BB-8 Robot

By: The BB-8 Project

IDD Senior Design: Final Design Review

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1. Introduction

The BB-8 Project is a continuation of an independent research project that was undertaken in the summer of 2019. The basis of this project is to create a functional BB-8 robot that mimics the motion of the BB-8 in the Star Wars franchise. This project will continue in future senior design semesters to update the functionality of the system and continue to incorporate more advanced algorithms and mechanisms to create a life-like droid. The end goal of this project is for the BB-8 to be used as a marketing tool for the prospective student office to display the achievements of students in their undergraduate program.

2. Problem Description

As of the beginning of the Spring 2022 semester, the BB-8 was marked as "mechanically functional." This meant that the BB-8 could roll forward, without the Head, and could be controlled by a human operator. The sphere, Head, Drivetrain, and Gimbal were created and designed using PLA, 3D printing plastic. This semester, our goal is to finish the functionality of the BB-8 to incorporate sensor data and control algorithms to make small, autonomous adjustments to the movement of the BB-8 to provide a smooth control experience. We will also redesign the structure of the BB-8 to be manufactured in harder plastic and aluminum to add durability to the system.

3. Overall Solution

The BB-8 Project contains five topic areas of work, each with their own subsystems. These include Communications, Head, Gimbal, Drivetrain, and Shell.

3.1. Electrical Overview

The core electrical system contains multiple motors, servos, actuators, sensors, and processors to provide the functionality to the BB-8 across the Gimbal, Drivetrain, and Head.

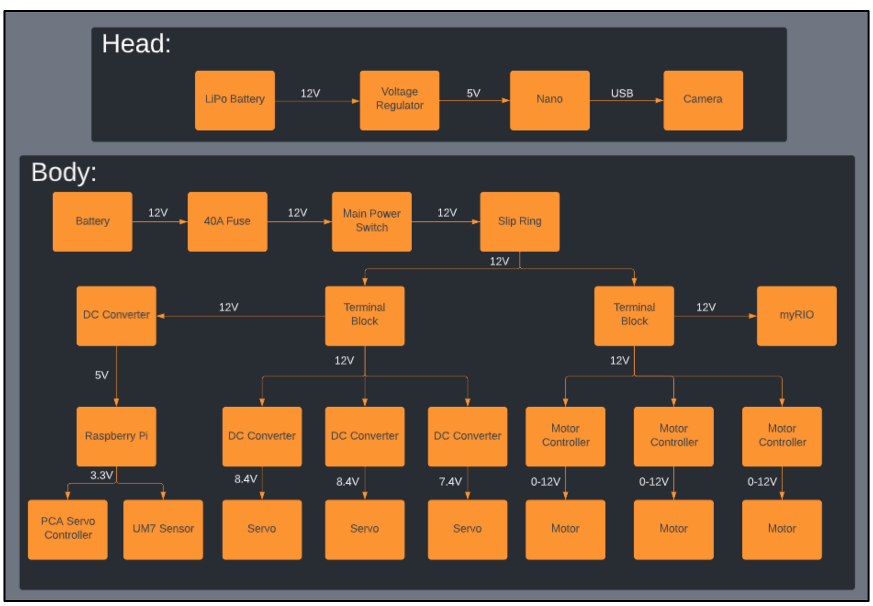


Figure 1: Electrical Diagram

The BB-8 incorporates two independent electrical systems for the Head, and the main body, depicted in Figure 1.

3.1.1.Power System

As shown in Figure 1, the Head contains a simple electrical system using a 12V LiPo battery connected to a voltage stepper. A 5V power line is then connected to the NVIDIA Jetson Nano with a USB camera.

The main body is significantly more complicated. This system uses 30 individual Li-Ion battery cells connected 10 in parallel and 3 packs in series, making 3S10P battery. This outputs a nominal voltage of 11.1V, typically seen as closer to 12V, and is rated for 30000mAH. These battery packs were created by spot-welding nickel plated stripping to the poles of each of the batteries.

After reviewing the power statistics for each device on this system, the average current consumption was estimated at 27A and the maximum current consumption at 43A. This system is currently rated for 45A, and all wiring and components have been rated at this current level. All connections were made using 45A Anderson Power pole connectors.

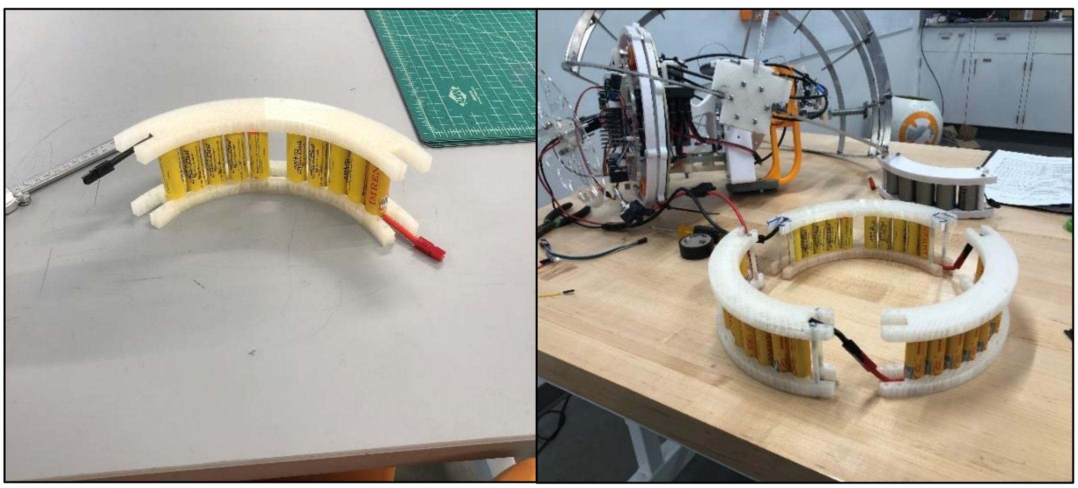


Figure 2: (Left) Individual Battery Pack and (Right) Battery Ring

3.2. Communications

Because our system incorporates three different processors, a communications architecture has been created to effectively transmit data between the different processes in different parts of the system.

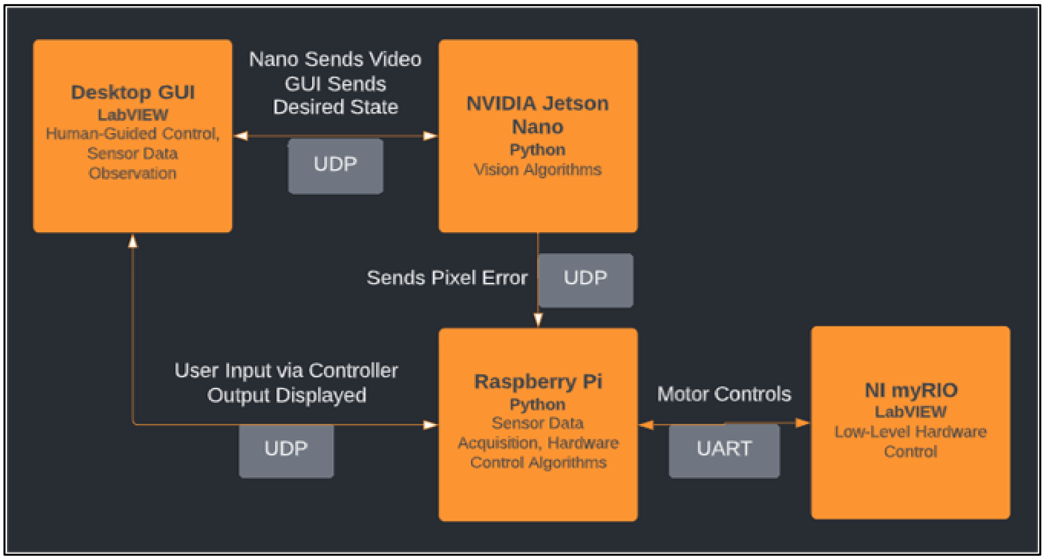


Figure 3: Communications Architecture

As seen in Figure 3, the communication protocol between the Head and the Core will be implemented using a UDP socket server. This is not a connection-based protocol, so speed is emphasized in this structure. This also means data can be sent from other devices to mimic the head for testing purposes.

The communication protocol between the NI MyRIO and the Raspberry Pi 4 will also be a UDP connection. This allows us to control the motors from both the driver station and the Raspberry Pi 4 depending on the needs of the user.

A wireless connection to the Raspberry Pi 4 from the desktop computer will also be implemented using a UDP socket communication protocol.

3.3. Head

The Head of BB-8 is used for vision capabilities. This includes the Jetson Nano processor, a LiPo battery pack, and a camera on the inside. The casing for the Head connects to the body via magnets.

3.3.1.Structure and Materials

The major design constraint for the Head was weight. This entire system needed to weigh less than 5 pounds to maintain a high degree of dexterous movement. The unburdened system moves radially in any direction at about 30 degrees per second.

This design of the system is a solid foundation paired with a highly customizable electronic platform. The foundation will serve as a rigid skeleton to protect the inner components.

The Head is connected to the body through a system of magnets. The Gimbal system is what allows the Head to move without motors. A platform was created out of PLA plastic, acrylic, and omni wheels. This serves two functions: first, to maintain the integrity of the Head's electrical components, and second to reduce the amount of friction between the Head and the body. The platform was printed with 80% infill, and the surface was reinforced with XTC-3D.

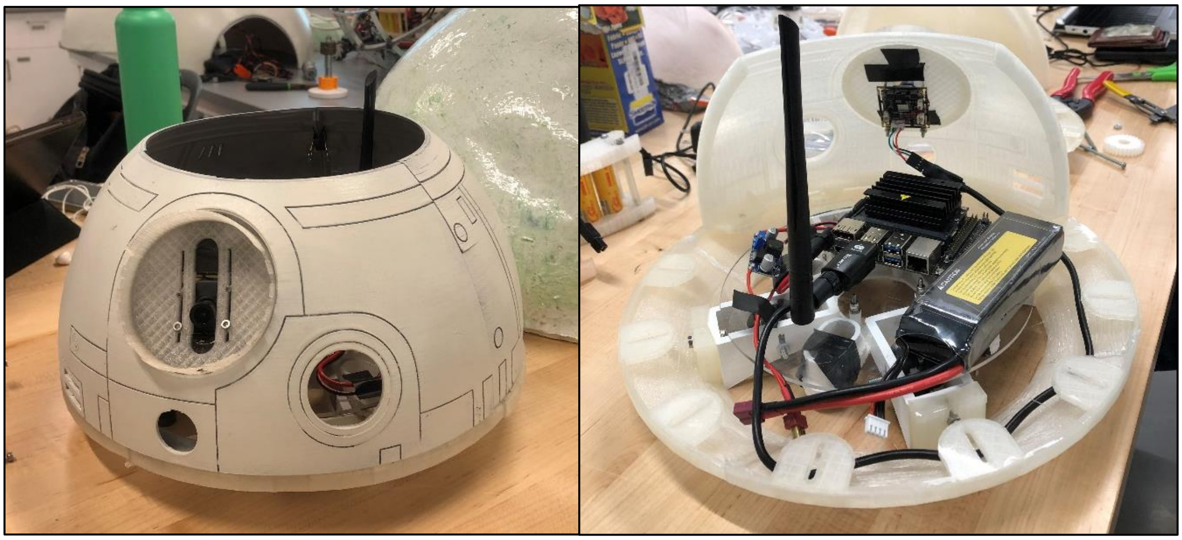


Figure 4: Physical Head

3.3.2. Software

The software in the Head captures image data, processes the data, and sends the pixel error to the Raspberry Pi to control the Gimbal mechanism. This software is written in Python and uses common libraries such as OpenCV and NumPy to produce the necessary functionality to detect and track different objects based on the task at hand. The diagram shown below is the overall software flowchart for the Head.

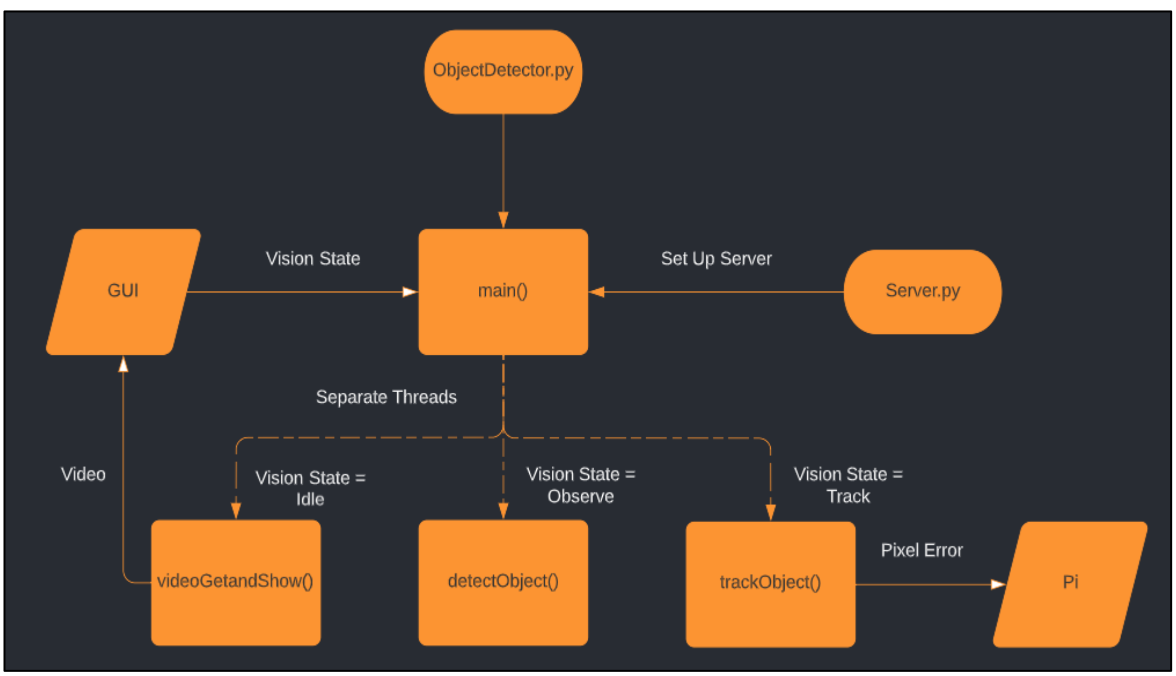


Figure 5: Software Diagram for the Head

The BB-8 has three different modes: Idle mode, Observation mode, and Tracking mode. Idle mode is the initial state of BB-8 that only shows a video feed. Observation mode perceives and identifies various objects within the feed. Idle and Observation mode are used with human guided control. Tracking mode tracks the centermost person and communicates to the body to keep the person at the center of the video feed. This mode is the basic autonomous motion that was implemented for this project.

Figure 6: (Left) Idle Mode, (Center) Observation Mode, (Right) Tracking Mode

3.4. Gimbal

The Gimbal mechanism is used to control the Head's movement within given bounds to avoid the Head from sliding off the BB-8 robot. A magnet is attached to the bottom of the Head platform that provides the force to keep the Head on top of the robot.

3.4.1.Structure and Materials

The cables of the Gimbal can realistically waste anywhere from 0 to 90% of transmitted forces depending upon the frictional constant. The minimum weight was considered at the most extreme angle so the Gimbal should be able to move considerably more mass. High torque 45kg-cm servos were installed to overcome the high forces. These Servos are attached to the core using servo splines. The team also attached electrical component plates to the splines to allow for a better use of electrical connections.

PLA plastic was used in this system due to its lightweight properties and ease of manufacture. PLA is an ideal material for these relatively low-stress areas. As seen in Figure 7 (Right), the red gears work in the profile created by the reaction wheel.

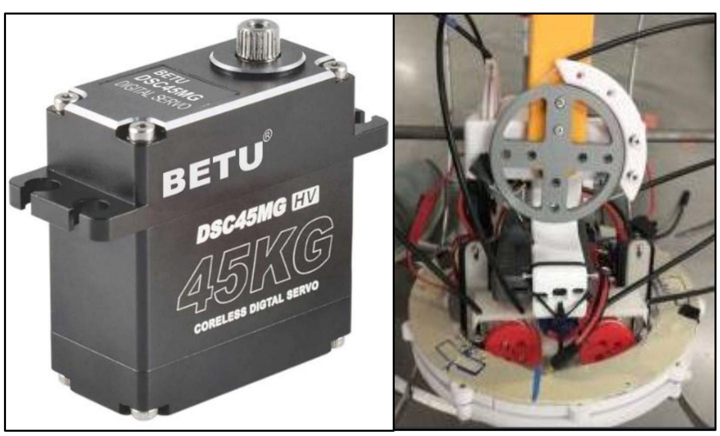


Figure 7: (Left) Servo, (Right) Gimbal Mechanism

3.4.2.Software

The software that controls the Gimbal (and by extension, the Head) movement is shared between the central processor, Raspberry Pi, and the Head processor, Nvidia Jetson Nano. The Head processor holds the technical positions it wishes to move (forward, backward, left, right, rotate). The central processor translates those positions into a standard position on the radial plane that the Head operates within. This small calculation dictates the PWM signal that is received by the servos, which then moves to the corresponding position in a standard PID control loop.

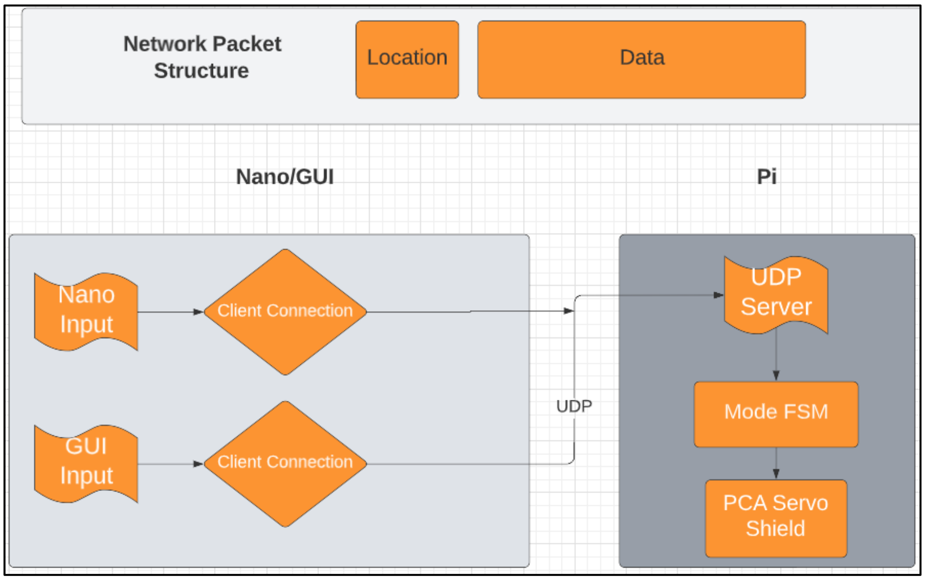


Figure 8: Gimbal Control Block Diagram

The bounds for the Head processor are dictated by the maximum Gimbal movement, which gives the possible positions to range ±2.9 inches forward and backwards, and ±3.5 inches left or right. This results in a total of 4.8 x 7in field where the Head can move about.

3.5. Drivetrain

The Drivetrain is the main mechanism that moves the entire robot. The center shaft is controlled by a single motor, running through a pully system, which allows for a Gimbal mechanism to rest on top of the center console. This creates a movement like a motorcycle tire, where the movement is linear when moving forward and backwards, and radial about an arc when turning left and right.

3.5.1.Structure and Materials

The main change to the Drivetrain system was to change the gear ratio from 1:1 to 5:3. This created a much higher torque at a lower max speed. The lower expected speed is not an issue because the BB-8 should only be able to move at a walking pace, which is about two meters per second. It is also important to consider battery packs. The team kept the same geometry and use the same reaction wheel charging system for the packs. The final weight of the internal system was just around 35lbs.

The Base Plate has been identified as a location of high stress. This was replaced by a quarter inch laser cut acrylic plate, which holds most of the electronics for the system.

A set of acrylic plates have been used to attach electronics to control the motors and servos. A skid plate was laser cut to allow the wires from the slip ring to not contact the electronic components.

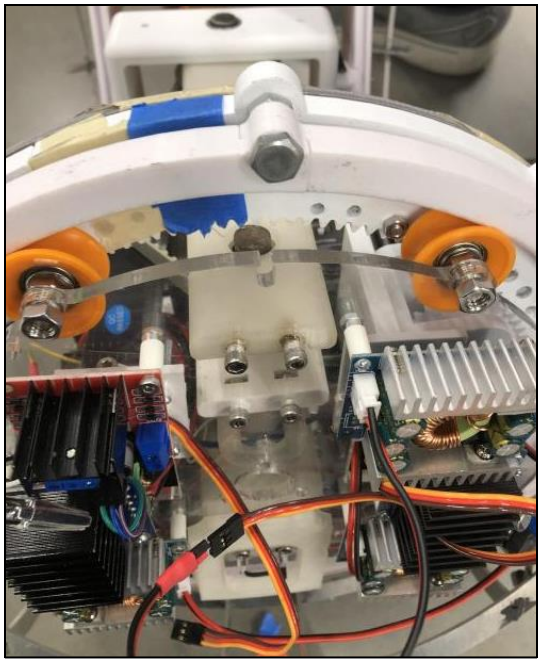


Figure 9: Base Plate

3.5.2.Software

The UM7 Sensor provides most of the feedback for controller operation, while an encoder will be used to assist in limited automatic movement. No localization will be used, so full autonomous motion is unrealistic for the controls at this time. All the drive functions are dictated by the sensor.

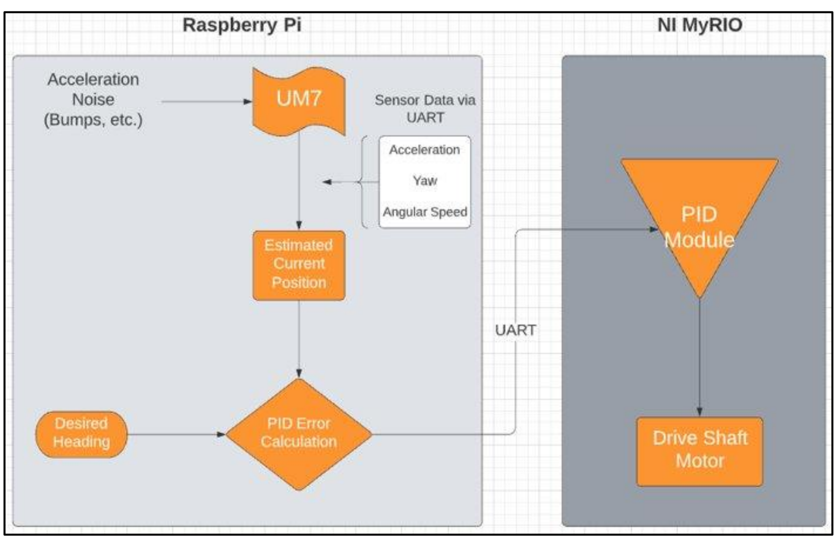


Figure 10: Drivetrain Control Block

From the UM7, yaw will be checked whenever a relatively large increase in angular speed is detected by the gyroscope. The yaw output of the UM7 uses relative magnetic field as well as gravity as vectors to check as a reference. This requires calibration to reduce drift, but by using the cross checking of the gyroscope, drift can be eliminated.

3.6. Shell

The Shell holds the Drivetrain while also acting as the main body that the BB-8 drives on. The Shell is split into two main parts: an interior skeleton and a cosmetic outer shell. The structure of the skeleton and shell is designed to support the full weight of the Head and Drivetrain, while also enduring any impacts that might occur.

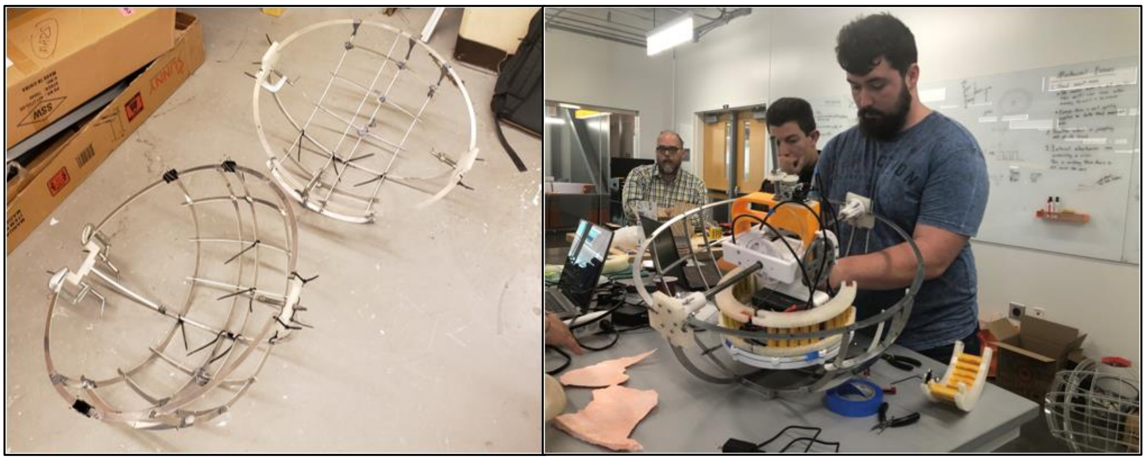


Figure 11: Aluminum Skeleton

The interior skeleton is designed to support the Drivetrain and main drive axis that the BB-8 drives on. This design also allows for both hemispheres to detach from each other to allow ease of access to the Drivetrain and easy assembly. On the drive axis where most of the forces are, ribs are attached to support the drive axis supports and ensure minimal bending. This ensures that the skeleton is the strongest where most of the forces are acting. There is also strong points of contact on the sides of the skeleton where the Drivetrain can securely attach to it. The interior skeleton is manufactured through a combination of 3D printing and water jetting. After the parts are manufactured, the skeleton parts are bonded using JB weld.

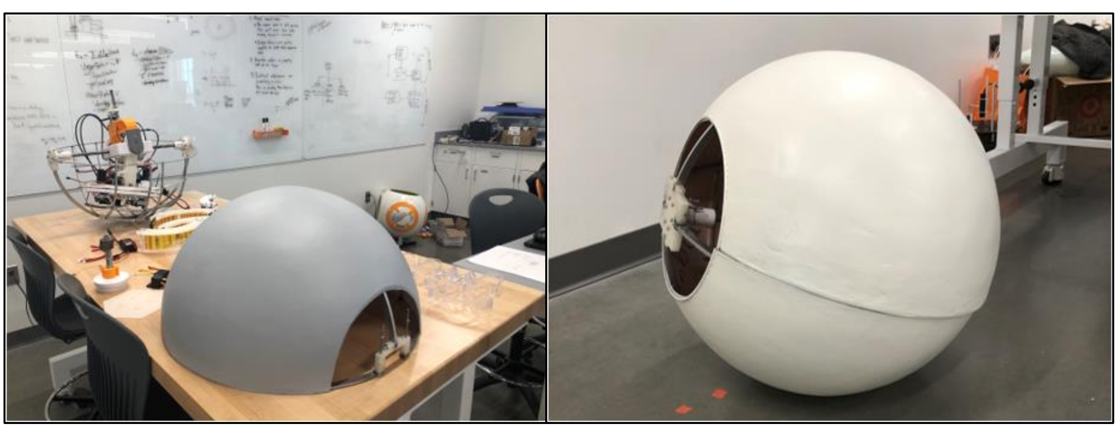


Figure 12: Cosmetic Shell

For the structure of the shell, it is designed mostly for cosmetic purposes while also supporting the spherical structure of BB-8. The shell is fabricated through a brush on casting technique on a MDF mold and 3D printing. The material for the shell is a polyurethane resin, Smooth Cast 65D. The resin is rated to endure the forces from BB-8 and ensure the spherical form without cracking. After they were cast, the panels were sanded, primed, and painted to achieve their finished states.

Figure 13: Cosmetic Shell, Skeleton, and Drivetrain

The last thing we wanted to accomplish for the structure is the separation of the shell by hemispheres, as seen in Figure 13. This allows for easy assembly and maintenance for the BB-8. To accomplish this, the shell is secured to the interior skeleton with Velcro strips at key areas on the skeleton. The drivetrain is then secured to the bottom skeleton hemisphere with magnets and both skeletons are secured together with magnets and screws. With both hemispheres assembled, the round plates will be attached to the side with magnets. The round plates are 3D-printed using PLA plastic due to their complex geometry and low risk of impact.

4. Engineering Principles

Throughout our degree plans, we have learned principles and gained skills that will benefit us in completing this project. The following outlines these principles for both the electrical and the mechanical sides of the project.

4.1. Electrical Principles

This project uses multiple software programming languages to control the hardware, acquire sensor data, and transmit data between processors. Documentation of this code as per industry standard is essential for future semesters to continue to use the code we develop in this project. Designing the code to be modular and import-friendly is also important in the case that it will have to be edited to include new functionality in future semesters.

The BB-8 also includes a well-structured electrical system. Proper circuit analysis for routing electrical pathways and maintaining safety standards will be essential for the project to pass inspection and perform appropriately.

4.2. Mechanical Principles

This project involves the use of multiple mechanical engineering principles. Some of these principles include mechanical design, strength of materials analysis, and machining knowledge.

Static and dynamic calculations as well as simulations were conducted on the parts of BB-8 before fabrication to make sure that the parts could withstand the necessary forces. These analyses are needed to estimate the max forces acting on BB-8 to determine what forces BB-8 can currently handle, and how we will need to improve BB-8. Strength of materials was used to compare different materials that BB-8 parts can be created out of, and the selection of the best materials will be chosen to fit our needs. Machining knowledge will be used to initially create our parts, then allow us to fabricate the parts with the use of additive and subtractive manufacturing techniques.

5. Environmental, Health, Safety, Sustainability, Social, Cultural, Global, Ethical and Professional Considerations and Constraints

Multiple considerations and constraints affected the design of the BB-8. Environmental considerations are one of our projects largest concerns due to the use of plastics and chemical elements. Utilizing proper disposal procedures for each material we use in creating the robot was implemented and any excess material not used in the Shell of BB-8 was properly disposed.

Considerations for the proper usage of Li-Ion and LiPo Batteries were also evaluated. To continue functioning properly, Li-Ion and LiPo batteries cannot reach a voltage less than 3.3V. Voltmeters were used to alert us when the voltage of the batteries become too low to ensure battery health was maintained. In addition to this, Li-Ion and LiPo batteries require proper charging procedures to maintain efficiency and longevity, which was followed according to manufacturer standards. Usage of Li-Ion and LiPo explosion packs and monitoring the charging process to ensure the batteries are taken off after fully charging limited the risk of a fire hazard due to explosion.

The maximum speed and weight of the BB-8 pose a hazard to both the system, its environment, and the human operator. Therefore, the maximum speed of the BB-8 will be limited to roughly 2m/s (4.47 mph), approximately the average walking speed of a person. We have determined that the final weight of BB-8 is 15.2kg (35lbs), which is far less than our set maximum weight limit of 22.7kg (50lbs).

Due to the copyright status placed on the BB-8 design and appearance by Disney Studios, our team researched into the ethical usage of the design. As we are creating BB-8 for educational purposes, and will not receive profit from this project, we fall under the Fair Use clause of copyright law, which states that “Fair use permits a party to use a copyrighted work without the copyright owner’s permission for purposes such as criticism, comment, news reporting, teaching, scholarship, or research” (“What Is Fair Use?”). Currently, our project is not in violation of copyright law.

6. Engineering Codes, Standards, and Guidelines

Autonomous mobile robots (AMRs) are a fairly new field of study in robotics; therefore, there are not many applicable engineering codes and standards at this time. ANSI/RIA R15.08 has been created for industrial AMR standards. While this is a good source to keep in mind in terms of general safety, it does not directly apply to our project as the BB-8 will not be used in an industrial environment.

ISO/IEC/IEEE 42010 is a software documentation standard. While designing the code for BB-8, our team will abide by these standards. In addition to this, we used the IEEE floating point standards when dealing with electronic hardware of BB-8.

7. Knowledge Acquisition

The design team acquired additional knowledge through a variety of means. The first system was standard datasheets. These datasheets help the team estimate and predict elements of design. Mentors and advisors like Dr. Rowland, Dr. Sheng, and Dr. Conner provided lots of information for both mechanical and electrical design. The ENDEAVOR lab itself helped to provide information of manufacturing through people like Wendy Hall. Daniel, the leader of the design team, has also worked on the BB-8 Project for many semesters and has been able to provide much assistance to the entire team.

8. Concept Evaluation

We had several concepts that our team evaluated, of which the Communications Architecture and Shell presented the largest areas of consideration.

8.1. Communications Architecture

The Communications Architecture for the BB-8 robot went through several iterations to get to the final product. Initially, the system was created with a TCP connection for all of the wireless communication ports. While testing, speed and throughput was determined to be a higher priority over continual data transfer. Originally, the feedback communications sent from the Nano to the Pi had a delay of nearly 4 seconds once the buffer on the TCP got filled up, which is too slow for real time tracking of objects.

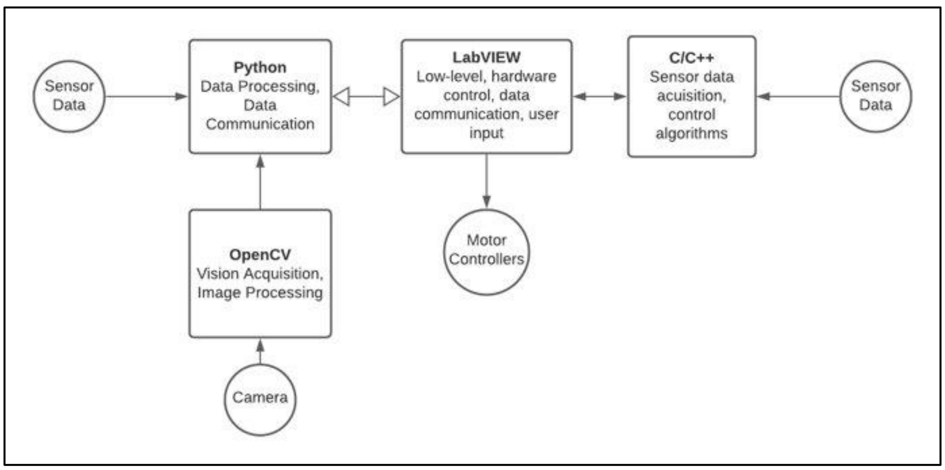


Figure 14: Initial Communications Architecture

The final Communications Architecture changed to a UDP-based system. This was instantiated to enable asynchronous testing between modules, as well as allow for fast communication between different processors, as shown above in Figure 3.

8.2. Shell

The design of our shell was discussed frequently throughout the semester and changed drastically due to new constraints being identified. As shown in Figure 15 (Top), our initial material matrix only included materials for casting. This was because we only planned to remake the panels from the PLA prototype. After our new constraints were recognized, some including a diameter increase and need of semi-rigid casting material. We researched more and created new design matrixes for our shell design and skeleton design.

Requierments & Criteria	PLA (Current Material in use)	PETG	Urethane Casting Resin -75 Shore D	Performance 80 D (Elastomer)
Manufacturing technique	4	4	3	3
Density (g/cc)	4	4	4	4
Cost/weight ($/Kg)	4	4	2	3
Cost Estimate ($)	4	4	2	4
Lead Time	2	1	3	3
Manufactueability	4	4	3	3
Strenght of Material	1	3	5	4
Total Points	**23**	**24**	**22**	**24**

Material Selection for Skeleton

Requirement and Criteria:	Weight	Wood	Arcylic	Polycarbonate	Aluminum	Legend: (1-10)
Ultimate Strength	0.3	0.6	1.5	1.2	2.7	Great
Tensile Strength	0.2	1.2	0.8	0.6	1.8	Average
Machinability	0.1	0.8	0.9	0.9	0.8	Bad
Cost	0.2	1.4	1	2	1	
Weight of Material	0.2	1.8	1.4	1.4	1	
Total:	1	5.8	5.6	6.1	7.3	

Shell Material Selection Matrix

Requierments & Criteria	Weight	PLA	PETG	Smooth-Cast 65D	Urethane -75 Shore D	Performance 80 D (Elastomer)
Manufacturing technique	0.2	1.6	1.4	1.2	1.2	1.2
Weight	0.1	0.9	0.9	0.7	0.7	0.7
Cost Estimate	0.1	0.8	0.7	0.5	0.5	0.5
Lead Time	0.2	0.8	0.8	1.4	1.4	1.4
Strenght of Material	0.3	1.5	2.1	2.4	2.7	2.7
Professional Advice	0.1	0.3	0.3	0.8	0.3	0.3
Total Points	1	5.9	6.2	7	6.8	6.8

Figure 15: (Top) Initial Shell Matrix (Bottom) Final Shell Matrices

After the new design matrixes were completed, we were able to select which materials would suit our project best and move forward with the fabrication of the shell and skeleton of the BB-8.

9. Engineering and Other Analysis

9.1. Casting and Molding – Cosmetic Shell

The cosmetic shell was created from brush casting Smooth Cast 65D polyurethane resin combined with Ure-Fil filler onto a MDF mold of a hemisphere that mimicked the structure of the skeleton. To achieve this, the MDF mold was designed using CAD software where it was cut into 16 different ¾" plates. From there, we were able to cut the pieces out with a CNC router from our sheets of MDF. Any excess MDF on the edges of the pieces was trimmed. All pieces were assembled using a spray adhesive to create the hemisphere, and then was prepared for casting. The preparation involved applying drywall to fill in any gaps, priming the mold to protect the MDF, and applying wax to the mold for a nice finish. After the preparation finished, mold release was applied before the casting process to ensure that the cast will release from the mold. The casting process was best achieved through trial and error. Working around the cure time of 2.5 minutes, the resin was cast on using a brush on method in thirds on the mold. Two trial units of Smooth Cast 65D combined with Ure-Fil 11 were used to create each cosmetic panel of BB-8 with a thickness of 1/8” using a total of four trial kit units. To release the mold, we trimmed away excess material on the bottom to expose the lip. After that, we drilled a hole in the top of the mold to create a release point. Compressed air was then sprayed into the hole as well as snaking some flexible putty knives around the edges of the mold to release it.

Figure 16: (Left) Creation of MFD Mold, (Center) Preparation for Casting, (Right) Casting Shell

After both panels were released, their interiors were coated in a small layer of XTC-3D to provide support for the structure. The panels were sanded down using a combination of dry and wet sanding to get the smoothest surface possible. A polycarbonate lip was added to create a flat lip as well as provide accurate side panel sections to cut out. A rotary tool was then used to cut out and sand the sections that the side panels would be attached to. Additional polycarbonate was added around the side panel sections to reduce the warping. Bondo was used afterwards to fill in any gaps too large to sand down. Dry and wet sanding would be required again to get a smooth surface for priming and painting the panels. During the priming, painting, and coating processes, the panels were constantly wet sanded to achieve a smooth surface. The final cosmetic panels came out well painted, smooth, and with viable dimensions to fulfil our needs.

Figure 17:Final Cosmetic Shell

9.2. Proof of Concept and Fabrication– Skeleton

The skeleton was prototyped a few times to ensure that the structure could support the Drivetrain and total weight of BB-8 properly. Prototypes were made from acrylic and polycarbonate. The acrylic prototype was created using a laser cutter while the polycarbonate prototype was created using a water jet machine. After the parts were cut out and assembled, we ran some weight and roll tests on them to see if the CAD was able to fulfil our needs. After the testing, these prototypes validated our CAD structure and highlighted problems that needed to be addressed before the creation of the final model. Some of these problems included improper thickness of skeleton, the need for more support to avoid deflection, and the change of material selection. These problems were addressed in the manufacturing of our final model and performed to the standards necessary for the project.

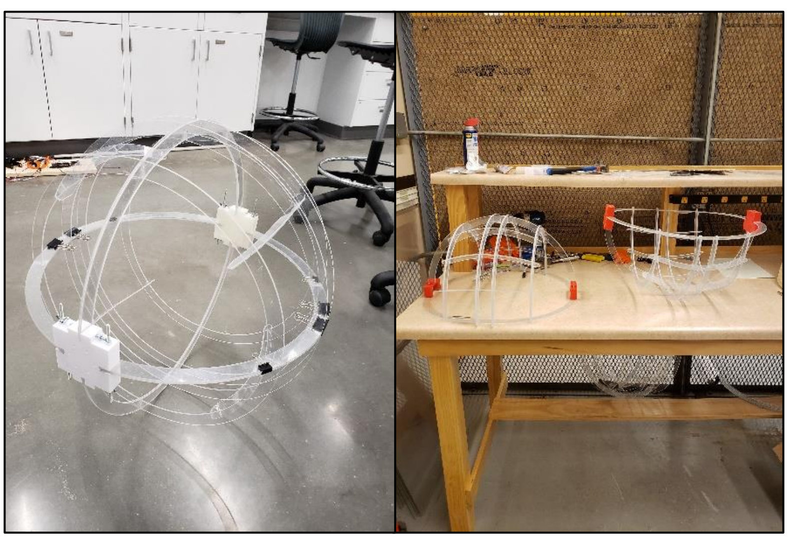


Figure 18: Polycarbonate Skeleton

9.3. Proof of Concept – Omnitank

The Omnitank was used to test the vision software to track various objects. The Gimbal used on the Omnitank mimics the limitations of the Gimbal movement for the BB-8. The camera installed on this robot has 1080p/30fps, similar to the Head camera for the BB-8. The Omnitank allowed our team to test the vision software in parallel to the development of the BB-8 system to increase the throughput of our team. Therefore, the Omnitank was used for any vision software testing, such as object detection, object tracking, and basic communications.

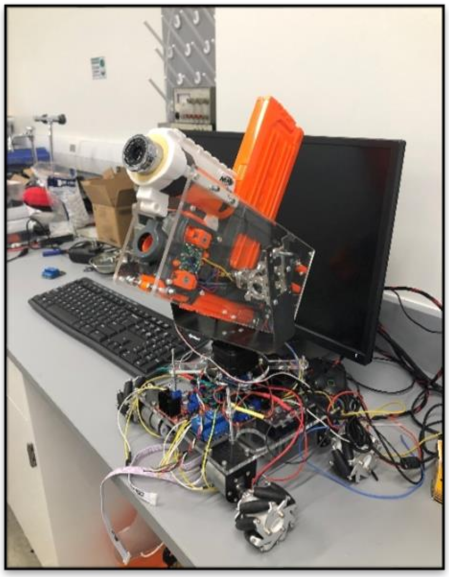


Figure 19: Omnitank

9.4. Proof of Concept – Kobuki

The Kobuki was used to develop the basis for the libraries that will be used to talk with the sensors used in the control loops in the system, as well as the standard control of the drive shaft from a sensor driven perspective. Also included in the libraries is a function to read controller inputs from either a wired or wireless input. See Appendix B for the Controls API. The result from the testing with the Kobuki Proof was an algorithm to reduce the drift impact on the system, as well as a basis for further integration of sensors if they are needed.

Figure 20: Kobuki

10. Testing and Quality Plan

10.1. Controls

Control feedback for this system is provided by the UM7 orientation sensor. It is a 12-axis orientation sensor with integrated Kalman filtering, which comes equipped with an accelerometer, gyroscope, and magnetometer. This data is used to obtain pitch, roll, and yaw. Some drift is encountered, but it is nullified by cross checking other sensors, namely the gyroscope to check for angular speed.

The last control feedback sensor is a small shaft encoder on the main drive shaft that assists in a small amount of automated movement. Full autonomous movement requires some form of localization, which is not in the scope of the project. For future iterations, the UM7 integrated with a shaft encoder, localization and image processing from the Head will allow for automatic movement.

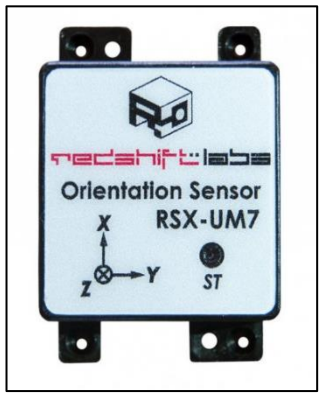
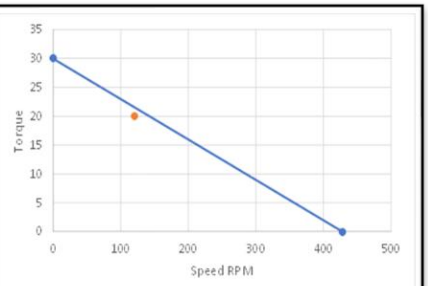


Figure 21: UM7 Sensor

10.2. Gimbal

Testing for the Gimbal was done on a testbench without the head or skeleton attached. Servo controllers were used to test both of the radial rotation axes about the system. At this point, the system moved and responded well to changes in direction; however, no load was applied. This was because of a limitation of current provided for the testing setup.

Motor Speed (Degrees/ Sec)	Torque (lbf/in)
0	30
428	0
120	20
Desired Point	



Torque of Servo "lbf/in"	20
Force Effiency	0.85
Head Distance "in"	12
Gear Ratio	4
Weight head	5.666666667

Weight_head = (Torque of Servo "lbf/in") * (Force Effiency)* (Gear ratio "#") / (Distance of head "in")

Motor Speed "60 Degrees/ Sec"	120
Gear Ratio	0.25
Angular Speed "Degrees/ Sec"	30

Angular Speed_head = (Motor Speed) * (Gear Ratio)

Figure 22: Gimbal Calculations

10.3. Drivetrain

The drivetrain was tested by attaching the new aluminum shell to the body. The system was able to move in a straight line at the correct speed under less the half power.

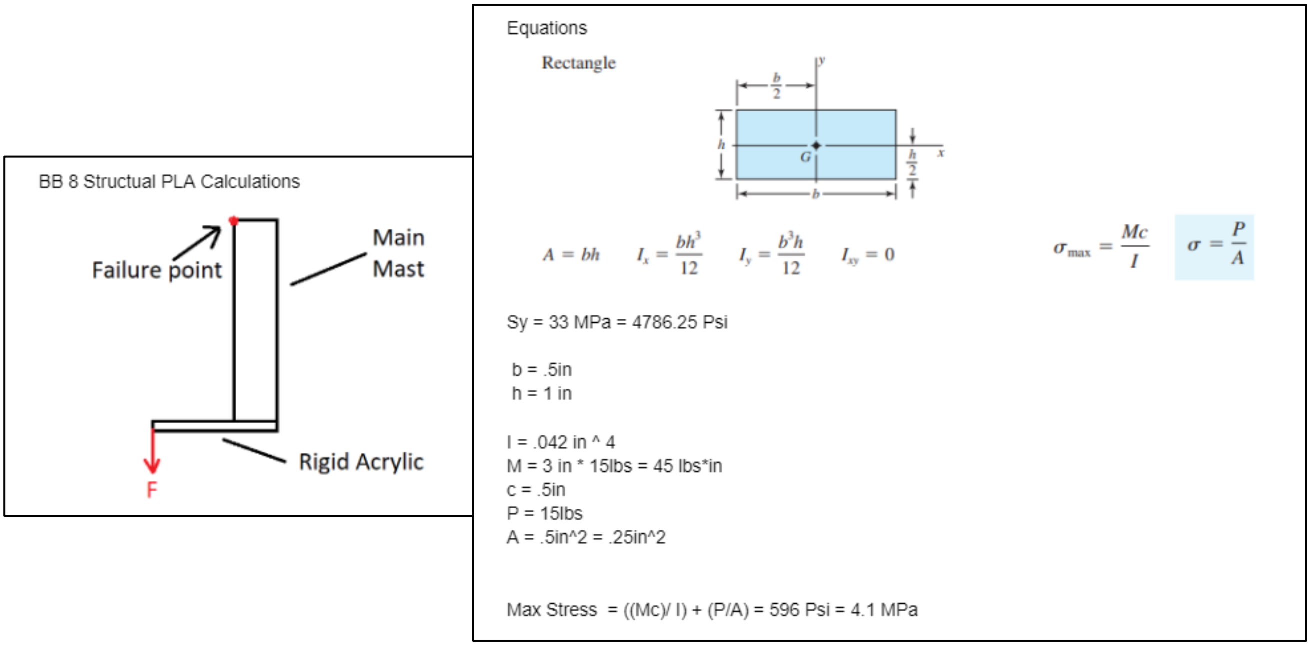


Figure 23: Drivetrain Calculations

10.4. Skeleton

The skeleton was initially tested in Solidworks using Solidworks Simulations. The skeleton was fixed at the point of contact with the ground and a force of 200N was exerted on the connectors to simulate the weight of the drivetrain. After performing the weight test in Solidworks, the results verified that the skeleton would have a max tensile stress of 15.8Kpsi along the main drive axis. This result was sufficient since the aluminum was rated to handle a max tensile stress between 17Kpsi to 27Kpsi.

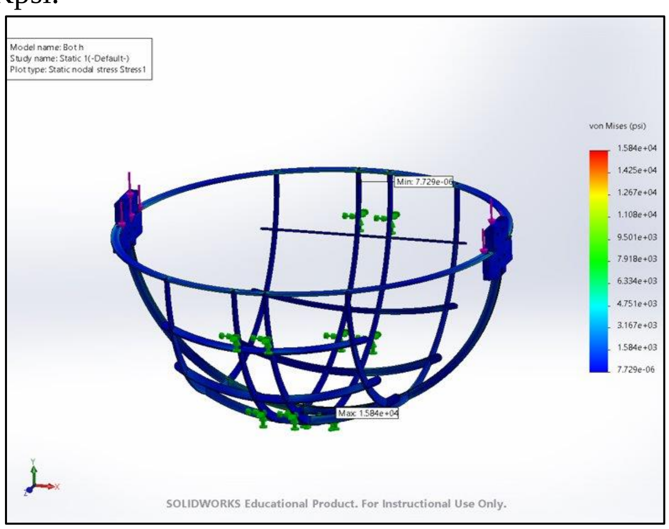


Figure 24: Skeleton Calculations

After the fabrication of the shell, further testing was done with the physical model and drivetrain. After physical testing was conducted, this involved a standard weight test, roll test, and strength test. Those results showed that the skeleton was again more than capable of supporting the drivetrain.

10.5. Shell

The cosmetic shell was initially tested in Solidworks using Solidworks Simulations as well. The simulation involved fixing the outer part of the shell and applying a uniform force of 200N which would be a bit larger than the force that the skeleton would induce to the interior of the shell. After the weight test, the results verified that the shell endured a max tensile stress of 2403Kpsi. While Smooth Cast 65D is only rated for 2400Kpsi, the max stress on the simulation only occurred at the lips where the panels would connect. In a physical test, no force would realistically be exerted on those areas. The elasticity due to being a semi-rigid material was also not considered in the simulation which increased the stress calculated. Looking at the point of contact for the main drive axis, the max stress calculated was about 75Kpsi which could support the weight of the skeleton and drivetrain.

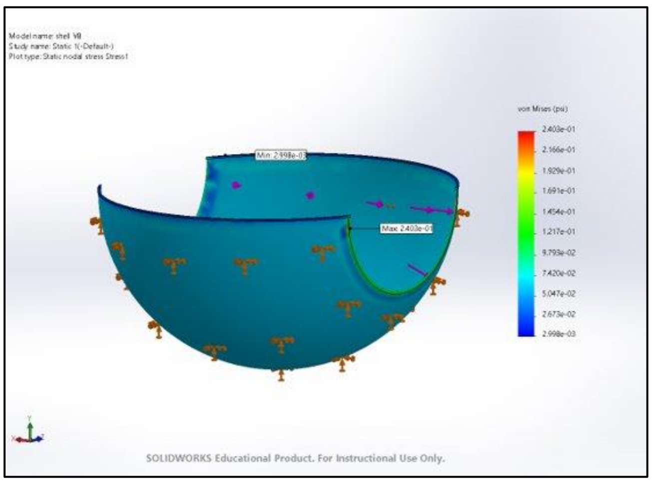


Figure 25: Shell Calculations

After fabrication, additional testing and quality insurance for the shell has happened with wear and tear in bringing the full device to the EXPO and Speedfest. During Speedfest, a piece of gravel punctured the cosmetic shell. This resulted in a hairline fracture that can be seen but not felt, and is easily temporarily patched with tape, and can be fully repaired by coating the fracture in the 65D resin. This accident proves that the control surface does not change with small wears and breaks through the cosmetic shell, and it can be easily repaired and maintained.

10.6. Communications

Full communications testing and maintenance was performed day of expo as well as throughout the communications network creation. In changing the original structure and moving to a closed-network LAN UDP system, the testing on each system can now be done individually on each subsystem. The only requirement to test any system or subsystem is to connect to the network and send the correct packets, including the corresponding identifiers that each system should either terminate or pass through.

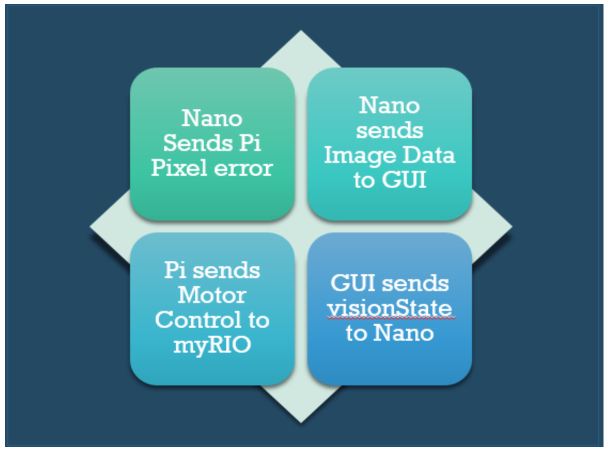


Figure 26: Testing Communications Architecture

10.7. BB-8 Full System Test

To fully integrate the system, we implemented a bottom to top testing and integration plan, as most of the Head control and movement can be accurately simulated using a small testing bed. We attached the Drivetrain to the skeleton and fleshed out any final fixes needed for controls. Once the cosmetic shell was completed and properly attached to the skeleton, the final step of integration of physical systems was attaching the Head to the center robot. The last step of the full integration was fully programming and ensuring connections within the network passed data properly around the system. All the communications were tested and maintained asynchronously from the general integration, as many of the parts required for the physical robot had manufacturing and fabrication times. Using the asynchronous and bottom to top integration methods, most of the electrical components were fleshed out and tuned in parallel with the fabrication process.

11. Costs

We were given a budget of $2,000. However, as a prototype was already made, many of the electrical components used in this project were already bought. Therefore, we did not expect any difficulties in keeping within our budget, as seen in the table below. The resultant budget was maintained and constantly considered. We stayed within our budget while executing a full design project. Below is an abbreviated finance summary. A fully detailed cost report and part order form are included in Appendix A.

System	Total Items	Cost
Gimble and Drivetrain Control and Maintanence	17	$663.10
Power and Electronics	37	$473.21
Shell mold and casting materials w/ Skeleton	16	$535.98
Misc		$114.03
	Total Cost	$1,789.32

Figure 27: Financial Summary

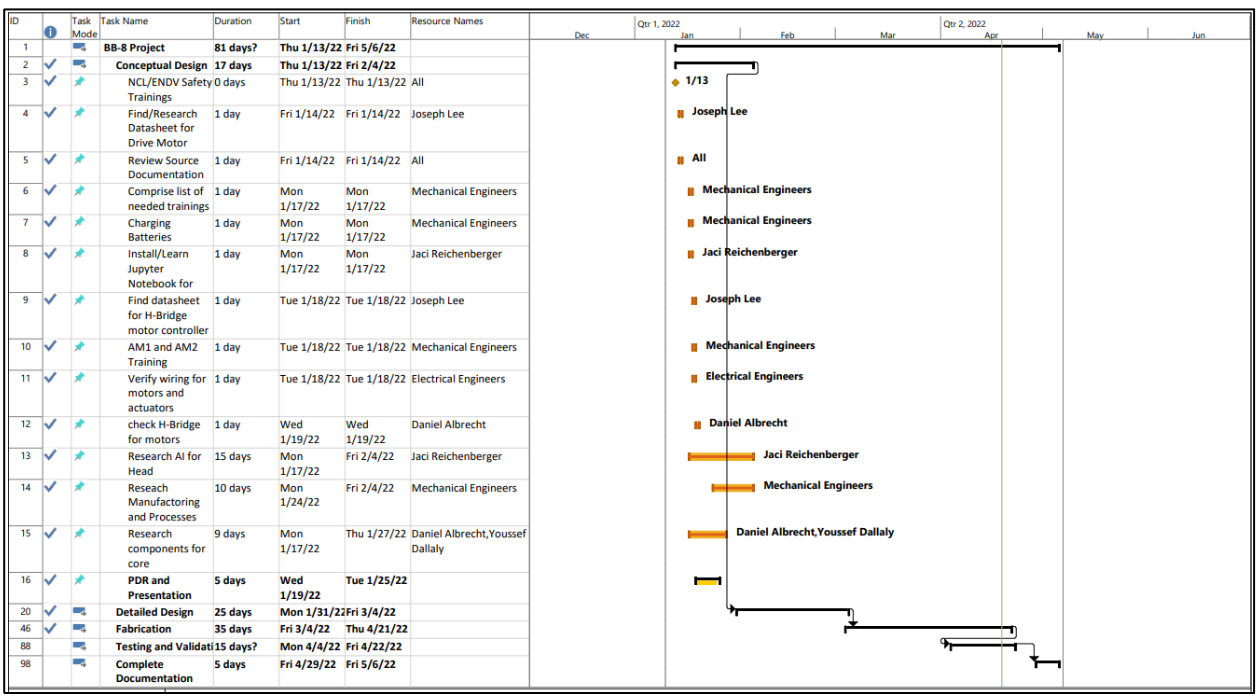
12. Risk Management

- Completion of the skeleton and Shell added a major time constraint to this project. Until manufacturing was completed, the software development for the Head movement, Gimbal, and Drivetrain was completed via their proof of concepts.
- Our development budget created a consideration for the project. This was handled through the proper ordering of parts and materials, and thorough preliminary design to eliminate waste.
- Communication between team members regarding tasking was evaluated. Project management structures for intermember task handling were installed to help advance the project.
- The safety of our team members and the system were a top priority. Safety guidelines for handling of various materials, procedures, and operations were explicitly reviewed by all team members to lower the risk of safety hazards to the health of our team members and the hardware we were using.

13. Project Plan

Our team created a Gantt Chart using Microsoft Projects to keep up to date with the various deadlines for our project. It is separated into five main phases: Conceptual Design, Detailed Design, Fabrication, Testing, and Complete Documentation

13.1. Conceptual Design Phase

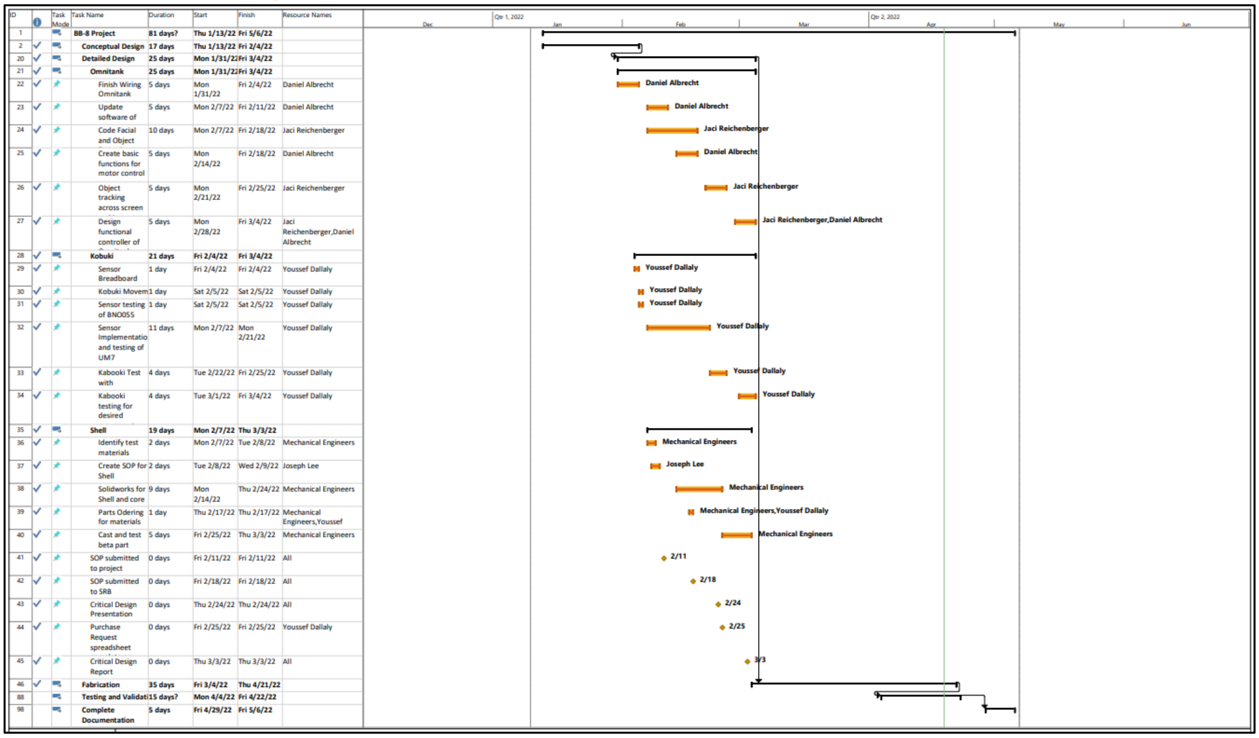


ID		Task Mode	Task Name	Duration	Start	Finish	Resource Names
1			**BB-8 Project**	**81 days?**	**Thu 1/13/22**	**Fri 5/6/22**	
2	✓		**Conceptual Design**	**17 days**	**Thu 1/13/22**	**Fri 2/4/22**	
3	✓		NCL/ENDV Safety Trainings	0 days	Thu 1/13/22	Thu 1/13/22	All
4	✓		Find/Research Datasheet for Drive Motor	1 day	Fri 1/14/22	Fri 1/14/22	Joseph Lee
5	✓		Review Source Documentation	1 day	Fri 1/14/22	Fri 1/14/22	All
6	✓		Comprise list of needed trainings	1 day	Mon 1/17/22	Mon 1/17/22	Mechanical Engineers
7	✓		Charging Batteries	1 day	Mon 1/17/22	Mon 1/17/22	Mechanical Engineers
8	✓		Install/Learn Jupyter Notebook for	1 day	Mon 1/17/22	Mon 1/17/22	Jaci Reichenberger
9	✓		Find datasheet for H-Bridge motor controller	1 day	Tue 1/18/22	Tue 1/18/22	Joseph Lee
10	✓		AM1 and AM2 Training	1 day	Tue 1/18/22	Tue 1/18/22	Mechanical Engineers
11	✓		Verify wiring for motors and actuators	1 day	Tue 1/18/22	Tue 1/18/22	Electrical Engineers
12	✓		check H-Bridge for motors	1 day	Wed 1/19/22	Wed 1/19/22	Daniel Albrecht
13	✓		Research AI for Head	15 days	Mon 1/17/22	Fri 2/4/22	Jaci Reichenberger
14	✓		Reseach Manufactoring and Processes	10 days	Mon 1/24/22	Fri 2/4/22	Mechanical Engineers
15	✓		Research components for core	9 days	Mon 1/17/22	Thu 1/27/22	Daniel Albrecht,Youssef Dallaly
16	✓		**PDR and Presentation**	**5 days**	**Wed 1/19/22**	**Tue 1/25/22**	
20	✓		**Detailed Design**	**25 days**	**Mon 1/31/22**	**Fri 3/4/22**	
46	✓		**Fabrication**	**35 days**	**Fri 3/4/22**	**Thu 4/21/22**	
88			**Testing and Validati**	**15 days?**	**Mon 4/4/22**	**Fri 4/22/22**	
98			**Complete Documentation**	**5 days**	**Fri 4/29/22**	**Fri 5/6/22**	

Figure 28: Conceptual Design Phase

The conceptual design phase for this project was completed after the presentation of the preliminary design review. This phase was for researching what needed to be done to BB-8 to complete our objectives for the semester. This phase did not change from the Preliminary Design Review to the Final Design Review.

13.2. Detailed Design Phase

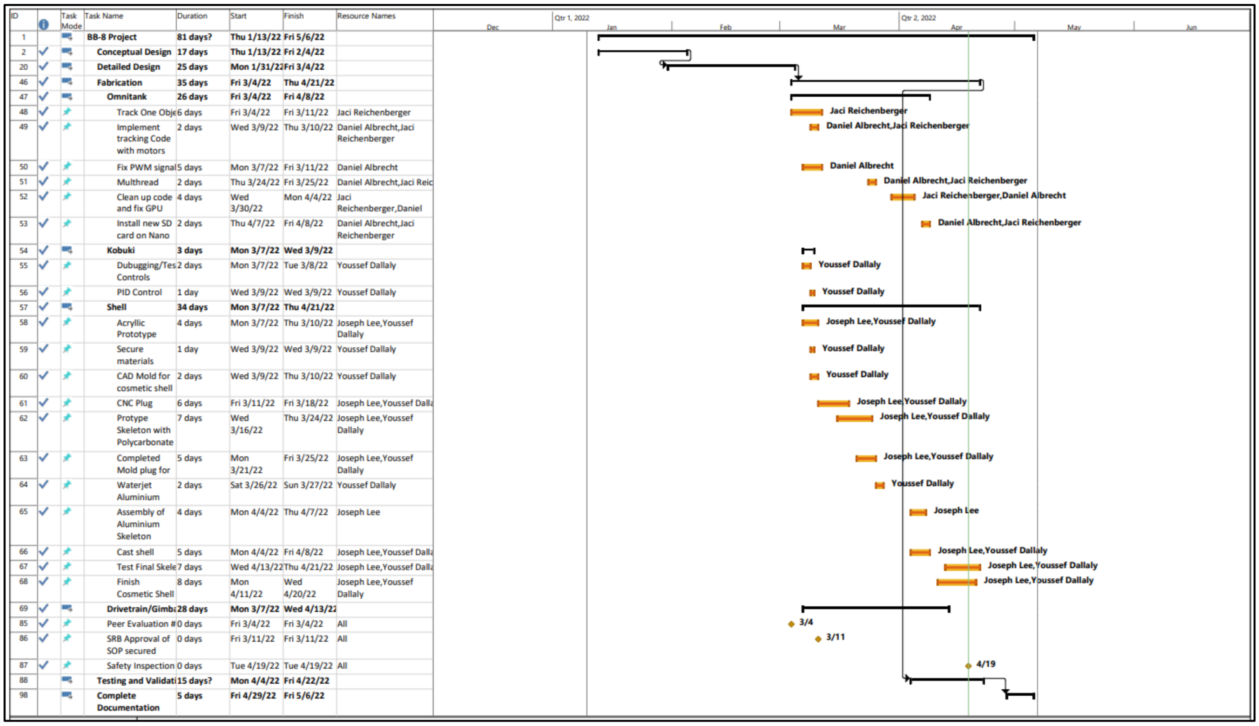


ID		Task Mode	Task Name	Duration	Start	Finish	Resource Names
1			**BB-8 Project**	**81 days?**	**Thu 1/13/22**	**Fri 5/6/22**	
2	✓		**Conceptual Design**	**17 days**	**Thu 1/13/22**	**Fri 2/4/22**	
20	✓		**Detailed Design**	**25 days**	**Mon 1/31/22**	**Fri 3/4/22**	
21	✓		**Omnitank**	**25 days**	**Mon 1/31/22**	**Fri 3/4/22**	
22	✓		Finish Wiring Omnitank	5 days	Mon 1/31/22	Fri 2/4/22	Daniel Albrecht
23	✓		Update software of	5 days	Mon 2/7/22	Fri 2/11/22	Daniel Albrecht
24	✓		Code Facial and Object	10 days	Mon 2/7/22	Fri 2/18/22	Jaci Reichenberger
25	✓		Create basic functions for motor control	5 days	Mon 2/14/22	Fri 2/18/22	Daniel Albrecht
26	✓		Object tracking across screen	5 days	Mon 2/21/22	Fri 2/25/22	Jaci Reichenberger
27	✓		Design functional controller of	5 days	Mon 2/28/22	Fri 3/4/22	Jaci Reichenberger,Daniel Albrecht
28	✓		**Kobuki**	**21 days**	**Fri 2/4/22**	**Fri 3/4/22**	
29	✓		Sensor Breadboard	1 day	Fri 2/4/22	Fri 2/4/22	Youssef Dallaly
30	✓		Kobuki Movem	1 day	Sat 2/5/22	Sat 2/5/22	Youssef Dallaly
31	✓		Sensor testing of BNO055	1 day	Sat 2/5/22	Sat 2/5/22	Youssef Dallaly
32	✓		Sensor Implementatio and testing of UM7	11 days	Mon 2/7/22	Mon 2/21/22	Youssef Dallaly
33	✓		Kabooki Test with	4 days	Tue 2/22/22	Fri 2/25/22	Youssef Dallaly
34	✓		Kabooki testing for desired	4 days	Tue 3/1/22	Fri 3/4/22	Youssef Dallaly
35	✓		**Shell**	**19 days**	**Mon 2/7/22**	**Thu 3/3/22**	
36	✓		Identify test materials	2 days	Mon 2/7/22	Tue 2/8/22	Mechanical Engineers
37	✓		Create SOP for Shell	2 days	Tue 2/8/22	Wed 2/9/22	Joseph Lee
38	✓		Solidworks for Shell and core	9 days	Mon 2/14/22	Thu 2/24/22	Mechanical Engineers
39	✓		Parts Odering for materials	1 day	Thu 2/17/22	Thu 2/17/22	Mechanical Engineers,Youssef
40	✓		Cast and test beta part	5 days	Fri 2/25/22	Thu 3/3/22	Mechanical Engineers
41	✓		SOP submitted to project	0 days	Fri 2/11/22	Fri 2/11/22	All
42	✓		SOP submitted to SRB	0 days	Fri 2/18/22	Fri 2/18/22	All
43	✓		Critical Design Presentation	0 days	Thu 2/24/22	Thu 2/24/22	All
44	✓		Purchase Request spreadsheet	0 days	Fri 2/25/22	Fri 2/25/22	Youssef Dallaly
45	✓		Critical Design Report	0 days	Thu 3/3/22	Thu 3/3/22	All
46	✓		**Fabrication**	**35 days**	**Fri 3/4/22**	**Thu 4/21/22**	
88			**Testing and Validati**	**15 days?**	**Mon 4/4/22**	**Fri 4/22/22**	
98			**Complete Documentation**	**5 days**	**Fri 4/29/22**	**Fri 5/6/22**	

Figure 29: Detailed Design Phase

This phase was used to break down the various parts of BB-8 to start creating the framework for our various parts of the project. This was where we separated the Omnitank and Kobuki proof of concepts to work in parallel with each other and with the Shell of BB-8. This was also where we finalized our designs and materials to be used for our final product. This phase ended with the Critical Design Review. The only major change that occurred from the Preliminary Design Review to the Final Design Review was that more tasks were added, but the overall timeframe of this phase was not changed.

13.3. Fabrication Phase



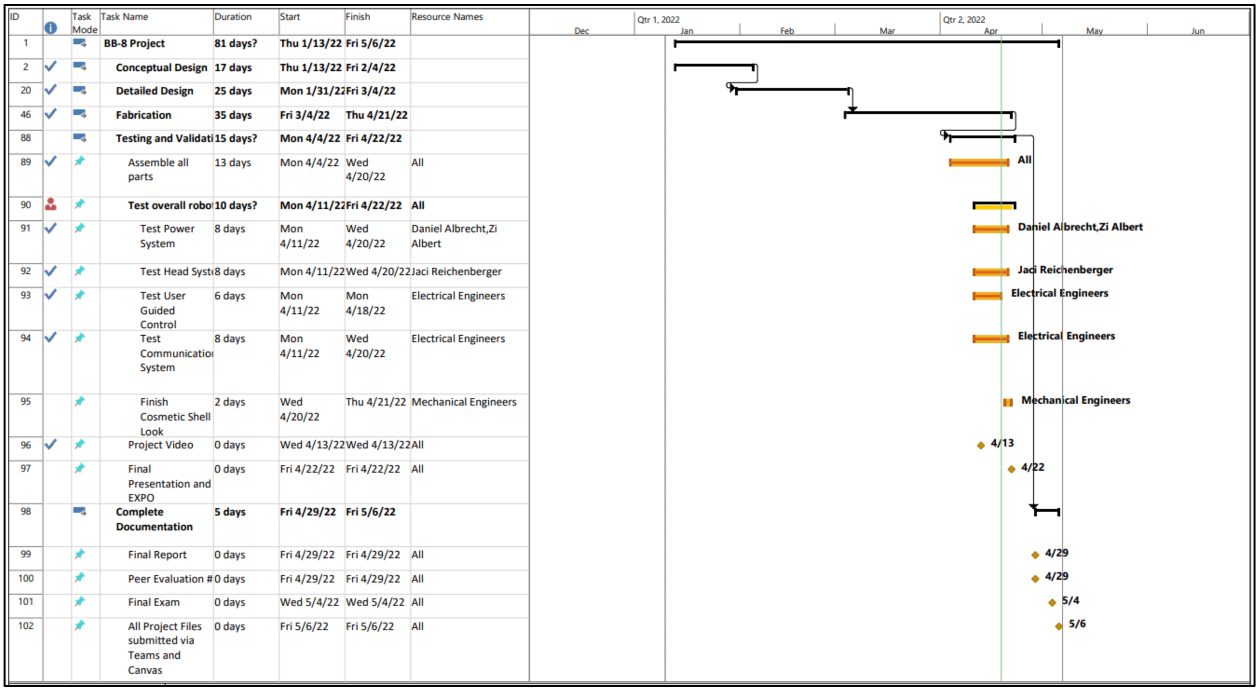
ID		Task Name	Duration	Start	Finish	Resource Names
1		**BB-8 Project**	**81 days?**	**Thu 1/13/22**	**Fri 5/6/22**	
2	✓	**Conceptual Design**	**17 days**	**Thu 1/13/22**	**Fri 2/4/22**	
20	✓	**Detailed Design**	**25 days**	**Mon 1/31/22**	**Fri 3/4/22**	
46	✓	**Fabrication**	**35 days**	**Fri 3/4/22**	**Thu 4/21/22**	
47	✓	**Omnitank**	**26 days**	**Fri 3/4/22**	**Fri 4/8/22**	
48	✓	Track One Obje	6 days	Fri 3/4/22	Fri 3/11/22	Jaci Reichenberger
49	✓	Implement tracking Code with motors	2 days	Wed 3/9/22	Thu 3/10/22	Daniel Albrecht,Jaci Reichenberger
50	✓	Fix PWM signal	5 days	Mon 3/7/22	Fri 3/11/22	Daniel Albrecht
51	✓	Multhread	2 days	Thu 3/24/22	Fri 3/25/22	Daniel Albrecht,Jaci Reic
52	✓	Clean up code and fix GPU	4 days	Wed 3/30/22	Mon 4/4/22	Jaci Reichenberger,Daniel
53	✓	Install new SD card on Nano	2 days	Thu 4/7/22	Fri 4/8/22	Daniel Albrecht,Jaci Reichenberger
54	✓	**Kobuki**	**3 days**	**Mon 3/7/22**	**Wed 3/9/22**	
55	✓	Dubugging/Tes Controls	2 days	Mon 3/7/22	Tue 3/8/22	Youssef Dallaly
56	✓	PID Control	1 day	Wed 3/9/22	Wed 3/9/22	Youssef Dallaly
57	✓	**Shell**	**34 days**	**Mon 3/7/22**	**Thu 4/21/22**	
58	✓	Acryllic Prototype	4 days	Mon 3/7/22	Thu 3/10/22	Joseph Lee,Youssef Dallaly
59	✓	Secure materials	1 day	Wed 3/9/22	Wed 3/9/22	Youssef Dallaly
60	✓	CAD Mold for cosmetic shell	2 days	Wed 3/9/22	Thu 3/10/22	Youssef Dallaly
61	✓	CNC Plug	6 days	Fri 3/11/22	Fri 3/18/22	Joseph Lee,Youssef Dalla
62	✓	Protype Skeleton with Polycarbonate	7 days	Wed 3/16/22	Thu 3/24/22	Joseph Lee,Youssef Dallaly
63	✓	Completed Mold plug for	5 days	Mon 3/21/22	Fri 3/25/22	Joseph Lee,Youssef Dallaly
64	✓	Waterjet Aluminium	2 days	Sat 3/26/22	Sun 3/27/22	Youssef Dallaly
65	✓	Assembly of Aluminium Skeleton	4 days	Mon 4/4/22	Thu 4/7/22	Joseph Lee
66	✓	Cast shell	5 days	Mon 4/4/22	Fri 4/8/22	Joseph Lee,Youssef Dalla
67	✓	Test Final Skele	7 days	Wed 4/13/22	Thu 4/21/22	Joseph Lee,Youssef Dalla
68	✓	Finish Cosmetic Shell	8 days	Mon 4/11/22	Wed 4/20/22	Joseph Lee,Youssef Dallaly
69	✓	**Drivetrain/Gimba**	**28 days**	**Mon 3/7/22**	**Wed 4/13/22**	
85	✓	Peer Evaluation #	0 days	Fri 3/4/22	Fri 3/4/22	All
86	✓	SRB Approval of SOP secured	0 days	Fri 3/11/22	Fri 3/11/22	All
87	✓	Safety Inspection	0 days	Tue 4/19/22	Tue 4/19/22	All
88		**Testing and Validati**	**15 days?**	**Mon 4/4/22**	**Fri 4/22/22**	
98		**Complete Documentation**	**5 days**	**Fri 4/29/22**	**Fri 5/6/22**	

Figure 30: Fabrication Phase

The fabrication of BB-8 took the longest time to complete and was the major time constraint of our project. This was due to the skeleton and shell needing to be complete before the entire robot can be put together and tested as a whole. Due to various lead times, this phase ran into the Testing Phase of this project, but ultimately, this phase was completed. Therefore, this phase took longer than initially expected, but was not too much of a deterrent to the Testing Phase.

13.4. Testing Phase

As seen in Figure 31, the testing phase took place shortly before the Fabrication Phase ended for the entirety of the BB-8 robot. Individual tests for the Head, Drivetrain, and Gimbal were conducted in parallel with the fabrication of the skeleton and shell. This phase was expanded so that further testing could be done, but the overall timeframe for this phase did not change.



ID		Task Mode	Task Name	Duration	Start	Finish	Resource Names
1			BB-8 Project	81 days?	Thu 1/13/22	Fri 5/6/22	
2			Conceptual Design	17 days	Thu 1/13/22	Fri 2/4/22	
20			Detailed Design	25 days	Mon 1/31/22	Fri 3/4/22	
46			Fabrication	35 days	Fri 3/4/22	Thu 4/21/22	
88			Testing and Validati	15 days?	Mon 4/4/22	Fri 4/22/22	
89			Assemble all parts	13 days	Mon 4/4/22	Wed 4/20/22	All
90			Test overall robo	10 days?	Mon 4/11/22	Fri 4/22/22	All
91			Test Power System	8 days	Mon 4/11/22	Wed 4/20/22	Daniel Albrecht,Zi Albert
92			Test Head Syst	8 days	Mon 4/11/22	Wed 4/20/22	Jaci Reichenberger
93			Test User Guided Control	6 days	Mon 4/11/22	Mon 4/18/22	Electrical Engineers
94			Test Communicatio System	8 days	Mon 4/11/22	Wed 4/20/22	Electrical Engineers
95			Finish Cosmetic Shell Look	2 days	Wed 4/20/22	Thu 4/21/22	Mechanical Engineers
96			Project Video	0 days	Wed 4/13/22	Wed 4/13/22	All
97			Final Presentation and EXPO	0 days	Fri 4/22/22	Fri 4/22/22	All
98			Complete Documentation	5 days	Fri 4/29/22	Fri 5/6/22	
99			Final Report	0 days	Fri 4/29/22	Fri 4/29/22	All
100			Peer Evaluation #	0 days	Fri 4/29/22	Fri 4/29/22	All
101			Final Exam	0 days	Wed 5/4/22	Wed 5/4/22	All
102			All Project Files submitted via Teams and Canvas	0 days	Fri 5/6/22	Fri 5/6/22	All

Figure 31: Testing and Complete Documentation Phase

13.5. Complete Documentation Phase

This final phase of the Gantt Chart, seen in Figure 31, is there to sum up the semester for this project. It is to ensure we finish all paperwork and reports needed by their respective due dates. This phase has not changed since the Preliminary Design Review.

14. Suggested Future Improvements

- Due to vendor shortages, a slip ring capable of holding 45A could not be purchased, so a slip ring rated for 30A, above the average current rating, is currently installed along with a 30A fuse for protection. This should be updated to a 45A fuse and a slip ring capable of supporting at least 45A as soon as supplies become available.
- Strengthen the Gimbal and Drivetrain systems by manufacturing components out of aluminum to prevent thermal warping and add dexterity.
- Change all structural or load bearing additive manufactured parts to subtractive manufactured parts.
- Create more intuitive Human-guided control system, possibly with phone orientation data.
- Improve current Tracking Mode in the Head to include more intuitive AI functionality.

15. Work Breakdown

Zi Albert: Knowledge Acquisition, Head Structure and Materials, Gimbal Structure and Materials, Drivetrain Structure and Materials

Daniel Albrecht: Introduction, Problem Description, Electrical Diagram, Power, Communications, Editing

Youssef Dallaly: Controls, Gimbal Software, Drivetrain Software, Kobuki, BB-8 Full System Test, Costs

Joseph Lee: Mechanical Principles, Shell Structure and Materials, Shell Testing and Proof of Concept

Jaci Reichenberger: EHS, Codes and Standards, Head Software, Omnitank, Project Plan, Risk Management, Editing

Zi Albert

Daniel Albrecht

Youssef Dallaly

Joseph Lee

Jaci Reichenberger

References

"IEEE/ISO/IEC 42010 - ISO/IEC/IEEE Systems and Software Engineering." *IEEE SA*, ISO/IEC/IEEE, 1 Dec. 2011, https://standards.ieee.org/ieee/42010/5334/.

Moretz, Laura. "Mobile Robot Standard R15.08-1-2020 -What You Need to Know: A3." *Automate News and Resources: Industry Insights*, A3 Association for Advancing Automation, 15 Feb. 2021, https://www.automate.org/industry-insights/mobile-robot-standard-r15-08-1-2020-what-you-need-to-know.

"What Is Fair Use?" *Copyright Alliance*, 14 Feb. 2021, https://copyrightalliance.org/faqs/what-is-fairuse/#:~:text=Fair%20use%20permits%20a%20party,be%20considered%20as%20fair%20use.

Appendix A: Complete Financial Summary

Ordering Sheet

All orders must be tax exempt!

Budget:	2000	< Enter amount given by sponsor

Instructions

1) Identify all parts, provide a detailed description, and their respective quantity required. For example, you may need to indicate size and color in addition to the part name.
2) Identify a vendor (Note: Shipping may be cheaper if you group items to purchase.)

*****Notice: Post a link for the item you wish to purchase. Proceed all the way through the purchase process to view the estimated delivery date. If the projected delivery date is too long, you may not receive your parts in time to complete your project.**
The links you provide for each item will be used for purchase and it is assumed by the buyer that you have confirmed delivery date is acceptable!
3) Include Grainger into your search for potential vendors (OSU gets free shipping and more options are available for placing orders).
4) Enter items into spreadsheet below. Ask your Mentor to approve items by initialing in Column J. Notify your purchasing agent when you are ready to purchase items and have secured faculty mentor approval.

Balance (Remaining Funds): 213.68

Date Requested	Supplier Name	Part #	Link to part	Comments/Additional Instructions	Quantity	Cost/Unit, Excluding Shipping	Cost for all Units	Shipping charges	Instructor/Mentor Approval	Order placed by	Supplier Order Number	ETA	Shipping Company
17-Feb	Amazon	Brake Cable Housing,Bicycle Brake Cable Housing, Bicycle Brake Cable Gear Wires Bikes Replacement Accessory for Mountain Road Bike,3 Meters	https://www.amazon.com/Housing-Bicycle-Replacement-Accessory-Mountain/dp/[illegible]		1	9.99	10	0	jpc	Conner			
17-Feb	Amazon	YASI Bike Brake Cable Shifter Cable, 8 Pack Bicycle Brake Cables Shift Cables Set for Mountain Bike and Road Bike, including 6 End Ferrules, 8 Cable End Caps, 8 Silicone O-Rings and 8 Housing End Caps	https://www.amazon.com/YASI-Mountain-including-Ferrules-Silicone/dp/[illegible]		1	6.98	7	0	jpc	Conner			
17-Feb	Amazon	Muzata Bike Cable Cutter Wire Rope Heavy Duty Stainless Steel Aircraft Up to 5/32" for Deck Stair Railing Seal Metal Housing Fencing with 4Pcs Bike Bicycle Cable Cap End M015, CT1	https://www.amazon.com/Muzata-Stainless-Shearing-Forceps-Bicycle/dp/[illegible]		1	16	16	0	jpc	conner			
17-Feb	Servocity.com	HSR-M9382TH Servo	https://www.servocity.com/hsr-m9382th-servo/[illegible]	7 turn max rotation model	2	178	357	8.99 (standard)	jpc	conner			
17-Feb	Servocity.com	Standard Hub Shaft ServoBlock™ (25T Spline) SKU:637112	https://www.servocity.com/standard-hub-shaft-servoblock-25t-spline/	If this and the servo are in the same cart, shipping will be for both of them	2	25.5	51	9	jpc	conner			
3-Mar	Amazon	Smooth-On Universal Mold Release 14 fl. oz.	https://www.amazon.com/Smooth-Universal-Mold-Release-Fl/dp/[illegible]		1	21.1	21	0				Friday, Mar. 25	
3-Mar	Amazon	Smooth Cast 65D Liquid Plastic Casting Resin - Trial Unit	https://www.amazon.com/Smooth-65D-Liquid-Plastic-Casting/dp/[illegible]		1	33	33	0				Friday, Mar. 25	
3-Mar	Lowes	LOCTITE Professional 13.5-oz Spray Adhesive	https://www.lowes.com/pd/LOCTITE-[illegible]-Professional-Performance/[illegible]	We can pick this up at the Lowes	1	11	11	0					
3-Mar	McMaster	18 Teeth Gear PARTNUMBER: 1277N753	https://www.mcmaster.com/gears/for-shaft-diameter~1-2-1/xl-series-corrosion-resistant-timing-belt-pulleys/	McMaster does not give a shipping estimate until the thing is ordered. All of these on the same order keeps the shipping down	1	17	17	9.1		LES	5381225	7-Mar	FedEx
3-Mar	McMaster	30 Teeth Gear PARTNUMBER: 1277N771	https://www.mcmaster.com/gears/for-shaft-diameter~1-2-1/xl-series-corrosion-resistant-timing-belt-pulleys/		1	22.2	22			LES		7-Mar	
3-Mar	McMaster	XL Dust-Free Timing Belt PARTNUMBER: 1679K29	https://www.mcmaster.com/drive-belts/width~3-8-1/teeth-location~teeth-on-one-side/pitch~0-200/outer-circle~16/		1	4.86	4.9			LES		7-Mar	
22-Mar	Servocity.com	1 inch servo screw	https://www.servocity.com/6-32-x-1-00-zinc-plated-socket-head-machine-screw/	Shipping applies to all of them	1	3.39	3.4	9	jpc				
22-Mar	Servocity.com	3/8 inch servo screw	https://www.servocity.com/6-32-x-0-375-1-8-zinc-plated-socket-head-machine-screw/		1	2.09	2.1		jpc				
22-Mar	Servocity.com	1/4 inch servo screw	https://www.servocity.com/6-32-x-0-250-1-4-zinc-plated-socket-head-machine-screw/		1	1.89	1.9		jpc				
22-Mar	Amazon	BETU 45Kg Coreless Servo Motor HV 8.4V, High Torque RC Digital Servo, Full Waterproof Servo, Stainless Steel Gear Servo with 25T Servo Horn (180°	https://www.amazon.com/BETU-Servo[illegible]Full-Waterproof-Stainless-[illegible]	Assuming we have amazon prime. We also need the 3-MAR order to be put on this order so we can start with our casting/priming stuff.	2	59	118	0	jpc			Friday, Mar. 25	
22-Mar	Amazon	SPST 12VDC 40A On-Off Toggle Switch	https://www.amazon.com/SPST-12VDC-Off-Toggle-Switch/dp/[illegible]	We do have some other lowprofile switches at ENDV already iof you would like to look	2	6.85	14	0	jpc			Mar. 31 - April 2	
22-Mar	MABD Electronics	IMREN IMR 18650 GOLD 3000MAH 40A HIGH DRAIN FLAT TOP RECHARGEABLE BATTERY	https://mabdelectronics.com/products/imren-imr-18650-gold-3000mah-40a-high-drain-flat-top-rechargeable-battery?variant=[illegible]&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic	Shipping is an estimate	20	7.99	160	13				2 day shipping	

22-Mar	McMaster	XL Dust-Free Timing Belt PARTNUMBER: 1679K213	https://www.mcmaster.com/drive-belts/width~3-8-1/teeth-location~teeth-on-one-side/pitch~0-200/	Shipping is not shown until order b/c that is mcmaster. Should be same as previous order.	1	8.38	8.4	9.40		LES	6358313		26-Mar	FedEx
22-Mar	McMaster	XL Dust-Free Timing Belt PARTNUMBER: 6484K226	https://www.mcmaster.com/drive-belts/width~3-8-1/teeth-location~teeth-on-one-side/pitch~0-200/		1	7.95	8			LES	6358313		26-Mar	FedEx
30-Mar	Stillwater Steel	2 - 2'x4' sheets of 1/8inch thick Aluminum (16 total square feet)	stillwatersteel.com	Can pick up from Stillwater steel	7.5	16	120	0						
4-Apr	Amazon	10 Gauge Fuse Holder - 10 AWG Inline Fuse Holder with 40 AMP ATC Blade Fuses (4pack)	https://www.amazon.com/10-Gauge-Fuse-Holder-Inline/dp/B088WRSPY1/ref=asc_df_B088WRSPY1/?tag=hyprod-20&linkCode=df0&hvadid=[illegible]	Shipping free with prime	1	9.99	10	0		jpc			7-Apr-22	
4-Apr	Amazon	IndusTec 50A 12VDC Automotive Toggle Switch SPST On-Off Marine High Current	https://www.amazon.com/IndusTec-Automotive-Toggle-Switch-Current/dp/B095BTB31W/ref=asc_df_B095BTB31W/?tag=hyprod-20&linkCode=df0&hvadid=[illegible]		1	8.99	9	0		jpc			7-Apr-22	
4-Apr	Amazon	Taidacent 2 Wires 5A 15A 20A 30A 40A 60A Slip Ring Collector Ring Rotary Electrical Contact (5A)	https://www.amazon.com/Taidacent-Collector-Rotary-Electrical-Contact/dp/B07bH8C141/ref=asc_df_[illegible]	got the 5A and 30 Amp versions	1	17.7	18	0		jpc			7-Apr-22	
4-Apr	Amazon	DZS Elec 12A DC-DC Step Down Buck Converter Low Ripple with Heat Sink 4.5V-30V to 0.8V-30V Vehicular Voltage Regulator	https://www.amazon.com/DZS-Elec-Converter-Vehicular-Regulator/dp/B071CWMRYD/ref=asc_df_B071CWMRYD/?tag=hyprod-20&linkCode=df0&hvadid=[illegible]		5	10.6	53	0		jpc			7-Apr-22	
4-Apr	Amazon	Dupli-Color - FP101 Scratch Filler& Primer Gray, 11 oz	https://www.amazon.com/Dupli-Color-FP101-General-Purpose-Sandable/dp/B000B6DG7C/ref=[illegible]		1	18.1	18	0		jpc			April 11, 2022 - April 13, 2022	
4-Apr	Amazon	Liquitex Professional Spray Paint, Cadmium Orange Hue, 12 Ounce	https://www.amazon.com/Liquitex-Professional-Spray-Cadmium-Orange/dp/[illegible]		1	17	17	0		jpc			April 11, 2022 - April 14, 2022	
4-Apr	Amazon	Dupli-Color - BCC0407 E7 Stone White Chrysler Perfect Match Automotive Paint - Aerosol, 8 oz.	https://www.amazon.com/Dupli-Color-BCC0407-Chrysler-Perfect-Automotive/dp/[illegible]		1	17.5	17	0		jpc			7-Apr-22	
4-Apr	Amazon	Dupli-Color BCL0125 Clear Exact-Match Automotive Top Coat, 8. Fluid_Ounces	https://www.amazon.com/Dupli-Color-BCL0125-Clear-Perfect-Automotive/dp/[illegible]		1	15	15	0		jpc			11-Apr-22	
4-Apr	Amazon	Johnson's Baby Powder, Naturally Derived Cornstarch with Aloe & Vitamin E for Delicate Skin, Hypoallergenic and Free of Parabens, Phthalates, and Dyes for Gentle Baby Skin Care, 15 oz	https://www.amazon.com/Johnsons-Baby-Powder-Cornstarch-Vitamin/dp/[illegible]		1	4.29	4.3	0		jpc			7-Apr-22	
5-Apr	Reynoldsam.com	Smooth-Cast 65D : Tr	https://www.reynoldsam.com/product/smooth-cast-semi-rigid/	Trial Unit	2	34.6	69	0						
5-Apr	Reynoldsam.com	Ure-Fil 11: Urethane thickener	https://www.reynoldsam.com/product/ure-fil-fillers/	Not rigid Unit. Just a heads up the website has the units in reverse order. We need a small amount so the 1lb Gallon is fine.	1	23.9	24	0						
7-Apr	Amazon	Chunzehui F-1011 6-Position 45A Power Pole Distribution Block Module, Connector Power Splitter Distributor Source Strip.	Amazon.com: Chunzehui F-1011 6-Position 45A Power Pole Di	Prime should be fast	2	33	66						April 11	
13-Apr	Powerwerks	Meter, DC Inline Power Analyzer, 45A Continuous, 12 Gauge, Powerpole Connectors	https://powerwerx.com/watt-meter-analyzer-inline-dc-powerpole?[illegible]		1	50	50	7	jpc					
13-Apr	Amazon	VIGRUE 1080PCS M2 M3 M4 Screws Nuts Assortment Set, Stainless Steel 304 Hex Socket Button Head Cap Screws Bolts Nuts Washers Kit with Allen Wrench, Silver	https://www.amazon.com/VIGRUE-M2-M3-M4-1080PCS-Stainless-Screws-Socket/dp/[illegible]		1	27.4	27	0	jpc				16-Apr	
13-Apr	Amazon	Rustark 330Pcs M2 M3 M4 M5 Metric Female Thread Brass Knurled Threaded Insert Embedment Nuts Assortment Kit	https://www.amazon.com/Rustark-Knurled-Threaded-Embedment-Assortment/dp/[illegible]		1	13	13	0	jpc				16-Apr	

17-Apr	Amazon	IEUYO 60 PCS 15/30/45 Amp Power Connectors Assortment Kit, Quick Disconnect Terminals Connectors, Battery Connector Modular Power Connector Kit Come Unassembled in Box, AWG10-20	https://www.amazon.com/Powerpole-Connectors-Assortment-Disconnect-Unassembled/dp/[illegible]		2	16.9	34		pc			20-Apr	
19-Apr	Amazon	https://www.amazon.com/GeeekPi-Raspberry-8GB-Starter-Kit/dp/[illegible]			1	299.99	299.99		pc			Monday, April 25	

Appendix B: Controls API

This API Assumes a port is being passed that corresponds to the correct communication port being used (ASSUMED TO BE SERIAL)

Kobuki.py

Movement (speed, radius, port)
Speed: Speed of the robot in mm/s
Radius: Radius of the turn (-1 or 1 for only turning motion)
Port: Serial port that is being used to communicate with Kobuki

Stop (port, duration)
Port: Serial port that is being used to communicate with Kobuki
Duration: duration of stop command, in second. This initiates a time.sleep()

Encoder.py

MoveLinear (distance, velocity, port)
Distance: Distance to move
Velocity: Speed and direction to move in the direction

Joystick.py

GetJoysticks()
Returns the names of the joysticks plugged in
ReadJoysticks()
Return the current values of the joystick output

UM7.py

SendReadPacket (port, address)
Address: Address of desired data
GetFirmwareRevision (port)
Returns the Firmware Version, used to test connection
ReadDataSmartly (port, address, data_length, decode)
Address: Address of desired data
Data_length: length of data, in BYTES
Decode: Default to false, used to decode data without preprocessing
FloatConverter (a, bits)
Use: Convert IEEE floating point registers to standard bytes
A: IEEE floating point value
Bits: default to 32, bitsize of the IEEE floating point
Returns IEEE floating point as standard INT

ToSigned16 (n)
Use: convert a number into a 16-bit signed integer
n: number to convert
Returns 16-bit signed version of n