Conceptual Design and Planning

Team 2: Nathan Gardner, Madison Kelly, Fatima Al-Heji, Luke McGill, Mark Beech
Electrical and Computer Engineering Department
Tennessee Technological University
Cookeville, TN
sngardner42@tntech.edu, mmkelly42@tntech.edu, fnalheji42@tntech.edu, lbmcgill42@tntech.edu, mlbeech42@tntech.edu

I. Introduction

The purpose of this project is to build a robot that will be sent to the SoutheastCon student competition in Orlando, Florida. This robot will represent Tennessee Technological University to schools around the Southeastern United States. This document will include further details on the team's conceptual design for the project.

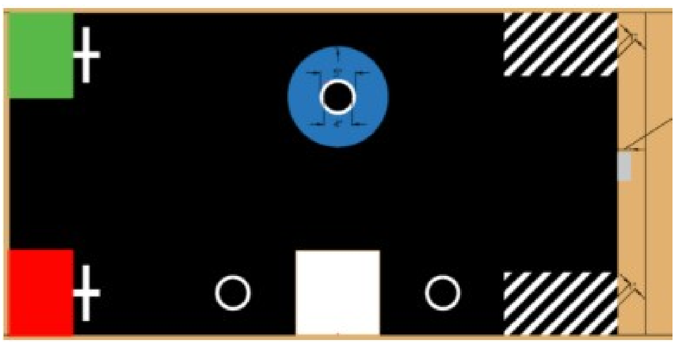

Fig. 1. Competition Area

II. Formulated Problem Statement

The robot's tasks include feeding the manatees and alligators, relocating the ducks to the pond, rebuilding the statues, or a stack of pedestals, depositing any unused objects, if there are any, in the recycling bins, and shooting animated fireworks for the finale after round completion.The robot must do all of these tasks fully autonomously.

There are ten ducks at the theme park, and one of the ten is a pink duck. The robot needs to bring the ducks back to the pond, and can place the pink duck on top of the reassembled statue for more points.

The statues must be rebuilt by the robot. Seven pedestals are in the arena and must be stacked by the robot. Statues can be two or three pedestals tall, and different point quantities are awarded for statues stacked with two or three pedestals. The point allocations are based on the location and if a duck is stacked on top, outlined in Figure 14. The arena has three white pedestals, two green pedestals, and two red pedestals. The color configurations are defined in Figure13, and the team can receive extra points for stacking a three tall statue with white, green, and red pedestals from the bottom to the top. Points can also be obtained by stacking pedestals in any color order to create statues, but this results in less points.

The robot must accurately move to specific areas in the arena such as the alligator aquarium attraction, manatees aquarium attraction, the pond attraction, duck statue attraction, recycling attraction, and the switch box.

Another task is to feed the alligators and manatees in their designated aquariums the correct color food chips. Each team will be provided with three green and three red food chips for the manatees and alligators respectively, and these will be placed next to the robots starting position. The food chips can be preloaded into the robot by one of the team members during the setup phase. Game points will be awarded for feeding food chips successfully to either animal, but more points will be awarded for feeding the correct food chips to the correct animal.

After completing each task, all unused items can be placed in the recycling area for additional points. This area is used to dispose of items that were not used in previous tasks from the field, if there are any unused items.

The last objective is the fireworks display. The theme park has a daily fireworks display to signify the end of the day. Activating the display will define the end of the round. There will be a horizontal switch that is to be connected to a Raspberry Pi and a computer monitor. The switch, when flipped, will run the program on the Raspberry Pi to play a five second fireworks video. The code may be in Python or Java, and must run on the Raspberry Pi. The video file format must be MPEG. Duck Gardens will provide a complimentary fireworks video if the team chooses not to make one; however, higher points will be awarded to videos based on creativity, clarity, and production quality.

III. Shall Statements

The shall statements are outlined in the project proposal, and will define the scope of this project. The following shall statements come from the team's revised project proposal.

Shall design an autonomous robot with a single start button, allowing the robot to start moving through its environment.

The robot will have a single emergency stop button at a point that is easily accessible and can be safely reached, which will shut down all physical movement performed by the robot in the case of an emergency.

Shall have a self-latching emergency stop push-button that has a positive operation. The button shall not be a graphical representation or a flat switch based on NFPA 79 - 10.7.2. [1]

This constraint addresses the need for the addition of practical engineering standards.

Shall design an autonomous robot that will earn all possible points for delivering the correct food chips to the manatees and alligators.

Shall design a robot which can find and move 90% of the ducks into a holding area connected to the robot. Shall locate the duck pond in the center of the arena within plus or minus one inch of error tolerance.

Shall transport and place 90% of the ducks stored inside the holding area to their final location in the duck pond.

Shall design an autonomous robot that will be able to flip a switch from left to right.

Shall design an animated fireworks MPEG video and write a Python script that will play the video when activated by the switch.

Shall find and move at least five pedestals into an internal holding area inside the robot.

Shall assemble one statue that is three pedestals tall and one statue that is two pedestals tall using all five pedestals obtained in order to maximize points obtained based on discussion in weekly meetings.

Shall place statues entirely inside the white inner circles within plus or minus one inch of error tolerance.

Shall place remaining unused pedestals that are held after the five required pedestals have been obtained within the internal holding area inside the robot.

Shall move the extra pedestals obtained over the five required pedestals in the recycling area.

Shall abide by the Department of Energy Standard 79 FR 7845 in our purchase or design of wall warts for energy conservation and efficiency. [2] This constraint addresses an ethical consideration by better ensuring the safety of the team and all others interacting with the robot as well as the addition of ethical standards.

Shall dispose of battery waste considering Environmental Protection Agencies Standard 40 CFR Part 273, specifically section 273.13 for battery waste disposal throughout the process of the project. This constraint will lessen the broader impact the team has on the environment as well as the addition of broader impacts.

IV. Statement of Ethical, Professional, and Standards Considerations

The team has diligently considered the ethical concerns, professional concerns, and potential standards that the project must meet. All of these will add constraints to the project, and affect design.

This robot will represent the Electrical and Computer Engineering Department and Mechanical Engineering Department of Tennessee Tech University on the regional level to other universities around the Southeastern United States. This representation could potentially affect how others view the team's school as well as fellow classmates. The team's stewardship of the title of the Tennessee Tech IEEE Chapter with the addition of a successful performance could make a difference on which students decide to pursue their education from our engineering program. It could also attract new potential employers who had never considered hiring students from Tennessee Tech to consider recruiting students from our program. This competition could reveal new opportunities for students that did not even participate in the competition.

Other than just professional impacts, this project could prove to have some ethical impacts as well. Any machine or robot with any sort of movement mechanism could cause safety concerns via human error, mechanical failures and improper insulation around any hot electrical wires. To address this issue, the team will need to make additional fail safes within the programming of the tasks to ensure the safety of everyone involved.

The environment could be negatively affected by the robot. Battery waste when not disposed of properly can cause damage to wildlife in the area where it is disposed. The batteries could start to break down and leak battery acid onto the ground or even into a body of water. To address this, the team will have to be mindful of where they are disposing of waste throughout the project.

The first standard that the team considered was a safety standard. The NFPA 79 - 10.7.2 standard, as stated previously, requires an emergency stop push-button that is self-latching and has a positive operation. The implementation of this emergency stop button will cause all robot motion to cease in the case of an emergency. The stop button will decrease the safety concerns of the robot itself in the event of a malfunction or emergency situation. By applying this standard, the team will be more familiar with the notation and functionality of the button. This safety standard exists to limit the number of latch or connection malfunctions for the emergency stop button.

The next standard the team took into consideration was the Department of Energy Standard 79 FR 7845. This standard has to do with the ethical considerations the team must abide by. This standard saves energy which protects the environment from CO2 and conserves the earth's natural resources. Proper care for the environment will be considered throughout this project, and specifically around efficient wall wart design.

V. System Diagram

A. Power System

The power system will be powered from a 120 VAC, 60 Hz source (standard wall plug), and will be sent to the robot's power supply, charging the robot's battery. The battery, as shown in Figure 1, will be connected to the e-stop which will ensure that the emergency stop button has not been pressed in order to begin operation. If the emergency stop is not pressed, the on/off switch will be able to operate in order to switch on the robot. It will then be sent to a power regulator that will control the wattage sent to all the various portions of the robot such as the microcontroller and the motors for locomotion or other tasks.

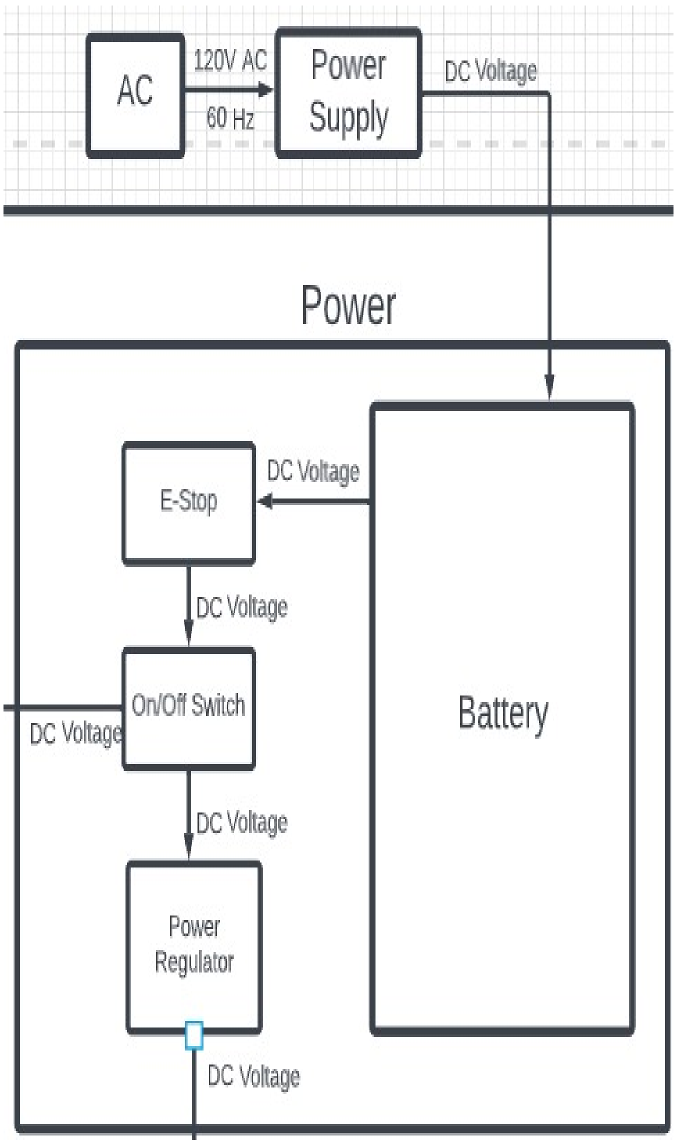

Fig. 2. Power System

B. Controller

The robot will be controlled via a microcontroller (MCU). The team will have to determine the appropriate microcontroller based on the general purpose input/ output (GPIO) constraints, as well as computational constraints for location, vision, and object manipulation logic constraints. The microcontroller will generate Pulse-Width Modulation (PWM) signals to the electronic speed controllers contained within the locomotion subsystem. PWM will be a good choice for the locomotion in order to better control the speed and direction of the wheels. The robot will need to traverse the playing board at a certain speed in order to ensure its entire predetermined path is covered within the three minute time constraint. The MCU will also send a PWM for motor speed control and likely a serial communication protocol for commands to the object manipulation subsystem. Object manipulation devices with public libraries will be chosen so that the team has a pre-built communication library to build on to create the interconnection communication architecture for each device (sensor, motor, speed controller, etc.).

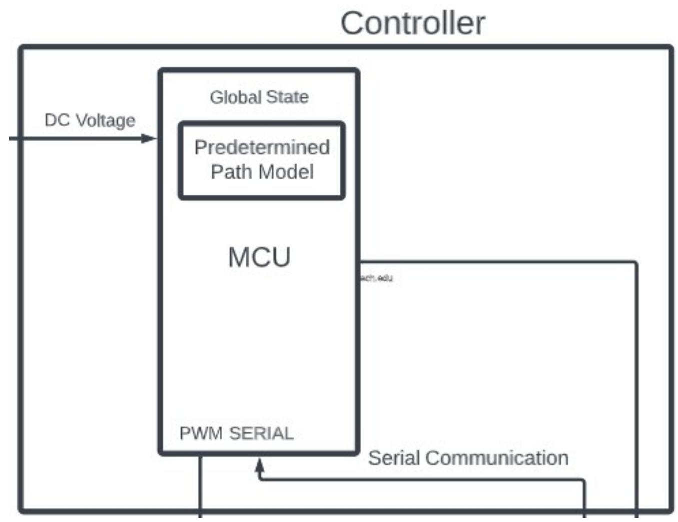

Fig. 3. Controller

C. Locomotion

Subject matter research was required on mecanum wheels in order to design the locomotion subsystem. Several implementations of mecanum wheels are popular, some with two motors and some with four motors. The range of motion is however limited in the two motor implementations and the robot is unable to spin while the center of the wheel remains stationary relative to the ground. For this reason, the main robot has been designed to have four motors for agile movements in the area required for duck and pedestal manipulation, while the microbot only has two, likely significantly lower torque motors because the stationary relative to the ground rotation has been determined by the team to be unnecessary for the microbot.

The locomotion subsystem consists of four electronic speed controllers that are passed PWM signals from the microcontroller, four drive motors, and four mecanum wheels. As previously mentioned, the electronic speed controllers will allow the robot to traverse the board at a certain speed and in a certain direction as the team will predetermine. Because of the team's strategy of planning a path along the entirety of the board, the robot will need to make some sharp turns. For that reason, the choice of using four separate wheels driven by four separate motors in order to have more control over the movement, and more specifically, the turning, of the robot. This subsystem will also be directly connected to the power regulator which will supply each electronic speed controller with some DC voltage that is adequate enough to drive the robot.

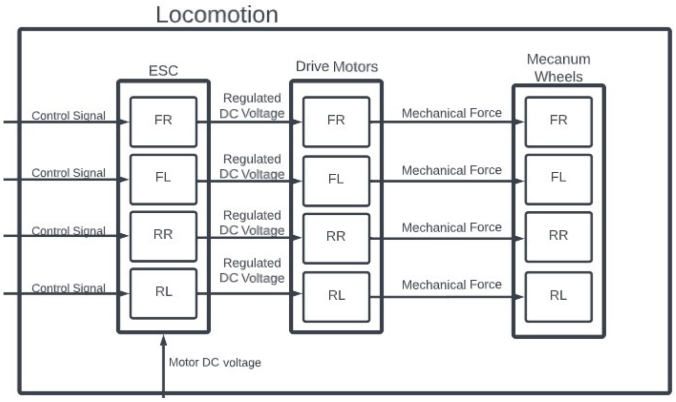

Fig. 4. Locomotion

D. Vision System

The vision system includes a sensor network for micro and macro measurements. Conceptually, different sensor networks are needed to detect position in the arena on a near or far scale because imaging and distance sensors have ranges in which they are effective. The vision system also includes a vision and location dedicated microcontroller for processing vision sensor data and updating data structures that can be more easily read by the main microcontroller unit in the main controller system.

The vision system block communicates with the controller subsystem through a serial communication protocol. The internal communication between the sensor networks and the vision and location microcontroller will need to either be an analog signal or a very high speed digital signal. As an example of this, infrared distance sensors generally output an analog voltage which represents the distance with a varying voltage value. This can then be read by the vision and location microcontroller and processed and stored.

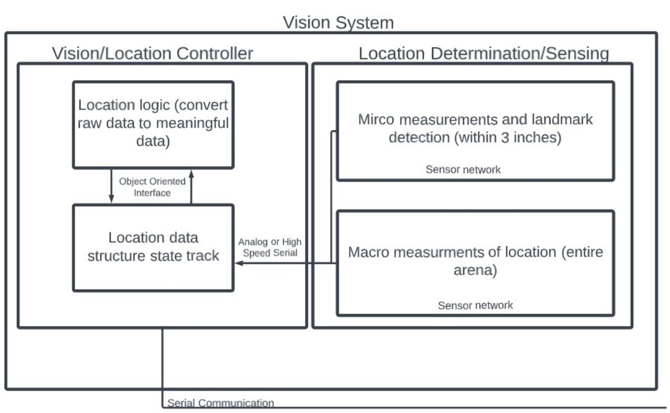

Fig. 5. Vision System

E. Object Manipulation

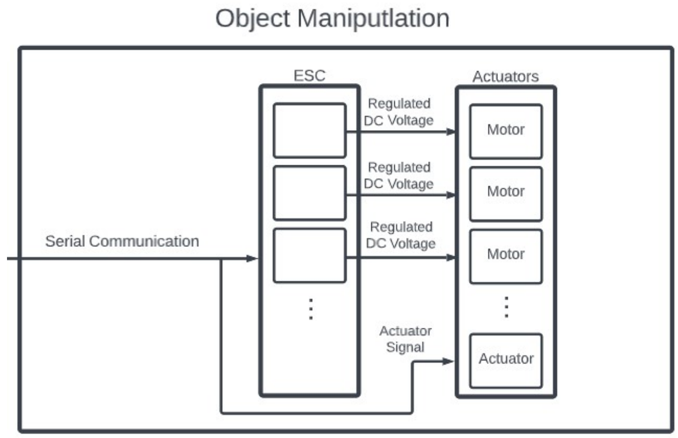

Fig. 6. Object Manipulation

The robot moves throughout the arena, there will be three or more states that make up its position: X location, Y location, and its orientation relative to a nearby landmark, with possibly more states if the robot has many sensors. The path is a sequence of position states that connect the start and the end state and determining this sequence is called predetermined path planning. The team is trying to dictate precisely how the robot moves through the environment, within +/- 1 inch. By setting the environment map (competition arena), the distance solution can be solved by connecting the start and the goal with strategic lines.

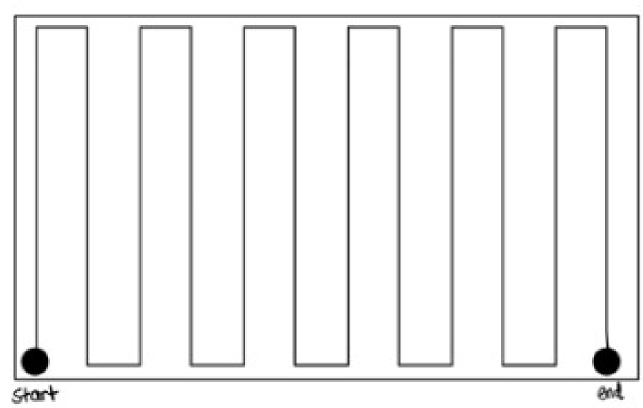

Fig. 7. Predetermined Path

The algorithms work by discretizing the environment, or breaking it up into discrete points or nodes, then finding the distance to the goal considering only the red nodes and the edges between the nodes. The team will calculate the distance that the robot needs to travel between nodes and the distance traveled from the start to end state.

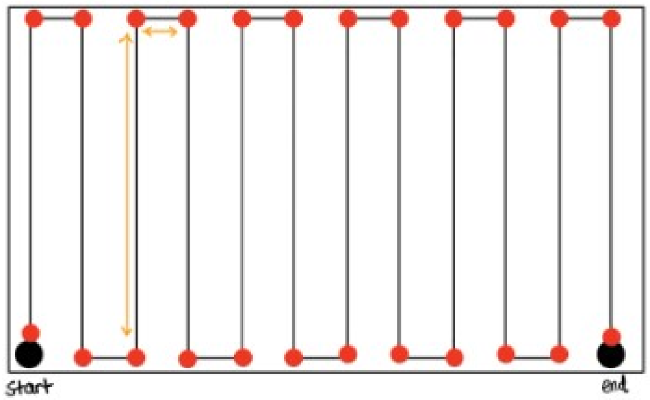

Fig. 8. Predetermined Path with Discrete Paths

While traveling the predetermined path, the robot gathers objects in its path. This is done with a conveyor system at the "mouth" of the robot. This is similar to how a snow plow works, except we are gathering the objects and not pushing them out of the way. The path will also need to overlap in order to cover the entire area of the arena, almost like a lawnmower overlaps its lines to mow the entire lawn. The mouth is a large hole on the front of the robot which is open in the direction that the robot is moving and towards objects in the robots path. The robot will move without stopping while obtaining objects in its path. Constant movement is needed in order to save time so that the robot has the ability to cover the entire area in a reasonable amount of time. The predetermined path can be designed so that the robot will pass the recycling area at the end of its arena sweep.

While the objects are entering the robot's mouth, these objects are stored internally in the robot as the robot travels around the arena. The inner-mouth, which is encountered after the object has entered the robot, has two holes which will physically distinguish between the ducks and pedestals based on shape and size. This physical distinction is used so that complex computer vision is not a necessity, and this physical distinction design decision refines our scope and focus for the project. The first section is designed to only allow the ducks to pass into the ducks container and the second section is designed to only allow the pedestals to pass into the pedestal container. The ducks are stored separately from the pedestals and in a different orientation. The pedestals are stacked in silos and the ducks are stored in a bucket-like container.

There is a chance to have a problem when the objects are stuck inside and blocking the robots mouth. There will be two holes inside the robot's mouth, the possible issue is the duck may block the hole or the pedestal may block the ducks' hole. This will be addressed with a plunger like shaft which can be used to clear out the mouth and to reset objects so they are able to follow the correct path and be correctly distinguished.

Silos are used for the pedestals so that they are stacked by the robot easily, which will have time later, and allow the statues, or stacks of the pedestals, to be dropped onto the arena with a false bottom.

Once all or most objects (ducks and pedestals) are obtained, the robot must move towards their final destination. The ducks should be placed in the duck pond and the pedestals on each white inner circle near the starting area. This should be done after the sweep of the entire field is complete. Once it is complete, the robot should head in the general direction of the pond and then use its microlocation detection to find the exact location of the pond in order to eliminate error with the duck pond placement. After dropping the ducks off at their location, discussed in the placing section, the robot should head in the general direction of one of the white inner circles and then use its microlocation to find the exact location,similar to microlocation with the duck pond. After statue placement, the robot should perform the same actions to find the second white inner circle.

After the robot has traveled to the landmarks where objects need to be delivered, the robot will begin placing all held objects in the correct locations. The pedestals are already stacked and will be placed onto their statue locations, or the inner white circles. The silos will allow the pedestals to be placed already stacked to create statues either two or three pedestals tall. Any remaining pedestals that will not be stacked into statues will be placed in the recycling attraction. The ducks collected will be placed inside the duck pond from the bucket. The bucket-like holding area will likely have a false bottom that can be removed so that the ducks can be in physical contact with the pond and be self contained once placed, as per the game rules [3].

During the final seconds of the competition, the robot will need to flip a switch right to activate to start the animated fireworks show display on the monitor near the arena. The switch is located on the far right side of the arena. The switch will need to be flipped with a small motor, likely a servo motor. This will need to be the final manipulation done for the round, and will signify the end of the round.

The interface between the location and vision microcontroller and the main microcontroller will need to be serial communication so that the location data can be sent to the main microcontroller.

Internally to the Object Manipulation block, communication will need to take place to drive the motors based on commands from the location and vision microcontroller. This will need to be a pulse width modulated signal where the duty cycle will represent the torque on the motor.

F. Microbot

The microbot system will be much smaller than the main bot and will only be responsible for one task. The microbot will be responsible for delivering the correct food chips to the manatees and alligators at the beginning of each round. This system will consist of five main subsystems within it including power, locomotion, ejection, controller and the connection to the main bot. In the following paragraphs, an overall description of each subsystem will be explained in as much known detail as possible.

The power subsystem consists of a battery that will be chargeable via a wall wart just like the main robot, but this will be charged from a different wall wart than the main robot. The battery will be connected to a regulator that will then be connected to the controller subsystem and the speed controllers used in the locomotion subsystem and the ejector subsystem. The regulator will be similar to the one mentioned for the main robot.

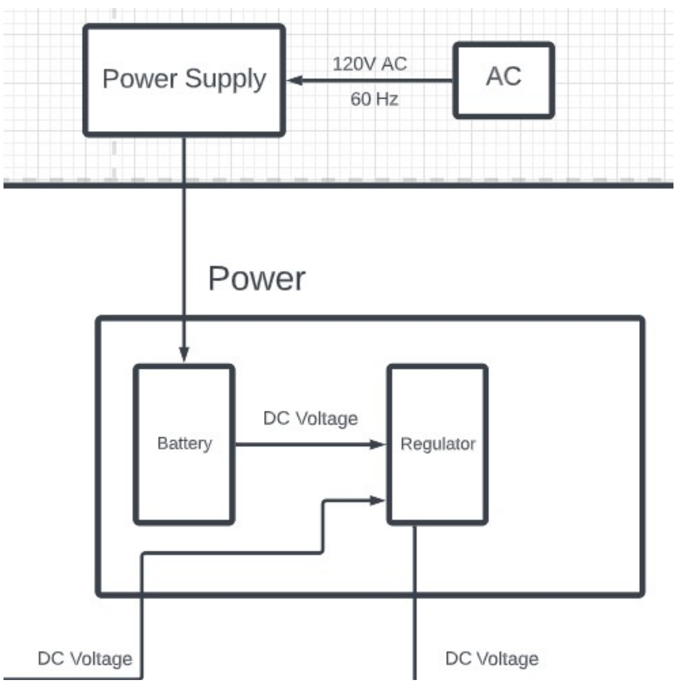

Fig. 9. Microbot Power

The controller will be used to control the speed controllers for the locomotion subsystem and take input from the color sensor in order to control the ejector speed controllers for the motors. The exact microcontroller/microprocessor has not been determined at this point in time. The controller will take in inputs from the color sensor and the regulator and output to the locomotion subsystem and the ejector subsystem.

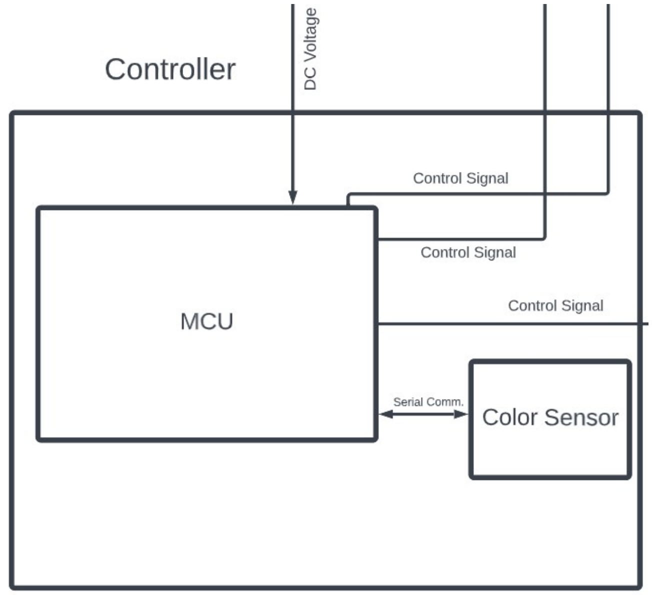

Fig. 10. Microbot Controller

The locomotion subsystem will consist of the speed controllers and motors that will drive the wheels on the microbot. The speed controllers and motors will most likely run off of a DC voltage supplied from the controller. The microbot will be able to move forward or backwards in order to reach both of the feeding areas.

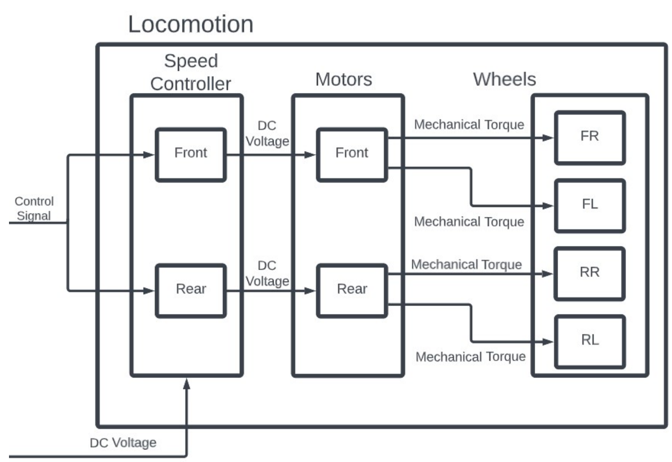

Fig. 11. Microbot Locomotion

The ejector subsystem is responsible for ejecting the food chips to the correct animal based on the color of the ground beneath the microbot. The color will be read via a color sensor as mentioned previously. The exact ejection mechanism has not been decided on at this time, but the food chips will need to be ejected from the microbot into the correct location each round.

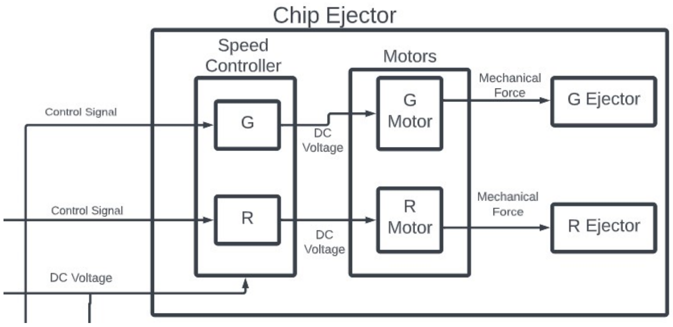

Fig. 12. Microbot Chip Ejector

The connection to the main bot will be some kind of mechanical connection that will be detached once the start button for the main robot is pressed. This will most likely be some kind of small latch that is holding onto the chassis of the main robot that can be opened by applying some voltage to it. This detachment will then enable the regulator, thus powering the microbot.

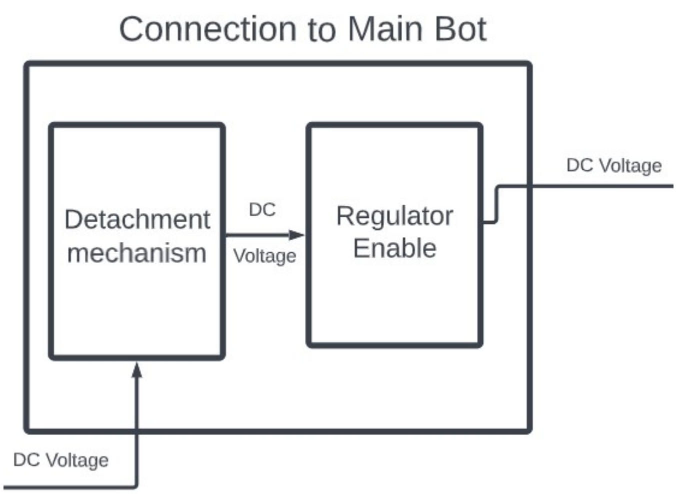

Fig. 13. Microbot Connection to Main Bot

G. Detailed Constraints

The most critical constraints that needed to be considered for this robot conceptual design is the robot's chassis size. The rules document restricts the size of the robot to 1'x1'x1' three-dimensional box. All components and subsystems must fit inside this 1'x1'x1' cube. This places size constraints on every other subsystem listed in this document.

The second most critical constraint is the power system, which places constraints on every subsystem that requires any form of electric energy, which is every top-level system outlined above other than the chassis and the power system itself.

Systems that are directly constrained by the power system are the controller system, the locomotion system, the vision system, object manipulation, and the microbot.

VI. Timeline and Work Breakdown

Conceptual Design and Planning	*Assignees*
Documentation	
Introduction	Madison Kelly
Formalated Problem Statement	Fatima Al-heji, Nathan Gardner
Shall Statements	Madison Kelly
Ethical, Professional, and Standards Considerations	Madison Kelly
System Diagram	Fatima Al-heji, Nathan Gardner
Timeline and Work Breakdown	Fatima Al-heji, Nathan Gardner
Citations	Nathan Gardner
System Diagram Design	
LucidChart Diagrams	Mark Beech, Luke Mcgill, Nathan Gardner
Power System	Luke Mcgill
Controller	Nathan Gardner
Locomotion	Luke Mcgill
Vision System	Nathan Gardner
Object Manipulation	Fatima Al-heji, Nathan Gardner
Microbot	Mark Beech
Miscellaneous	
Gantt Chart	Nathan Gardner

Fig. 14. Competition Area

The work breakdown for conceptual design is above and has people assigned to each task both for documentation and for system diagram design. The updated Gantt is attached in the appendix in Figure 17.

VII. Citations

References

[1] "NFPA 79," NFPA 79: Electrical Standard for Industrial Machinery. [Online]. Available: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=79. [Accessed: 13-Oct-2022].

[2] "The Federal Register," Federal Register :: Request Access. [Online]. Available: https://www.federalregister.gov/documents/2014/02/10/2014-02560/energy-conservation-program-energy-conservation-standards-for-external-power-supplies. [Accessed: 13-Oct-2022].

[3] "IEEE SoutheastCon 2023 hardware competition," IEEE SoutheastCon 2023 Hardware Competition. [Online]. Available: https://ieeesoutheastcon.org/wp-content/uploads/sites/392/IEEE-SoutheastCon-2023-Hardware-Competition-Rules-v1.4.pdf. [Accessed: 12-Sep-2022]

VIII. Appendix

Points	Task
36	Three pedestals stacked on the duck pond statue location inside the inner circle and in the correct order (base level – white, second level – green, third level – red) with a pink duck on top
33	Three pedestals stacked on the duck pond statue location inside the inner circle and in the correct order (base level – white, second level – green, third level – red) with a yellow duck on top
30	Three pedestals stacked on the duck pond statue location inside the inner circle and in any order with a pink duck on top
27	Three pedestals stacked on the duck pond statue location inside the inner circle and in any order with a yellow duck on top
27	Three pedestals stacked on the duck pond statue location inside the inner circle and in the correct order (base level – white, second level – green, third level – red)
24	Three pedestals stacked on the duck pond statue location inside the inner circle and in any order
24	Three pedestals stacked on the duck pond statue location inside the outer circle and in the correct order (base level – white, second level – green, third level – red) with a pink duck on top
21	Three pedestals stacked on the duck pond statue location inside the outer circle and in the correct order (base level – white, second level – green, third level – red) with a yellow duck on top
18	Three pedestals stacked on the duck pond statue location inside the outer circle and in any order
18	Three pedestals stacked on the duck pond statue location anywhere in the park and in the correct order (base level – white, second level – green, third level – red) with a pink duck on top
15	Three pedestals stacked on the duck pond statue location anywhere in the park and in the correct order (base level – white, second level – green, third level – red) with a yellow duck on top
12	Three pedestals stacked on the duck pond statue location anywhere in the park and in any order
30	Two pedestals stacked on a non-pond statue location inside the inner circle and in the correct order (base level – white, second level – green) with a pink duck on top
27	Two pedestals stacked on a non-pond statue location inside the inner circle and in the correct order (base level – white, second level – green) with a yellow duck on top
24	Two pedestals stacked on a non-pond statue location inside the inner circle and in any order with a pink duck on top

21	Two pedestals stacked on a non-pond statue location inside the inner circle and in any order with a yellow duck on top
21	Two pedestals stacked on a non-pond statue location inside the inner circle and in the correct order (base level – white, second level – green)
18	Two pedestals stacked on a non-pond statue location inside the inner circle and in any order
18	Two pedestals stacked on a non-pond statue location inside the outer circle and in the correct order (base level – white, second level – green) with a pink duck on top
15	Two pedestals stacked on a non-pond statue location inside the outer circle and in the correct order (base level – white, second level – green,) with a yellow duck on top
12	Two pedestals stacked on a non-pond statue location inside the outer circle and in any order
12	Two pedestals stacked on a non-pond statue location anywhere in the park and in the correct order (base level – white, second level – green) with a pink duck on top
9	Two pedestals stacked on a non-pond statue location anywhere in the park and in the correct order (base level – white, second level – green) with a yellow duck on top
6	Two pedestals stacked on a non-pond statue location anywhere in the park and in any order
2	Placing a duck, food chip, or pedestal in the recycling attraction
7	Each correct food chip fed to the manatees
7	Each correct food chip fed to the alligators
3	Each incorrect food chip fed to the manatees
3	Each incorrect food chip fed to the alligators
5	Each duck in the pond
3	Each duck, chip, or pedestal in a recycling area
10	Start the fireworks
10	Auto-start feature used and successful

Fig. 15. Scoring for Southeast Con Competition [1]

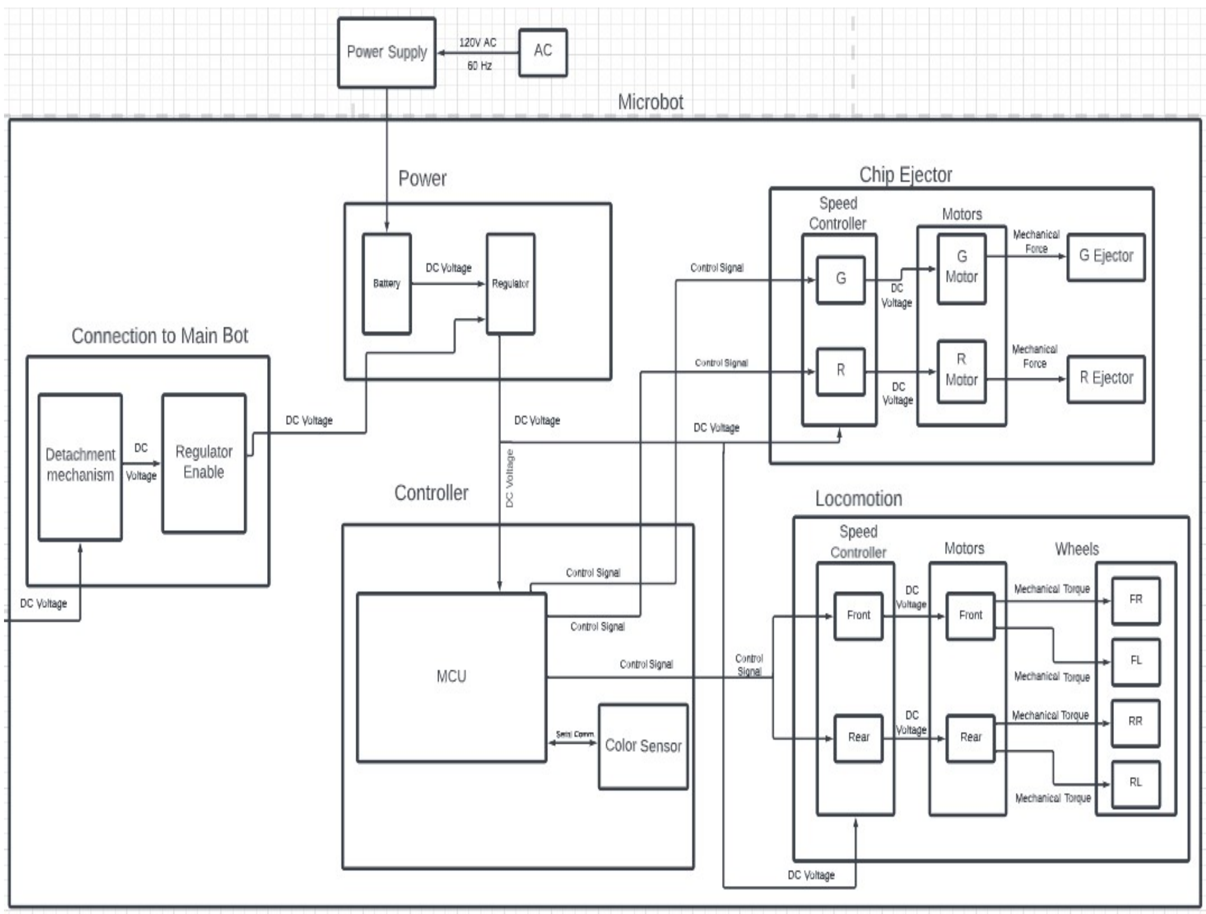

Fig. 16. Complete Microbot System Block Diagram

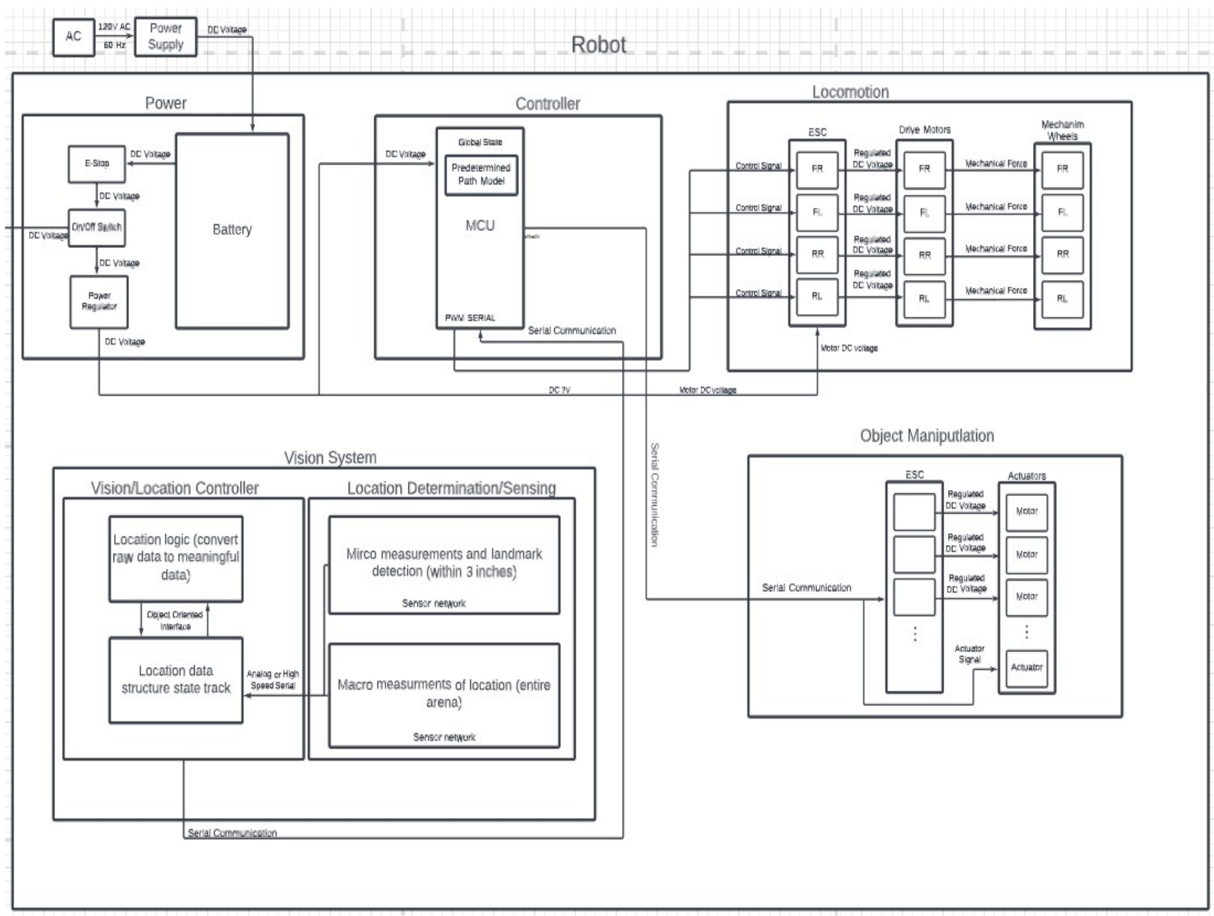

Fig. 17. Complete Robot System Diagram

IX. Appendix

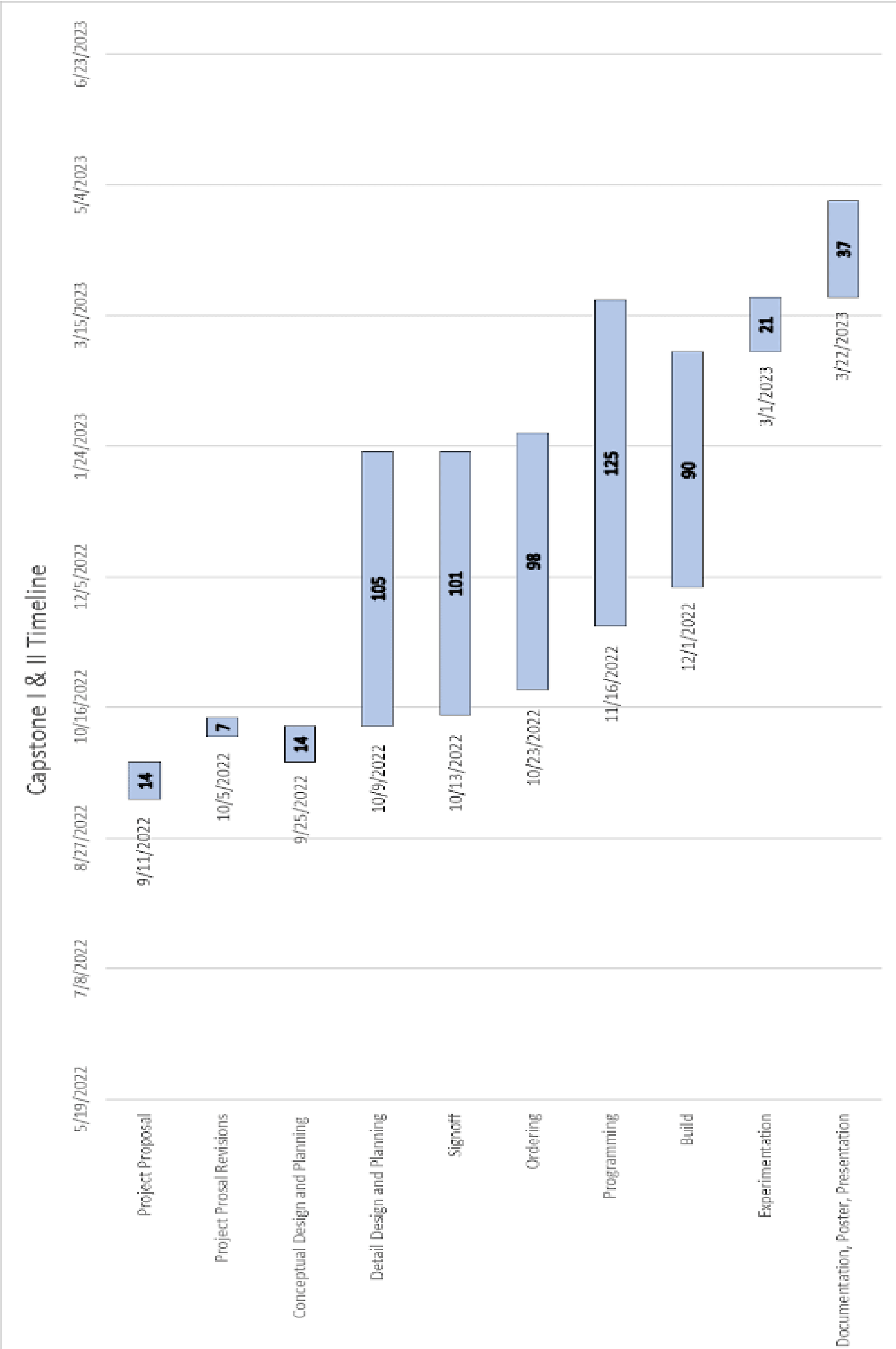

TABLE I
Timeline for Capstone I and II