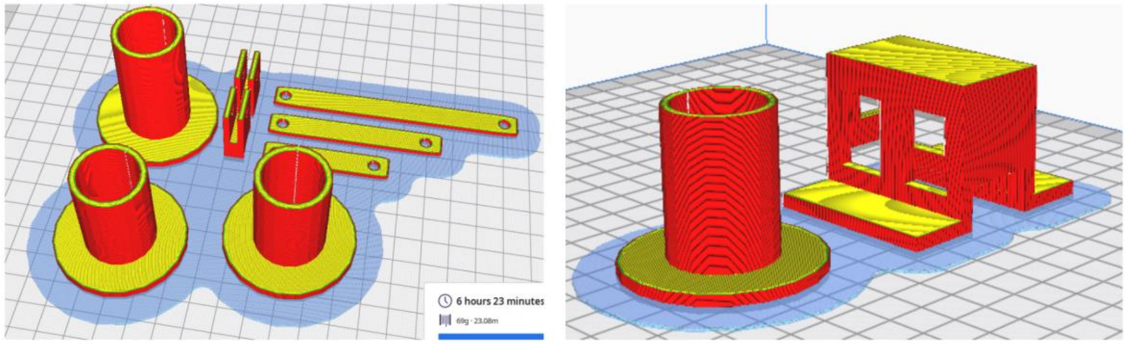

Figure 3: 3D Printed Parts [10]

4. Audio

The audio solution that was chosen was to use both the HiFiBerry Amp2 and two DAEX25Q-4 Audio Exciters. The Amp2 is able to provide up to 60W of power, supports sample rates from 44.1kHz – 192kHz [1], and powers the Pi that it is connected to. The Amp2 attaches to one of the Raspberry Pis via the GPIO pins and gets power from our 12V power source to power the exciters. The excitors have an impedance of 4 Ohms, 20W RMS power handling, and can produce frequencies from 40Hz to 20kHz [2].

Unlike regular speakers, excitors need a material substrate to use as a diaphragm. The exciters were attached to a relatively thick foam board, which was determined to be one of the best materials for distortion mitigation and sound propagation. After some testing, it was determined that the capabilities of this audio system certainly meet the criteria set by the project requirements.

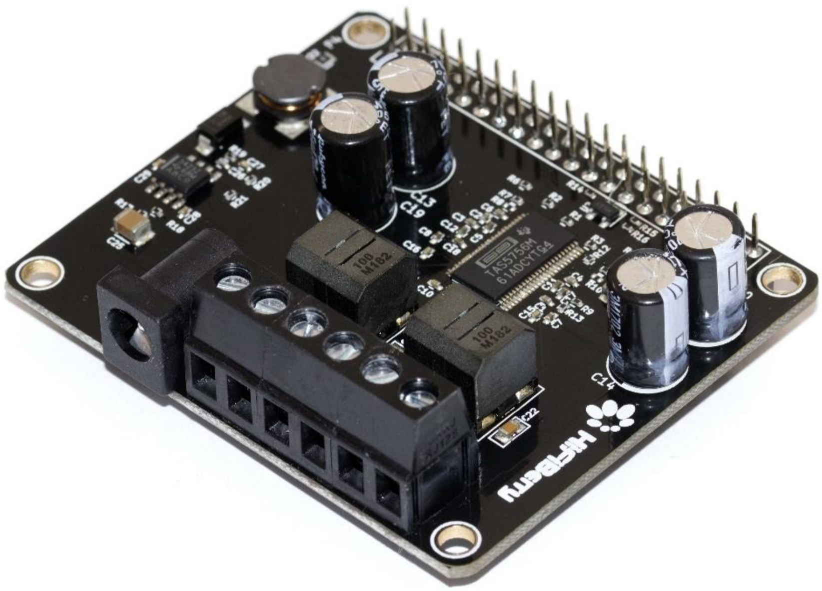

Figure 4: HiFiBerry Amp2 [1]

Figure 5: Audio Exciter [2]

5. Servos and Servo Controller

A total of six servos were used in the system (unless you count the handful that burnt out at the exhibit and during testing). A horizontal servo for the person-tracking is installed below each pumpkin and is controlled directly by that pumpkin's respective Raspberry Pi. The three vertical servos used for mouth movement are directly controlled by a Mini Maestro 12-channel servo controller. The connection between the Maestro and Pi uses a UART interface, with an RX pin and TX pin.

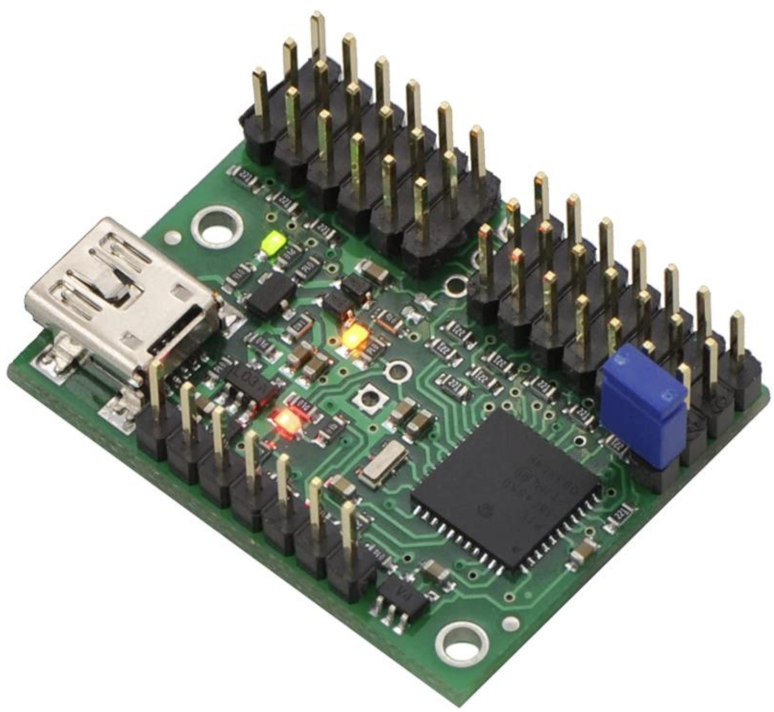

Figure 6: Mini Maestro [3]

A voltage level shifter is also required since the Maestro takes 5V signal input and the Raspberry Pis GPIO pins can only produce 3.3V. A level shifter/converter is a device that essentially bi-directionally converts from one voltage to another. For this purpose, a 4-channel BSS138 was used.

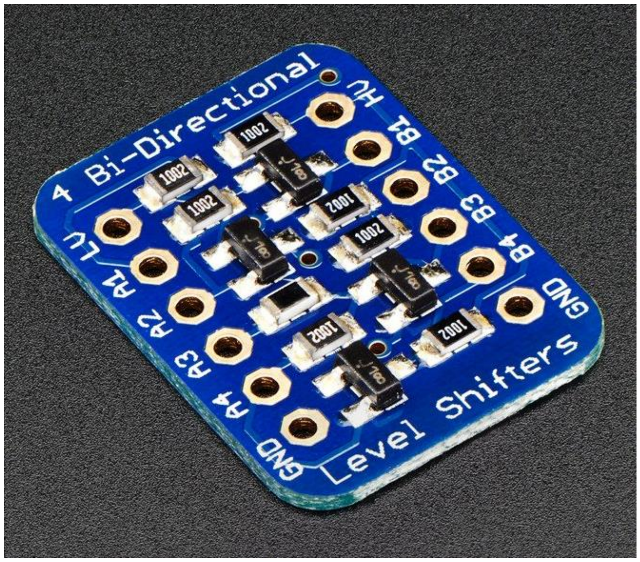

Figure 7: Bi-directional Level Shifter [4]

For the servos themselves, six MG996R servo motors were chosen. These servos are allegedly considered “high torque” on the product description page. Based on how many burnt out, though, it would seem that may not actually be the case. These servos take 4.8V in, and as such can be driven by the Maestro controller (which outputs 5V). The servos have a running current draw of 500mAh, a stall current of 2.5A (at 6V), and a range of 120 degrees.

Three LEDs are also connected to the Maestro, since there are nine out of twelve free channels to use after the servos are plugged in. The LEDs are programmed to light up at specific times during the programmed routine. Unlike the servos, the LEDs are given a constant high by the signal pin. The servos use PWM on the signal line to have their position set. The Maestro natively supports PWM, however the 3 servos attached to the Pis required the use of an external GPIO library that supports PWM. Said library did produce some jitter issues but did not affect the movement significantly.

6. Raspberry Pi

As shown in the block diagram, four Raspberry Pis are used in the system. All four are Raspberry Pi 3 Model A+ units, which feature 2.4/5GHz WiFi connectivity, 512MB of RAM, Bluetooth 4.2 support, and a quad-core CPU. A 40-pin GPIO header is also present, along with HDMI, USB 2.0, Micro-USB, and 3.5mm audio ports.

Figure 8: Raspberry Pi 3 Model A+ [5]

The system would have been able to use a single more powerful Pi for all of the required functions, but the project guidelines necessitate multiple Pis communicating wirelessly.

7. Power Supply and Power Distribution

While the power supply used at the Pumpkin Trail was composed of both a large car battery and many combined USB battery packs, the project in its final form is powered completely by the 12V 100Ah battery. Additionally, a fuse box was implemented to make switching fuses cleaner and easier.

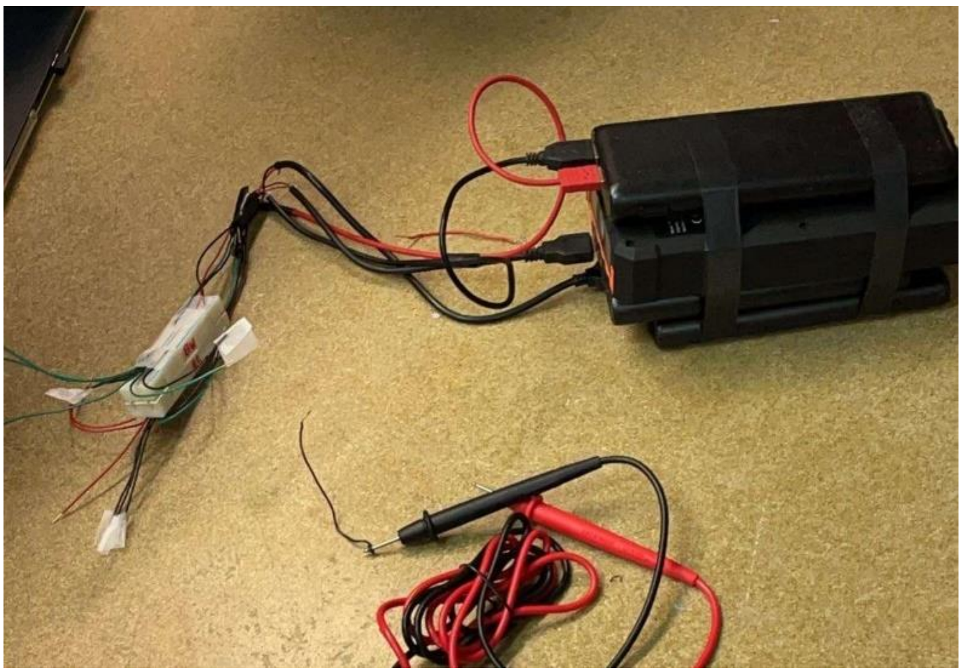

Figure 9: Previous Battery Pack Power Solution [10]

Four different fuses are used in the system. The 10A fuse is connected in series with the rest of the system so as to protect the entire system from overdraw. A 5A fuse limits the current draw from the from all six servos. Another 5A fuse limits the current draw from the three non-audio Pis. Lastly, the 3A fuse limits the current draw audio Pi and exciters.

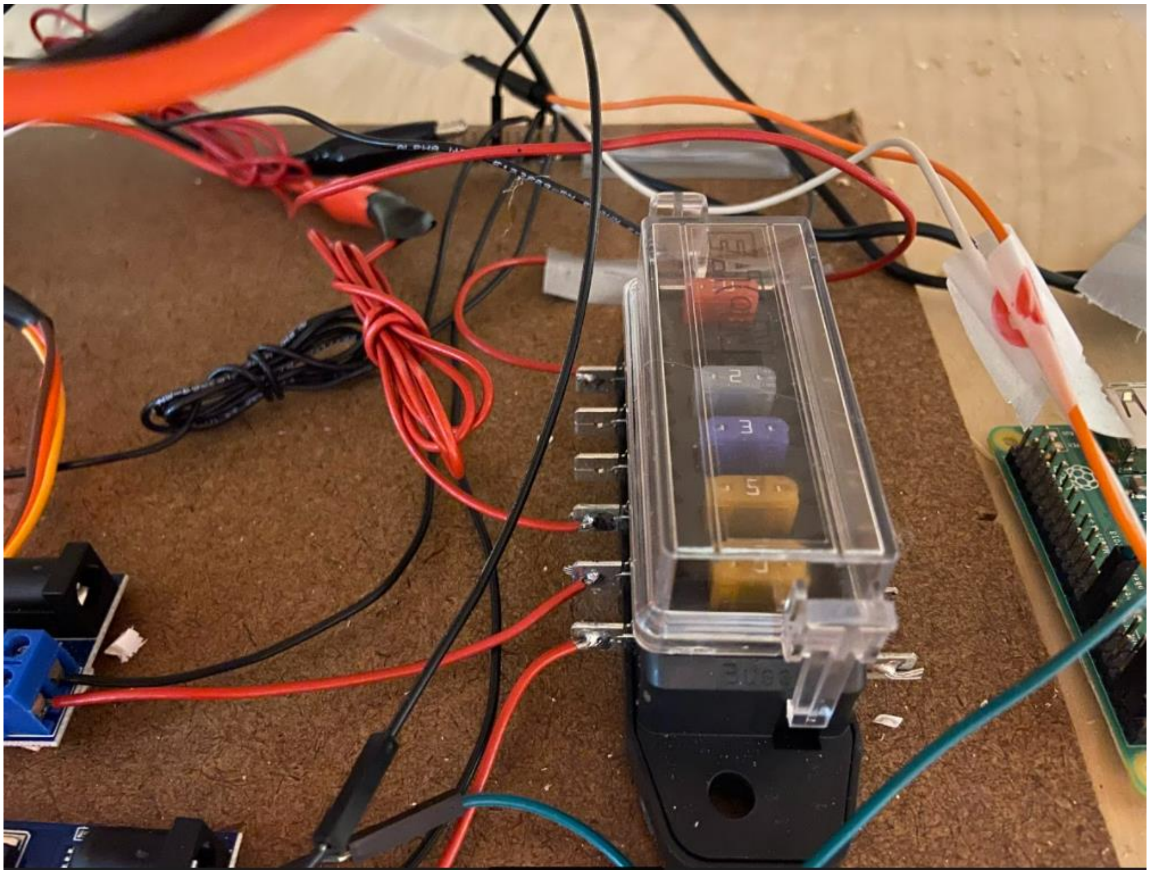

Figure 10: Fuse Box During Testing [12]

Since the operating voltage of many pieces within the project is 5V, two buck converters were used (one coming from each 5A fuse). One buck converter regulates the voltage for the six servos, while the other buck converter regulates the voltage to the three non-audio Pis as well as the Maestro. The UCTRONICS 5A buck converter has an input range from 9V-36V that is then stepped down to 5V. It also has a USB port, though only the terminals were used. Buck converters were said to be more efficient than other solutions that had been thought of, and the pieces do indeed perform well and run relatively cool.

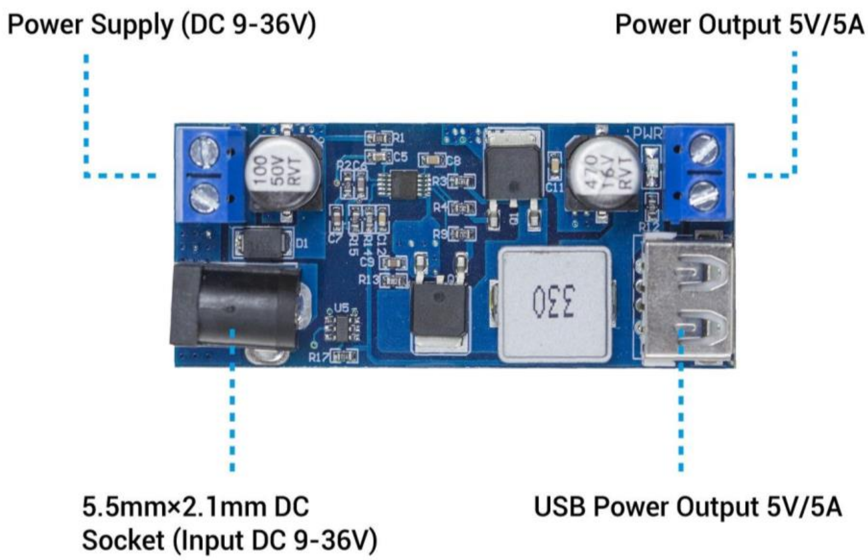

Figure 11: Buck Converter Diagram [13]

Figure 12: Large Battery Used for Audio [8]

8. IR and Thermal Sensor Hardware

Two kinds of sensors were originally used in the system: a thermal camera and two movement sensors. The added camera will be discussed shortly. The two HC-SR501 PIR motion sensors are mounted roughly in front of each outer pumpkin and are used to detect when people are nearby. The IR sensors have an input voltage of 4.5V-20V, a FOV of around 100 degrees, and an effective range of up to 7 meters [6]. The IR sensors trigger the en masse routine, as discussed later in the software portion. As seen in Figure 13, each motion sensor has a sensitivity potentiometer which allows the trigger sensitivity to be altered on the fly.

Figure 13: Motion Sensors [6]

The Adafruit AMG8833 IR thermal sensor is installed in the middle of housing facing forward (right next to the other camera as seen in Figure 2). This specific sensor outputs thermal information in an 8x8 array over an I2C interface. The sensor has a 60-degree field of view and can detect humans up to 23 feet away, which worked perfectly for the location that TTU Robotics was designated at the Pumpkin Trail.

While there was some heat pollution due to the venue being outside in the sun, the actual effect on the tracking was almost negligible. Night quickly arrived each day, and as such made any potential heat tracking issues a non-issue for both groups.

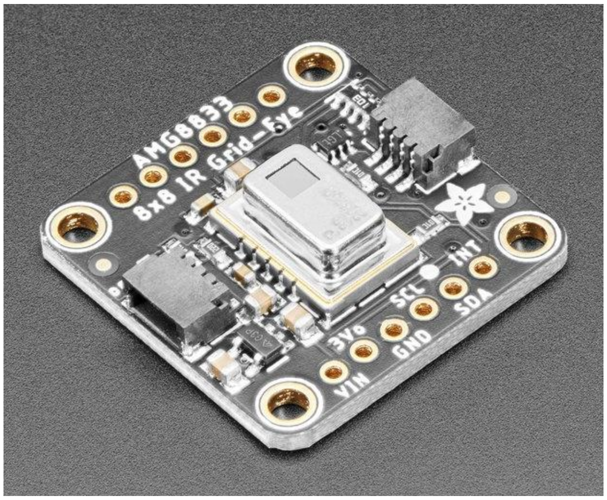

Figure 14: Adafruit Thermal Camera [7]

9. IR and Thermal Sensor Code

The code used to interface with the motion sensors is very straightforward. When the sensor gets a trigger, it sends a high to the Raspberry Pi it is attached to. The Pi simply reads the state of the GPIO pin that the sensor is connected to and interprets it as a Boolean variable. If that variable is high when another check is done, a specific variable is updated. When that variable reaches a value of 1, the short individual routine is played. When a value of 10 is reached, then the en masse routine will be triggered and the variable will be reset. Both IR sensor triggers contribute to the variable’s increase.

The thermal sensing code is slightly more complex. As mentioned before, the sensor and a Pi communicate using I2C, and an 8x8 array of temperature information is given. Originally, the code scanned the output array to find the highest temperature reading and set the servo position for the middle Pi accordingly.

```
['26.3', '26.3', '25.8', '26.5', '26.5', '27.0', '26.5', '26.0']
['26.3', '26.3', '26.3', '26.7', '26.5', '26.7', '26.5', '27.0']
['26.0', '26.0', '26.5', '26.3', '26.7', '27.0', '27.5', '26.7']
['26.5', '26.5', '26.3', '26.7', '26.3', '26.5', '27.0', '27.0']
['27.3', '26.7', '26.5', '26.5', '26.7', '26.5', '26.3', '27.0']
['27.8', '26.0', '26.5', '26.3', '26.3', '27.0', '26.5', '26.5']
['26.7', '26.5', '26.5', '26.5', '26.7', '26.5', '26.0', '26.3']
['26.3', '26.3', '26.0', '26.5', '25.8', '25.8', '26.3', '26.5']
```

Figure 15: Thermal Array Example [11]

Due to servo jitter issues, the code was later amended. An algorithm was designed that would find the 3 hottest pixels in the array, take the average of the surrounding pixels for each, and then compare those values to use for the servo positioning. This did indeed reduce jitter, as well as make tracking humans more accurate due to the algorithm now favoring larger bodies of heat.

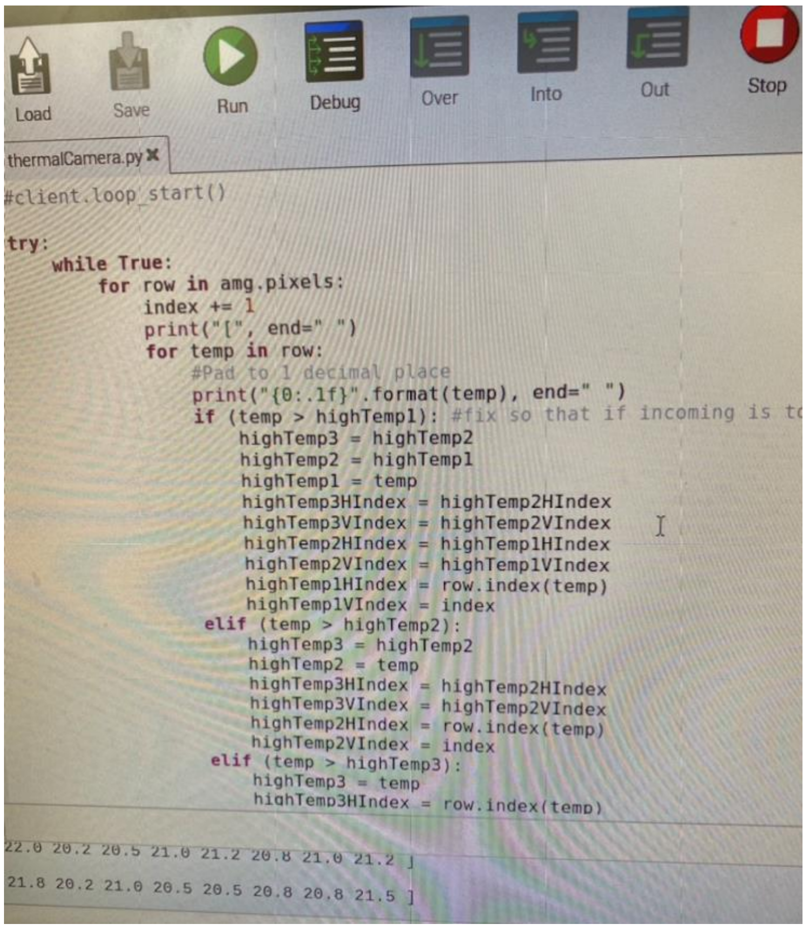

Figure 16: Updated Thermal Code Snippet [11]

10. Camera and OpenCV

As was required by the holiday twist, a visible light camera was integrated into the system so as to be able to track when too much heat pollution is present. For this, the ELP-USB100W07M-MHV100 was chosen. As is probably evident from the name, this camera seems to only be available outside of the US. Regardless, it has a 720p sensor and uses a USB 2.0 interface, and as such could be plugged into one of the Pis USB ports.

Figure 17: USB Camera [14]

Many options were present when determining how best to utilize the camera. Face tracking ended up being essentially the only viable option. When using thermal tracking, there is inherently something different about the human target you want to track; it is hot. The camera cannot simply track motion as there are many issues and false positives that come with that.

The specific method of face tracking used was an algorithm known as Haar cascades. The Pi takes an image from the camera, compares it to a trained classifier model (which is stored on the Pi in an XML file), and determines the position of the face in the frame. The Pi both draws a bounding box around the face and sends out a horizontal positional value. This positional value is the same format as the thermal camera, and as such can be easily integrated into the main system.

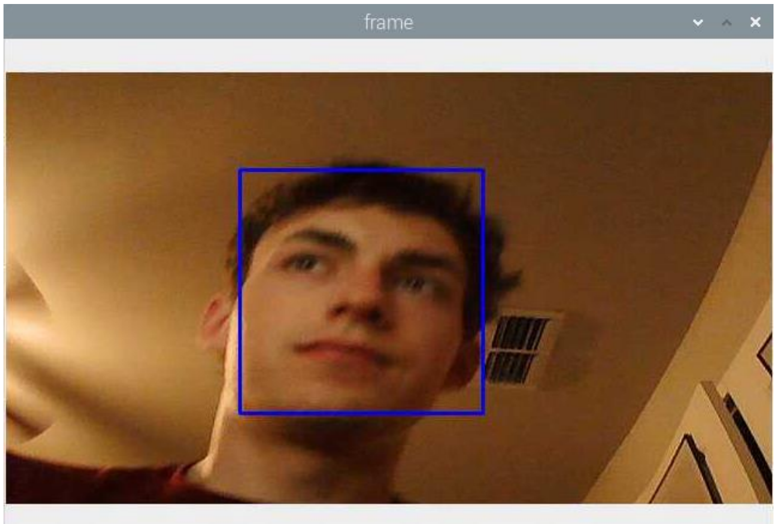

Figure 18: Face Detection Demo

11. Wireless Pi Broker System

MQTT (or Message Queuing Telemetry Transport) is a communications protocol that this system has all but used for the Pi-to-Pi communication. Specifically, Paho Python was used as the backbone library for being able to publish and receive messages using said MQTT protocol. A standalone cellular WiFi hotspot provided by Tori Marnell was used as the wireless network to allow the Pis to communicate in a remote location.

Regarding the code associated with the broker system, each Pi had to have the Paho library installed. The Pi designated as the "broker" had to have additional functionality added.

The way the broker system works is a client must subscribe to topic. Along topics, messages can be published. Any client subscribed to that topic can receive the published message.

```
def publish(client, msg):
    print("in publish")
    result = client.publish(topic, msg)
    status = result[0]
    if status == 0:
        print(f"sent `{msg}` to topic `{topic}`")
    else:
        print(f"failed to send message to topic {topic}")
    time.sleep(5)
```

Figure 19: Example Publish Code [11]

An example of structural pseudo code that interprets messages from the sender side is something like "if variable X is equal to HIGH, call publish function and send the message 'LEFT' to the LeftSensor topic." On the receiver side, the code would be something like "Constantly store the LeftSensor topic message. If the received message ever equals 'LEFT', check state of RightSensor. If both messages are received, activate group routine."

A small note about MQTT, at least from all of the information gained in this project, is that it is not ideal for this type of use case. MQTT is generally regarded as a high latency protocol, which means that when trying to send information to be processed in real time (or low latency) the system may “lag”. This was apparent at times, as the horizontal movement would sometimes get out of sync and jitter. The final product still functioned well, however.

12. Pumpkin Routines and Movement

During the sound and movement routines, vertical mouth movement as well as flashing LED lights take place as mentioned before. The routines were programmed using the Maestro’s proprietary coding low-level coding language and stored on the Maestro as functions called routines.

```
#5 golden rings
16
begin
dup
while
250 4000 7000 frame_0
250 7000 7000 frame_0
1 minus
repeat

100 4000 4000 4000 lightsoff

#4 calling birds
3
begin
```

Figure 20: Maestro Group Routine Code Example [12]

Using the Maestro library on the Pi, the specific routines can be indexed and played using a single line of code. This allowed easy synchronization of the audio and Maestro routines. The original individual and group routines respectively were ghost sounds/screams, and a near minute long singing of the first part of the song “Monster Mash” by Bobby Picket. The holiday themed individual and group routines were a short clip of the song “Let it Snow,” and a slightly longer (yet truncated) version of “The 12 Days of Christmas.”

13. Pumpkin Trail and Workarounds

This project quickly became stressful as it dawned on the group that the truncated due date was approaching. As mentioned before, certain features that would have ideally been working simply were not coming together in time, regardless of the amount of effort that was being put in. The decision was made to put together a working project, even if it didn’t technically meet all of the required specifications.

Seen below in Figure 21 is the block diagram of the system that was functional at the Pumpkin Trail event.

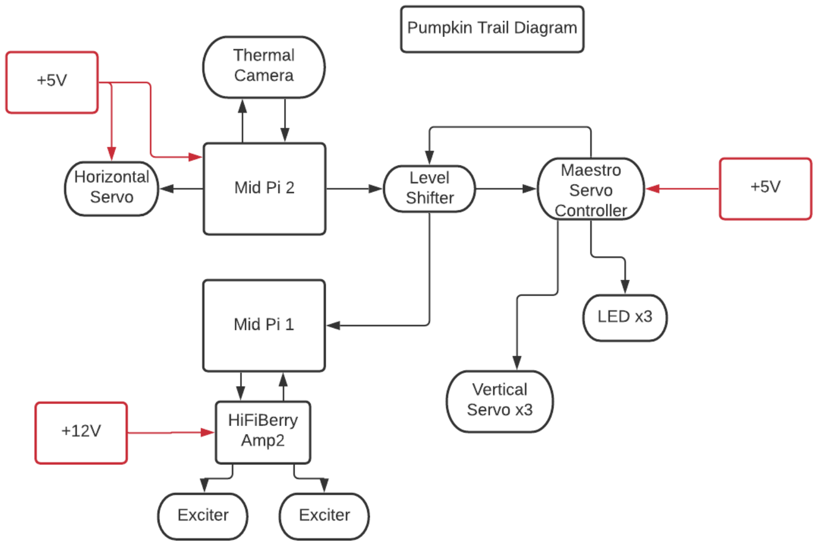

Figure 21: Pumpkin Trail Block Diagram

The first main issue was a large one: the broker system was not going to be able to realistically work. The broker could sometimes send messages, and clients could occasionally receive messages, but at a worryingly low rate if at all.

The IR sensor functionality was tested and working correctly, but without a working communication protocol there is no way to receive the IR information from the outer Pis. To try and at least have this portion functioning, Pi-to-Pi communication over GPIO pins was attempted. For whatever reason, the Pi's hated both sending and receiving HIGHs or LOWs from each other. This meant that even local interaction between Pis was apparently impossible.

The idea to use the Maestro to activate a single pin was produced late Wednesday night and ended up being what allowed the system to synchronize the movement and audio. During the main subroutine, one of the extra channels on the Maestro was set to be high for the duration of the movement. This channel was then run back through the level shifter (so as to convert the Maestro 5V to the Pi 3.3V), which connected to a GPIO pin on the audio Pi. The audio Pi was coded to activate the 45 second “Monster Mash” clip whenever it received a high on that pin.

The project demonstrated at the Pumpkin Trail works as follows: The Pis are powered with the battery pack power supply. The WiFi hotspot is turned on and the Pis are remotely connected to via VNC viewer, which is installed on the Pis and on a laptop. The programs are activated on each Pi and monitored via the laptop. The thermal sensor is always on and sending information to the middle horizontal servo, which allows the Venom pumpkin to turn its head to look at passersbys. After a certain amount of time, the group subroutine is activated. The middle pumpkin returns its head to facing forward, and the vertical movement for each pumpkin is functional during the singing routine (other than on the last day, which saw the middle pumpkin’s vertical movement become a casualty.)

Handsy children and transportation issues were close to being the demise of the project. A few hours in the lab in between days restored the system to essentially its original functionality, with an LED or two not working and occasional vertical servo issues.

14. Safety and Ethics

Safety hazards that have been encountered working on this project are hazards such as being around relatively high current and voltage, being around wood cutting machinery, and using high-heat tools. Ways to mitigate these hazards (respectively) are to always double check your circuit design and equipment, wear proper protection such as eyewear and long pants, and always be aware of where you place your tools (as they could damage people, equipment, or your workspace).

It is hard to see how any part of this project has any potential ethical controversy, however an argument could be made for the worrisome nature of face tracking. The world is becoming increasingly concerned with how easy and prevalent person tracking is by both governments and other groups. Luckily this project can barely process the face data fast enough to spit out a position value, but one could see how on a larger scale the malicious possibilities would be abundant.

15. Dear Future Engineers,

As we were asked to write a section giving advice to future groups working on the project, I do have some tidbits of information that I think would be useful. Firstly, I think the group sizes should be smaller. I suppose this is advice to the professor, though I think that having less people in the group would have counterintuitively made the project easier. There was a non-negligible amount of group drama, and it is hard to say whether it was due more to group size or innate individual qualities.

Secondly, make a pact with your group to communicate openly about things. Multiple group members did not seem inclined to want to work with each other or report on individual progress and had that not been an issue this project would have gone a lot smoother.

Thirdly, put more stress on the power supply and chassis design than you think there should be. I feel as if those were two of the main components that would have tied things together earlier than we did.

Lastly, divvy out the work as best as you can. This sort of goes hand in hand with my first and second points, but I felt that work assignment was a little uneven this semester. This also started causing group stress, as some members viewed others as not being beneficial to the project.

16. Conclusion

In conclusion, the 3D animatronic pumpkin system described in this paper has demonstrated its ability to track individuals, move pumpkins horizontally and vertically, play sounds and music based on current routine, and more. It "check marks" the large majority of the project requirements and has certain qualities (such as the vertical mouth movement) that were not required to implement.

While the original project did not complete every requirement described in the project guidelines, the group was able to produce something that attracted attention and gave the TTU Robotics label a good look at the Pumpkin Trail.

On demo day, ever part of the project was running and functional. It was nice to see the project that had been worked on for so long work completely as intended. I believe that while this project was not as technically jarring as the one in Project Lab 1, it still taught me valuable skills regarding Raspberry Pis, OpenCV, wireless communication, servos, wood-shopping, group politics, and mental fortitude.

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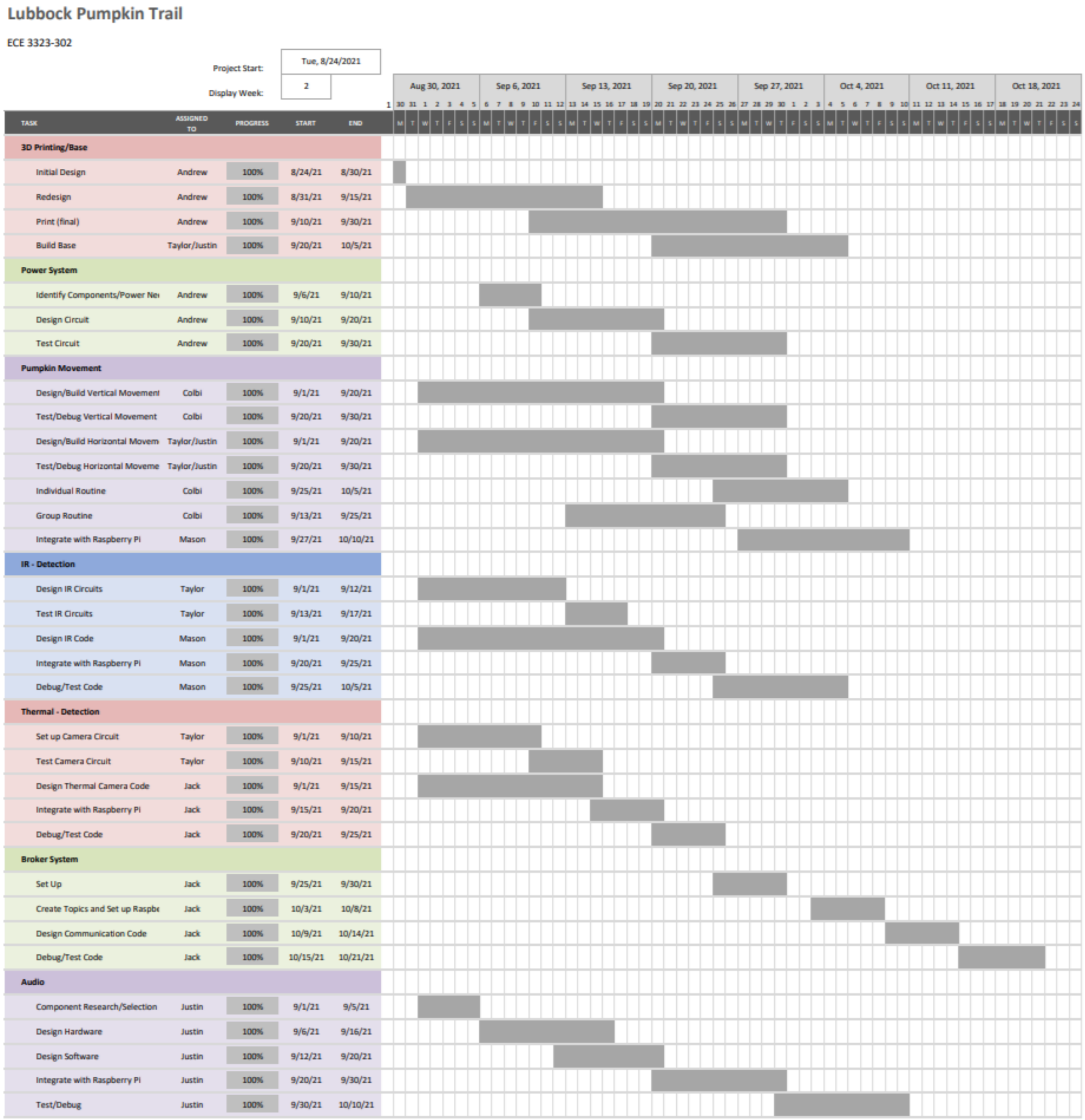
Appendix A

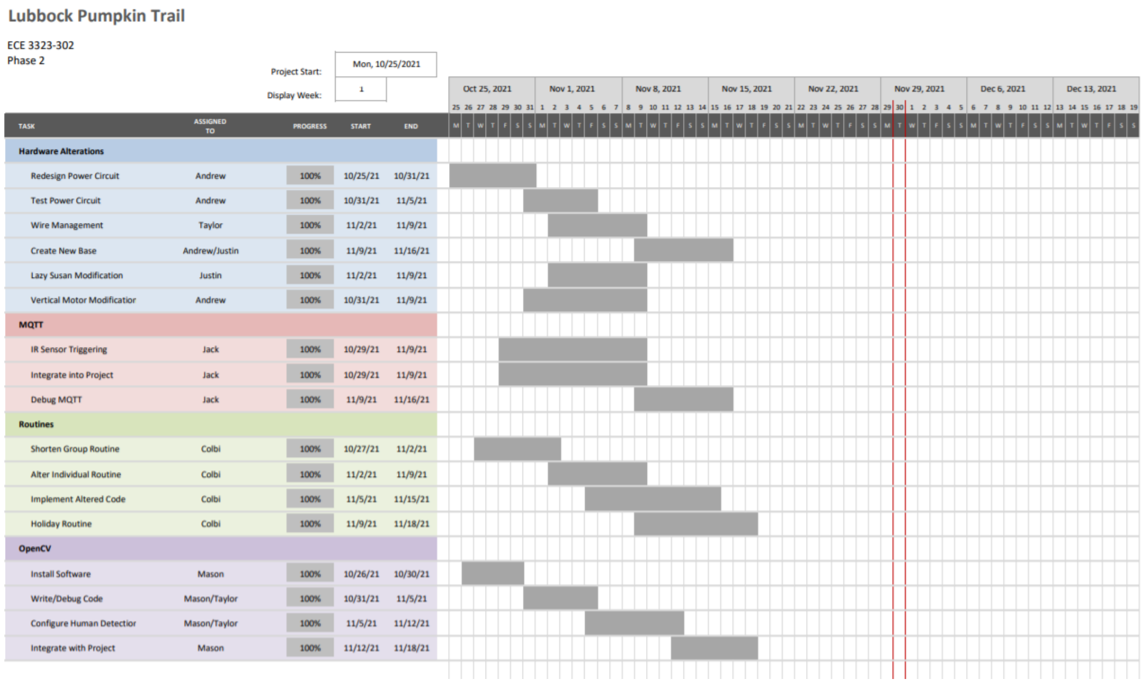
Gantt Chart (Pre-Pumpkin Trail)



A Gantt chart is used to visually represent time spent on different aspects of a project. Before completion, it is used to gauge how much time should be put into various tasks. After completion, it is used to show that distribution of time in a concise and informative way.

Appendix B

Gantt Chart (Post-Pumpkin Trail)



For both our pre- and post- Pumpkin Trail Gantt charts, we kept up relatively well for the majority of the semester. Obviously since we did not sate all of the project requirements by the time of the pumpkin trail, it cannot be said that we were on track all of the time. The work load post-trail was more manageable and as such was much easier to stay on track with. Regardless, the Gannt chart helped us keep focus and was a good visual indicator of work accomplished and (more importantly) work that needed to be done.

Appendix C

Budget (up to week 12)

Week	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
Andrew	8	4	6	7	5	3	6	7	11	10	12	10	89
Justin	5	4	3	7	9	5	5	7	25	7	13	6	96
Mason	5	4	4	7	9	8	5	6	41	7	7	3	106
Jack	5	6	10	9	8	6	8	13	38	6	6	2	117
Colbi	5	6	2	10	8	7	8	10	28	8	7	6	105
Taylor	4	4	4	7	8	4	6	9	20	6	6	2	80
Total Hours	32	28	29	47	47	33	38	52	159	44	51	29	589
Labor Cost	$576	$504	$522	$846	$846	$594	$684	$936	$2862	$792	$918	$522	$10602
Overhead	$576	$504	$522	$846	$846	$594	$684	$936	$2862	$792	$918	$522	$10602
Total Cost	$1152	$1008	$1044	$1692	$1692	$1188	$1368	$1872	$5724	$1584	$1836	$1044	$21204

Component	Cost ($)	Quantity	Website	Purchase Date	Total Price ($)
Servo Motors (6 Pack)	$25.99	3	Amazon	9/2/2021	$165.00
3D Printing Filament	$20.00	3	Amazon	9/2/21	$60.00
12 Channel Servo Controller	$29.95	1	Pololu	9/6/21	$29.95
Adafruit Thermal Camera	$44.95	1	Adafruit	9/6/21	$44.95
Rasberry Pi	$30	4	Mouser	9/1/21	$120.00
IR Sensors (4 Pack)	$9.99	1	Amazon	9/6/21	$9.99
Dayton Audio Exciters	$12.99	2	Mouser	9/6/21	$25.98
HIFIBERRY AMP2	$59.60	1	Hifiberry	9/6/21	$59.60
LD1085 Voltage Regulator	$4.00	5	Mouser	9/18/21	$20.00
Mini USB Cable	$20.00	1	Walmart	9/20/21	$20.00
1 1/4" PVC	$1.31	3	Home Depot	9/27/21	$3.93
Plastic Tote	$11.98	1	Home Depot	9/27/21	$11.98
Lazy Susan Turntable	$5.03	3	Home Depot	9/27/21	$15.09
Ratcheting PVC Cutter	$13.98	1	Home Depot	9/27/21	$13.98
Table Cloth	$4.00	1	Walmart	9/27/21	$4.00
Foam Panel	$5.98	3	Home Depot	9/27/21	$17.94
Black Spray Paint	$1.32	2	Walmart	10/10/21	$2.64
TACKLIFE T8 Pro Car Jump St	$69.99	1	Tack Life Tools	10/20/21	$69.99
Portable Charger Power Bank	$22.05	1	Amazon	10/20/21	$22.05
Fuse Box	$10.00	1	Auto Shop	11/1/21	$10.00
USB Camera	$53.67	1	Evelta	11/1/21	$53.67
Wood	$16.00	1	-	11/10/21	$16.00
				Total	$796.74

The budget charts are theoretical amounts of money that would be spent to allow us to complete our project had we actually been working for an employer. The total came out to around $22,000 dollars, which is quite large. We recorded equipment used, time spent, and materials used.

Regarding our budget used from the stock room, almost $456 was used out of our allotted $500. Since a handful of purchases came from our own pockets (either due to time crunches or laziness), we would have definitely gone over budget had we only used the stockroom funds.