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.

This conceptual design document is meant to fit into the larger process of engineering design in that it explains the goal of this project and specific things that any stakeholders should understand. The document sets the team up for detailed design, which will be the next step after this document has been released. This document contains the following fully formulated problem statements, fully decomposed conceptual solution, constraints and where they arise from, how the constraint will be analytically validated, and a detailed design schedule.

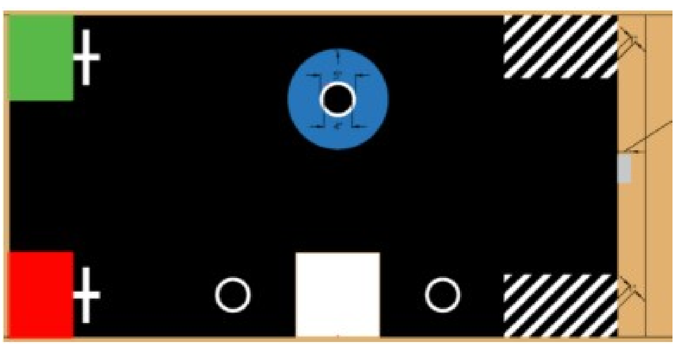

Fig. 1. Competition Arena

II. Formulated Problem Statement

A. 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.

The first task is to feed the manatees and alligators 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 will 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.

The second task is relocating the ducks to the pond. The rules outline that for every duck that ends up entirely in the inner pound by the end of the competition will award five points each. Ducks will be collected by the robot in a sweep of the arena, and will be stored internally inside the robot until the sweeping path is completed. The robot will then move all of the ducks to the center duck pond and drop them all. The ducks will sit in the duck pond from that point to the end of the round.

The third task is rebuilding a stack of pedestals. The collection plan for pedestal stacking is very similar to the duck collection plan mentioned previously, but pedestals will be placed in a separate storage area where they can be stacked internally to the robot, which will likely be realized as a silo. The silos will then be moved to the two inner white circles, so they can be dropped with a false bottom into the inner circles for point allocations determined as valuable in the planning process.

Unused pedestals will 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 pedestals left after the five needed to complete the two statues.

The final 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.

B. 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.

1) Shall design an autonomous robot with a single start button, allowing the robot to start moving through its environment.
2) 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.
3) Shall create an easily reachable (not blocked by motors, chassis, wheels, or any other object) emergency cut off switch to allow the team to disable the robot in the case of an emergency.
4) 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.
5) Shall represent knowledge using IEEE standard IEEE 1872-2015 Ontologies for Robotics and Automation used to represent knowledge about the typography of the arena. This ontology will be used to represent relationships between the landwards in the area and what is known. It should not change during the competition, so it can be predefined. [2]
6) Shall design an autonomous robot that will earn all possible points for delivering 100% of the correct food chips to both the manatees and alligators.
7) Shall design a robot which can find and move 90% of the ducks into a holding area connected to the robot.
8) Shall locate the duck pond in the center of the arena within plus or minus one inch of error tolerance.
9) Shall transport and place 90% of the ducks stored inside the holding area to their final location in the duck pond.
10) Shall design an autonomous robot that will be able to flip a switch from left to right.
11) Shall design an animated fireworks MPEG video and write a Python script that will play the video when activated by the switch.
12) Shall find and move at least five pedestals into an internal holding area inside the robot.
13) 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.
14) Shall place statues entirely inside the white inner circles within plus or minus one inch of error tolerance.
15) Shall place remaining unused pedestals that are held after the five required pedestals have been obtained within the internal holding area inside the robot.
16) Shall move the extra pedestals obtained over the five required pedestals in the recycling area.
17) Shall abide by the Department of Energy Standard 79 FR 7845 in the team's purchase or design of wall warts for energy conservation and efficiency. [3] 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.
18) Chassis will be designed with an aluminum frame. Aluminum is abundantly available under the earth's surface and mining can be offset with post-mining rehabilitation and efficient recycling. This constraint will lessen the broader impact the team has on the environment.

III. 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 the Tennessee Tech engineering program. It could also attract new potential employers who had never considered hiring students from Tennessee Tech to consider recruiting students from the 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 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. In consideration of ethics, intentional interference at the competition will not be tolerated, and power considerations will be taken for any possible SONAR or LIDAR transmitter/receiver pair so that it does not project noise into the environment and interfere with other competitors' robot operation.

IV. System Diagram

System diagrams are explained and attached in the following section. The subsystems are listed in order of priority from highest to lowest and are listed in the order they will be designed in.

A. Consumption

While traveling the predetermined path, the robot gathers all objects, namely the ducks and pedestals, in its path. This is done via a conveyor system at the "mouth" of the robot. The path will be designed in order to cover the entire arena efficiently, similar to mowing a lawn. The mouth is a large hole on the front of the robot which is open in the direction that the robot is moving. The mouth will have some kind of funnel that will direct the objects into the conveyor system. 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 per the competition constraints. The predetermined path can be designed so that the robot will pass the recycling area at the end of its arena sweep. All objects will be sorted and moved into a holding area described below.

The consumption subsystem will consist of the conveyor mechanism that "eats" the objects and the motors associated with the conveyor system. The motors will be controlled by a DC voltage supplied by the power system.

The mechanical engineering team will create simple prototypes to serve as a proof of concept. These prototypes will test the mechanical functions of the conveyor belt system to ensure each object is grabbed and moved into the robot.

B. Storage

After the objects enter the robot's mouth, the objects are sorted and stored internally in the robot as the robot travels around the arena. The exact sorting mechanism has not been decided yet, but there will be a mixed solution of mechanical and electrical design. The ducks will be sorted passively, while the pedestals will be sorted actively. By this, it is meant that the sorting action will only intervene for pedestals, while the ducks just keep going across the conveyor and eventually end up in their storage space. The ducks and pedestals will need to be stored separately, so they can be delivered where they need to go at the end of the round. The pedestals are stacked in silos that will allow up to three pedestals to be stacked internally, while the ducks are stored in a bucket-like container. This bucket will be internal at the beginning of the round and rotate out to act as a trailer once the round begins to work around the size constraints. This trailer will be behind the robot, opposite of the mouth and will have two wheels to allow the trailer to roll smoothly.

There is a chance to have a problem when the objects are stuck inside and blocking the robots mouth. The possible issue is the duck may block the pedestal hole and get stuck.

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. These silos will have a removable bottom allowing the pedestals to be placed onto the arena stacked. 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 [4]. The duck bucket, or trailer, will have a removable bottom as well that will be removed using a rack and pinion system.

The bucket and silo designs will be prototyped by the mechanical engineering team to verify that this storage system will be space efficient and work well with the overall design.

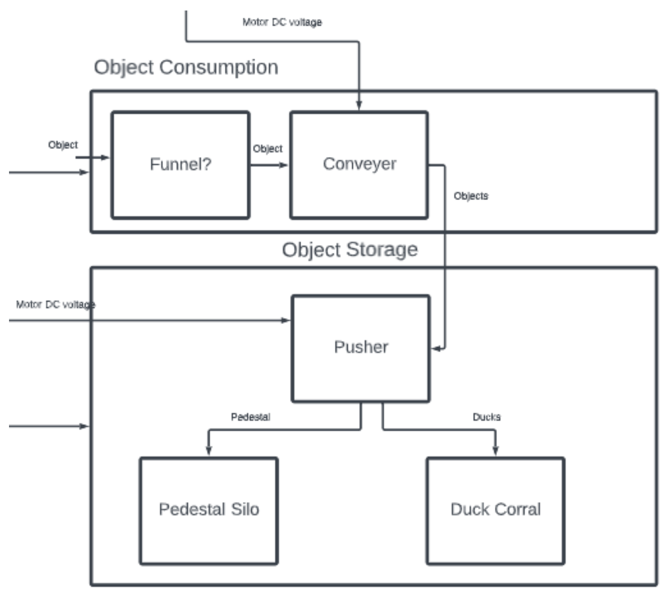

Fig. 2. Object Consumption and Object Storage Subsystems (two subsystems together for clarity)

C. Vision

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 most 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.

Vision systems have two major components such as orientation, and range finding. One of the robot's tasks is identifying specific spots such as the pond and the vision system can address that task. The vision system will use the camera's predetermined x-y coordinate system and the image of the component that is recorded in memory. The vision system and vision controller use this information to determine locality based on the landmarks in the arena near it.

A camera in a vision system is used to measure the amount of light reflecting off an object and to clearly detect edges and colors.

Lighting systems are used to display desired aspects of objects and produce contrast between objects and backgrounds. The application of vision depends on the choice of light type. The vision system will use one of the three types of light sources, incandescent, fluorescent, or laser lighting.

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 a very high speed digital signal or analog signal. For example, 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, processed, and stored.

The vision subsystem consists of an object tracker implementation using a vision system that considers rotation, and scaling for a range of distinct objects. The arena landmarks are represented by color, form, and size which allows for detection at different distances.

Sensing and digitizing are two processes that result in a visual image with enough contrast to be digitalized and kept in the computer's memory. Image processing and analysis is the process of reducing the amount of data in the digital image and interpreting the image. Preprocessing, segmentation, description, recognition, and interpretation are other divisions of this function. An image is segmented into interesting objects. The computation of traits such as size, form, and other attributes that can distinguish one item from another is known as description. The object is defined by recognition. The team plans to use open source computer vision algorithms for image processing within the vision system. This system will now be doing object detection, but will be identifying important landmarks in the arena. The components of a full vision system are hardware and software for sensing, processing, and using the results to control the robot.

The light source illuminates the object in the fundamental imaging process, and the camera records the reflected light. With the aid of the proper transducers, the image created by the camera is turned into an analog signal, such as voltage. The analog voltages are turned into an algebraic array through digitization. The image to be processed and interpreted by the computer using predetermined algorithms is contained in this array.

ADC is needed to transform the analog picture signal from the camera into a digital format that can be processed by a computer. A given pixel array is stored in the Frame Grabber, an image storage and computing device. Additionally, noise filtering, picture augmentation, image description, and image storing are all included in image processing. Last but not least, the essential necessity of a vision system is to produce a suitable way of encoding visual data.

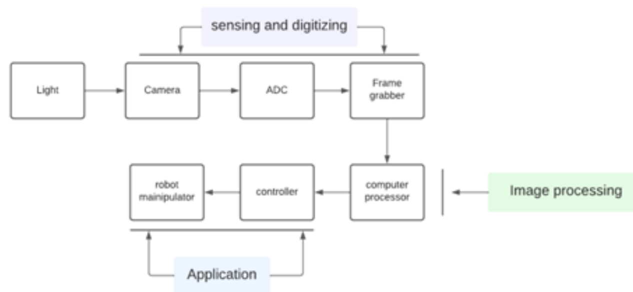

Fig. 3. Vision Diagram

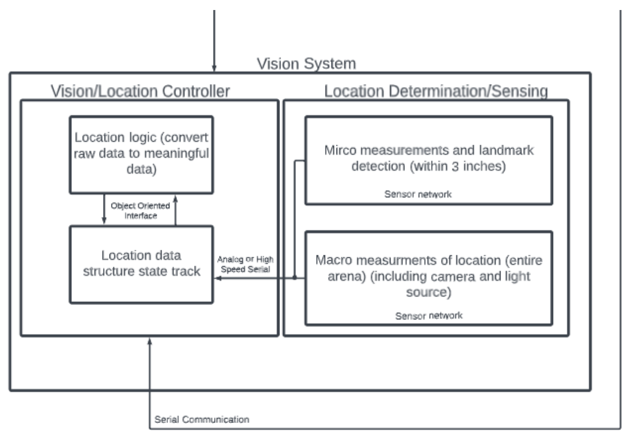

Fig. 4. Vision System

D. Controller

The robot will be controlled via a microcontroller (MCU). The main constraints on the microcontroller subsystem are general purpose input/output (GPIO) constraints as well as computational constraints for location, vision communication, and object manipulation logic constraints. The microcontroller will generate Pulse-Width Modulation (PWM) signals to the various motor drivers 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 quickly in order to ensure its entire predetermined path is covered within a rigorous time constraint, or three minutes for each round. The robot will most likely need to slow down while turning, placing objects, flipping the fireworks display switch and anything else that may need precision movement. The MCU will also send a serial communication protocol for commands to the object manipulation subsystem. The microcontroller will therefore need several digital input and output ports. Several microcontrollers are widely available that have many (14 to 20) general purpose digital pins that can be configured as input or output. During detailed design for the microcontroller, consideration will be taken as to how many digital input/output ports are needed, and a microcontroller will be purchased that exceeds the expected need by a reasonable margin. This will help avoid possible running out of I/O during the manufacturing phase. Ideally and conceptually, the team plans to select object manipulation devices with public libraries so that the team has a pre-built communication library to build on in order to create the interconnection communication architecture for each device (sensor, motor, driver, etc.).

The team does not plan to constrain the design to a specific board as this is only conceptual design; Boards that are strongly being considered are the Aurduino Uno and Leonardo or an STM 32-bit L4 series microcontroller option. The first of which seems like a stronger candidate because of the community and public libraries available for arduino microcontrollers.

The power input for the microcontroller needs to be in the 7 to 12 DC volt range according to the specifications of the Arduino microcontrollers that are available on the market. The STM 32-bit L4 series microcontroller runs off of a supply voltage of 1.71 to 3.6 V.

The analytical methods that will be used to validate compliance to the constraints are ensuring that the team purchases a microcontroller that meets the specification of the detailed design constraints outlined earlier in this document and in more detail in the detailed design document. The team plans to use electronic measurement equipment to verify correct voltage levels on Vdd buses and digital logic analyzers to verify serial, SPI, and I2C communication protocol verification.

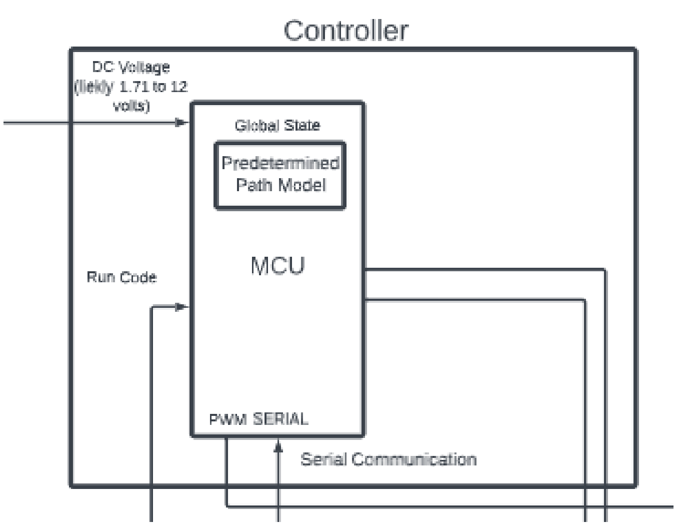

Fig. 5. Controller

To analytically test the microcontroller subsystem, we will write testbenches or unit tests to test C and C++ files thoroughly and to prove that they are logically correct for the application that they are written for in the microcontroller system.

E. Locomotion

The locomotion subsystem describes how the robot will traverse the playing field. Due to the strategy of sweeping the playing field to collect ducks and pedestals mentioned previously, the robot will need to be able to make 90° turns similar to a zero turn mower. In order to do this, the robot will need four wheels and four motors.

Once all, or most objects, 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 the vision systems 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, the robot should head in the general direction of one of the white inner circles and then use the vision systems 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.

To determine the type of wheels that will be used, subject matter research was required on mecanum wheels. 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 will be designed to have four motors for agile movements and 90° turns.

The first portion of the locomotion subsystem consists of four motor drivers. DC voltage will power the motor drivers but a PWM signal from the microcontroller will control the motors operation and speed. Each PWM signal will drive a motor controller. One mecanum wheel will be attached to one motor. The two primary functions of the locomotion system are forward movement and turning. The PWM signal from the microcontroller will determine the speed of the motors. The speed for forward motion will be the same across all motors at a given time, but driving some of the wheels at different speeds and in different directions is how the robot will rotate and turn. The robot will need to move slower for finer movement when navigating close to a landmark. This subsystem will also be directly connected to the power regulator which will supply each motor driver with some DC voltage that is adequate enough to drive the robot.

Motor speed along with the physical path of the playing field will be the primary constraints on the locomotion subsystem. With regards to analytical methods with which the team can validate compliance to constraints, with a 3” overlap, the robot will need to make four total turns, which implies that the total travel distance will be 480 inches. Each turn will take approximately five seconds. If the motors can drive the robot at 8 inches per second, the initial sweep of the field will take one minute and twenty seconds.

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.

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.

In order to verify the solution, the team will model the planned system on LTSpice to ensure it is working properly. The PWM signals sent from the Microcontroller can be simulated to check the voltage supplied to the motors from the motor drivers. Motor drivers can be simulated with the use of transistors and various biasing on LTSpice.

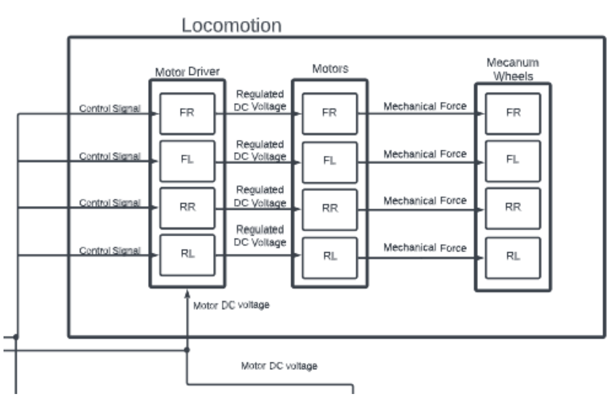

Fig. 6. Locomotion

F. 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 6, will be connected to the on/off switch. The on/off switch will be able to switch on all the power into the robot. Immediately following the on/off switch in the system diagram, the power regulator that will control the wattage sent to all the various portions of the robot. The e-stop button will cut power to the locomotion and actuator motors. If the e-stop is not pressed, it will allow power to flow from the start button. The start button will trigger the robot to begin its predetermined path along the board. As previously mentioned, this locomotion and object manipulation can be stopped at any time with the press of the e-stop button.

The wall wart will follow the constraints laid out in constraint 17. It will take the 120 VAC power coming from the wall plug and convert it to DC voltage that will supply the power regulator. The e-stop button will follow the constraints laid out in constraints 4 and 5. The e-stop button will be between the start button and the locomotion and actuator motors in order to stop all motion in the event of a malfunction. The locomotion, more specifically, the drivers for the motors will need to be supplied a different voltage than the controller, and that voltage will be supplied by the power regulator. The controller, depending on which one is selected, will most likely need somewhere between 1.71-12 VDC. The power regulator will need to be such that it can meet these voltage requirements by taking power from the battery and stepping it down to the specific voltages needed for the various components. The step-down circuit will be bought and not built by the team.

The power circuit will be tested through LTSpice simulations. The purchased step-down circuit specifications will be tested to ensure it is delivering the correct voltage and current to its outputs using multimeters and looking at the datasheet.

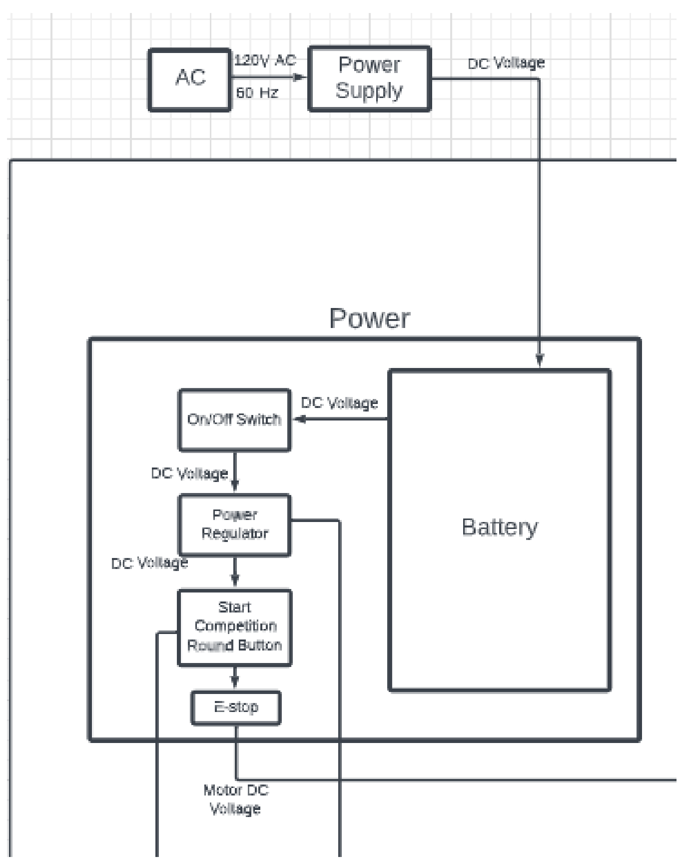

Fig. 7. Power System

G. Firework Activation

During the final seconds of the competition, the robot will need to flip a switch to the right to activate 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. There will also be an arm that will be attached to the motor and will make contact with the switch. The main microcontroller will be performing the timing analysis and will trigger when the switch flip needs to happen, or 20 seconds before the three minute timeframe. This will need to be the final manipulation done for the round, and will signify the end of the round.

To verify that this solution (enable and disable) works, the team will simulate a similar circuit in LTSpice and look at pre-existing solutions that are similar to the team's design and compare them. The team will research and test how much force is needed to flip a light switch in order to determine the strength of the motor used for this subsystem.

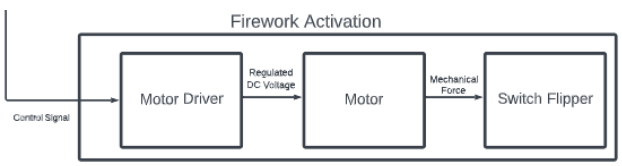

Fig. 8. Firework Activation Subsystem

V. Timeline and Work Breakdown

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 10, and specific work breakdown is listed in the Appendix in Table 2.

VI. 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] "IEEE Standard Ontologies for Robotics and Automation," in IEEE Std 1872-2015 , vol., no., pp.1-60, 10 April 2015, doi: 10.1109/IEEESTD.2015.7084073.

[3] "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].

[4] "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]

VII. APPENDIX

Points	Task
36	3 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. Without touching anything.
33	3 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. Without touching anything.
30	3 pedestals stacked on the duck pond statue location inside the inner circle and in any order with a pink duck on top. Without touching anything.
27	3 pedestals stacked on the duck pond statue location inside the inner circle and in any order with a yellow duck on top. Without touching anything.
27	3 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). Without touching anything.
24	3 pedestals stacked on the duck pond statue location inside the inner circle and in any order . Without touching anything.
24	3 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. Without touching anything.
21	3 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. Without touching anything.
18	3 pedestals stacked on the duck pond statue location inside the outer circle and in any order. Without touching anything.

18	3 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. Without touching anything.
15	3 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. With or without touching anything.
12	3 pedestals stacked on the duck pond statue location anywhere in the park and in any order. Without touching anything.
30	2 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. Without touching anything.
27	2 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. Without touching anything.
24	2 pedestals stacked on a non-pond statue location inside the inner circle and in any order with a pink duck on top. Without touching anything.
21	2 pedestals stacked on a non-pond statue location inside the inner circle and in any order with a yellow duck on top. Without touching anything.
18	2 pedestals stacked on a non-pond statue location inside the inner circle and in the correct order (base level – white, second level – green). The one with the duck above is 21. Without touching anything.
18	2 pedestals stacked on a non-pond statue location inside the inner circle and in any order . Without touching anything.
18	2 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. Without touching anything.
15	2 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. Without touching anything.
12	2 pedestals stacked on a non-pond statue location inside the outer circle and in any order. Without touching anything.
12	2 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. With or without touching anything.
9	2 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. With or without touching anything.
6	2 pedestals stacked on a non-pond statue location anywhere in the park and in any order . With or without touching anything.
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
10	Start the fireworks

10	Auto-start feature used and successful
5	Submitting an entry into a SoutheastCon 2023 Student Branch Promotion Competition. Limited to one entry.

Fig. 9. Scoring for Southeast Con Competition [1]

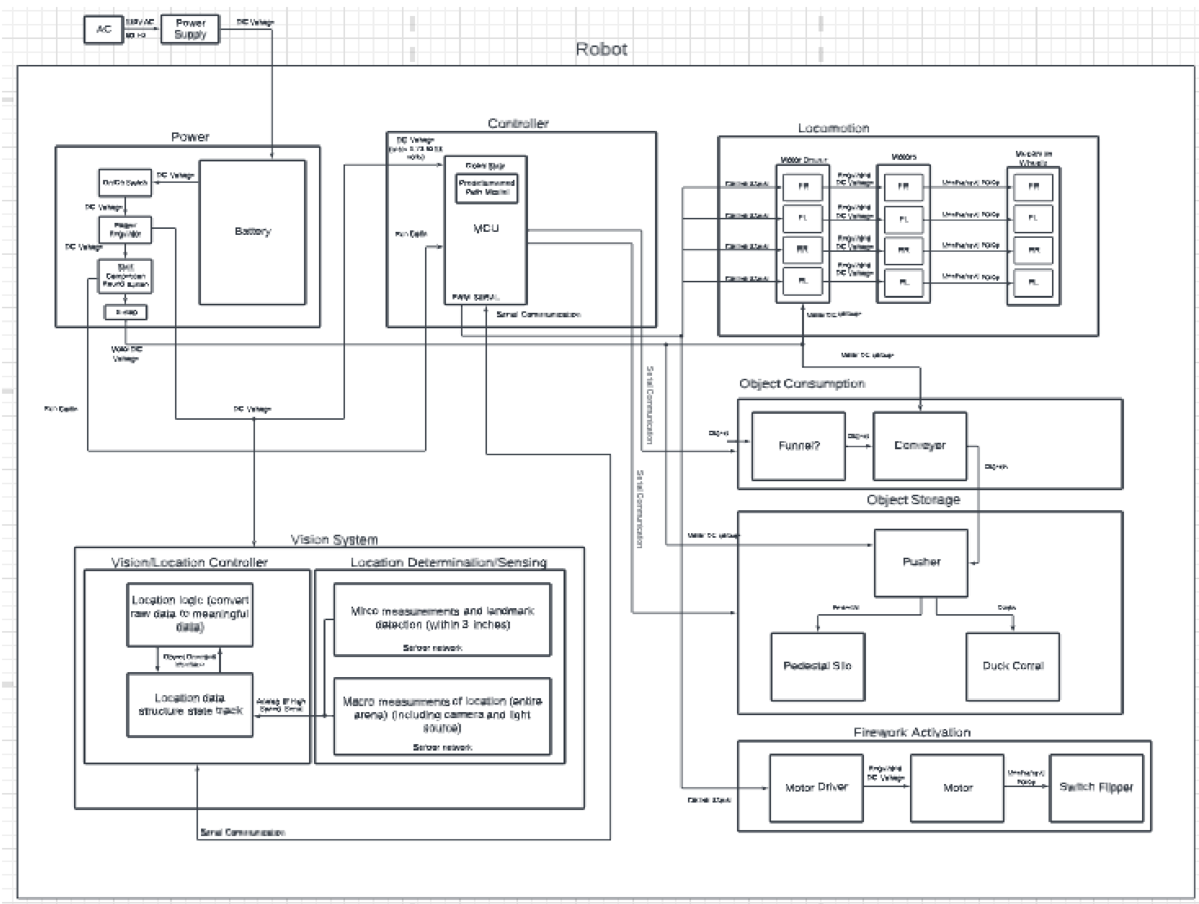

Fig. 10. Complete Robot System Diagram

VIII. Appendix

Event				
Capstone Timeline	**Start Date**	**End Date**	**Duration**	**Member Assignment**
Project Proposal	9/11/2022	9/25/2022	14	*All Team (done)*
Project Prosal Revisions	10/5/2022	10/12/2022	7	*All Team (done)*
Conceptual Design and Planning	9/25/2022	10/9/2022	14	All Team
Object Consumption: Detailed Design and Analytical Testing	10/31/2022	11/4/2022	4	Mark Beech
Vision Subsystem: Controller, Detailed Design and Analytical Testing	10/31/2022	11/7/2022	7	Fatima Al-Heji
Object Consumption: Signoff	11/5/2022	11/9/2022	4	Mark Beech
Vision Subsystem: Sensor system, Detailed Design and Analytical Testing	11/10/2022	11/17/2022	7	Fatima Al-Heji
Vision Subsystem: Signoff	11/18/2022	11/25/2022	7	Fatima Al-Heji
Object Storage: Sorting, Detail Design and Analytical Testing	11/10/2022	11/17/2022	7	Madison Kelly
Object Storage: Storing, Detail Design and Analytical Testing	11/17/2022	11/22/2022	5	Madison Kelly
Object Storage: Signoff	11/23/2022	12/9/2022	16	Madison Kelly
Controller Subsystem: Detailed Design and Analytical Testing	12/9/2022	12/16/2022	7	Nathan Gardner
Controller Subsystem: Signoff	12/16/2022	1/16/2023	31	Nathan Gardner
Locomotion Subsystem: Motor Drivers, Detail Design and Testing	12/9/2022	12/16/2022	7	Luke McGill
Locomotion Subsystem: Motors, Detail Design and Analytical Testing	1/12/2023	1/19/2023	7	Luke McGill
Locomotion Subsystem: Mechanum Wheels, Detail Design and Testing	1/19/2023	1/22/2023	3	Luke McGill
Locomotion Subsystem: Signoff	1/22/2023	1/26/2023	4	Luke McGill
Fireworks Display: Detail Design and Analytical Testing	1/12/2023	1/19/2023	7	Mark Beech
Fireworks Display: Signoff	1/19/2023	1/26/2023	7	Mark Beech
Power Subsystem: Detailed Design and Analytical Testing (LTSpice)	1/12/2023	1/19/2023	7	Madison Kelly
Power Subsystem: Signoff	1/20/2023	1/26/2023	6	Madison Kelly
Detail Design and Planning	10/9/2022	1/26/2023	109	All Team
Signoff	11/5/2022	1/26/2023	82	All Team
Ordering	11/5/2022	1/26/2023	82	All Team
Vision Subsystem: Programming	1/27/2023	3/21/2023	53	Fatima Al-Heji
Controller Subsystem: Programming	1/27/2023	3/21/2023	53	Nathan Gardner
Build	1/12/2023	3/1/2023	48	All Team
Experimentation	3/1/2023	3/22/2023	21	All Team
Documentation, Poster, Presentation	3/22/2023	4/28/2023	37	All Team

TABLE I
TIMELINE BREAKDOWN WITH ASSIGNMENTS

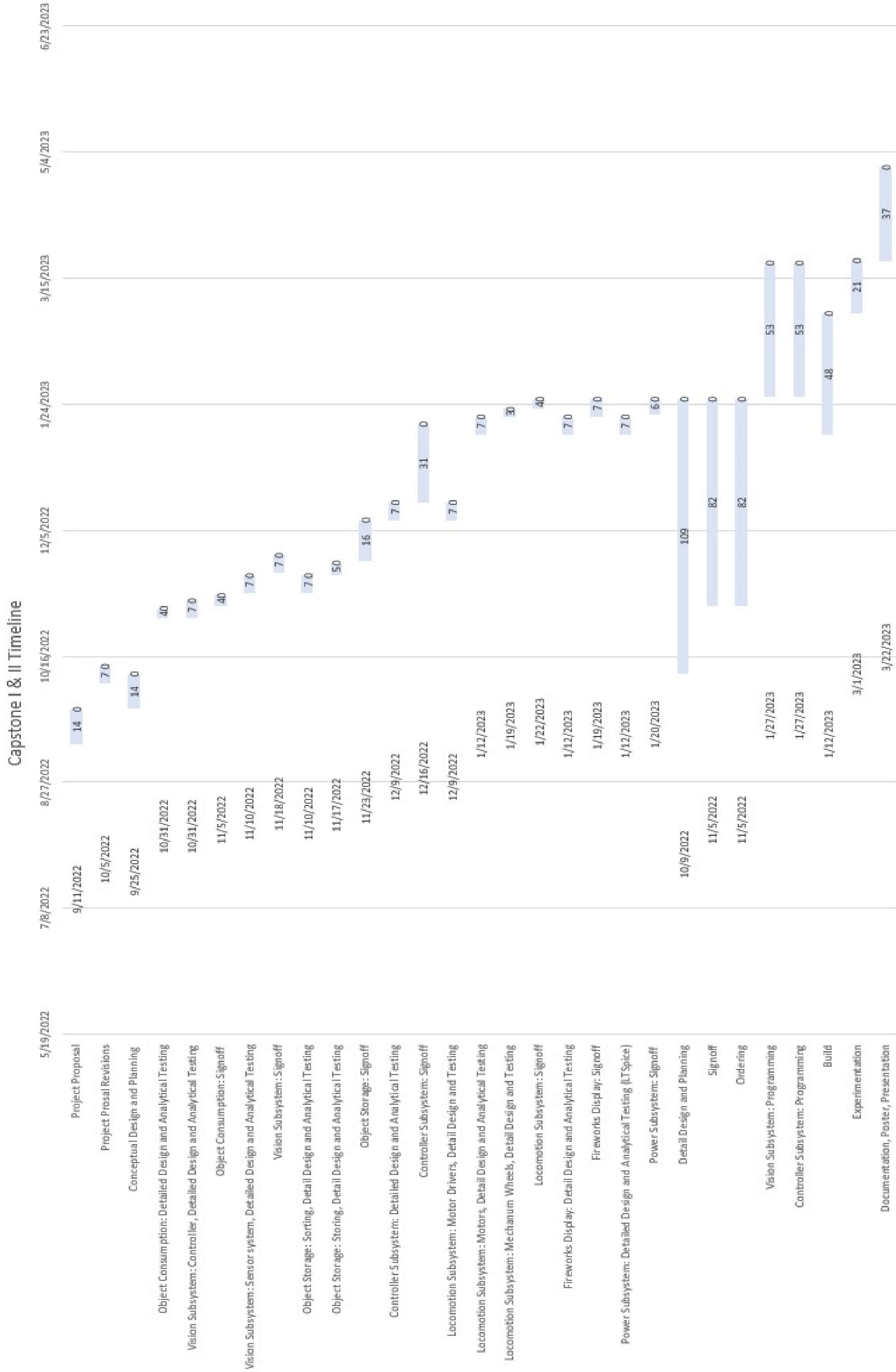

Fig. 11. Gantt Chart for Project