Modular IEEE Robot Platform Conceptual Design

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I. Nomenclature

IEEE	Institute of Electrical and Electronic Engineers
SECON	IEEE Southeast Conference
Tech	Tennessee Technological University

II. Introduction

The IEEE SECON hardware competition exhibits changing specifications each year that design teams must adapt to in order to place well in the competition. To combat previous issues faced by Tech's teams, a generic robot platform is being developed to address many of the previously faced issues in a modular, reproducible way. System integration will be a critical focus of the process to prevent incompatibility between subsystems, so iterative testing will be done frequently during the design process. Each subsystem is only as good as the others make it, which is why the best chance of success will come from the efficiency of intersystem cooperation. The team will also consider safety and customer satisfaction as paramount, so alignment with the customer, IEEE, legislative bodies such as the FCC, and general engineering ethics will be heavily considered and integrated into every design step. In the following sections of the document, a theoretical design plan will be established with time frames and constraints that will shape the project flow.

A. Formulated Problem Statement

The SECON competition always requires a robot that can sense, move, and charge its battery. Five major systems (chassis, sensing, motor control, battery charging, and master control) have been developed to attain all three basic requirements, and the following constraints will allow the new generic robot platform to achieve these basic tasks safely and effectively:

1) The robot shall have a single start button. Once activated, the robot will begin navigating its environment.
   - This constraint was explicitly required by the official hardware competition rules [1]–[3].
2) The robot shall possess an allocated data input point for an alternative start method.
   - This constraint was requested by the customer, Professor Jesse Roberts, and will allow future teams to have easy access to a recurring method of gaining extra points.
3) The robot shall be autonomous with customizable dimensions and the stock design only occupying up to one-half of the allowed cubic foot (1 ft x 1 ft x 6 in) [1]–[3].
   - This constraint was constructed with two factors in mind: SECON dimension requirements and the reservation of space for future teams to add components for more complex tasks. After all alterations, the robot must fit into a one cubic foot area, so the team set forth the constraint to only occupy half of the allotted space at most. A reach goal is to minimize the occupied space as much as possible.
4) The robot shall contain modules that are plug-and-play adaptable for different IEEE competition requirements.
   - This constraint was constructed to address the changing layouts and tasks SECON imposes on the competition each year. Increasing platform flexibility will enable teams to recycle the systems year after year even though many of the parameters may not look like the previous year.
5) The robot shall possess a robust, centralized charging system that does not require the removal of the battery and that allows the robot to be used while being charged.
   - This constraint was requested by the customer to allow future teams two main advantages over previous years: (1) keeping the battery on the chassis prevents electrical failures due to replacing equipment, and (2) having a robot that can be used while charging will allow teams to test the robot for hours without having to stop and recharge batteries.
6) Wireless charging shall be evaluated as an option for charging the robot.
   - This constraint was requested by the customer as a potential way to make charging the robot more convenient for the team. This feature would allow teams to charge robots while using the robot for practice and experimentation. When considering broader impacts, it was identified that wireless charging must be the secondary form of charging if used because it cannot be utilized at competition. Wireless charging will be investigated to determine feasibility. This is a reach goal for the project.
7) The robot shall possess a single emergency stop button

that is accessible and stops all robot movement without removing power to essential processors that is compliant with standard NFPA 79-10 [4].

- This constraint was constructed in accordance with the SECON competition rules and the national fire protection agency standards [1]–[4]. Since there is no user control over movements, there must be a way for the robot to be shut down if it enters an undesired state or becomes a safety hazard. This button must only stop the movement of the robot (by interrupting power to the motors) instead of all processors to ensure all software systems are able to shut down properly. NFPA 79–10 outlines the requirements for emergency stop systems in industrial robotics [4].

8) The robot shall contain a power bus that is not inhibited by DC motor operation.
   - This constraint was requested by the customer as a solution to a common problem encountered by robot teams. DC motor operation can inhibit operation of other circuitry, especially shared power supplies, and so there must be isolation and additional protective circuitry between the DC motors and other electronics.
9) The robot shall travel inclines and declines up to 25 degrees
   - This constraint was constructed to address the incline presented in the 2024 SECON competition and any future inclines of similar steepness [1].
10) The robot shall turn 360 degrees left and right and move forwards and backwards based on sensor inputs.
    - This constraint was constructed to address the basic interactions of the sensor subsystem, motor control subsystem, and master controller and define basic ranges for the horizontal movement capabilities.
11) The robot shall have a navigation system that controls movement.
    - This constraint was constructed according to IEEE SECON hardware competition rules that state that the robot must move autonomously [1]–[3]. The navigation system will consist of the sensing subsystem and the motor control subsystem, and their communication will be facilitated by the master controller.
12) The robot shall know its location within a two-inch tolerance.
    - This constraint was set by the customer. The customer requested that the robot be able to know where on the board it is located and report that location to the user. The report will aid in calibrating the location in the sensor microcontroller.
13) The robot shall possess a maximum speed of 2 feet per second.
    - This constraint was constructed to address the time limitations of the competition [1]–[3]. Since all previous competitions have a three-minute time limit, a speed of two feet per second would allow the robot to move adequately around the board and complete tasks in a timely manner.
14) The robot shall have a user manual that explains all functions and capabilities of the robot.
    - This constraint was constructed by both the customer and the project team members because the robot design will be used for future teams that were not a part of the design process. It is imperative that design motives and implementation notes be documented to ensure that the robot is used to its full potential and the proper operation of all subsystems is preserved. This constraint also is in compliance with the need for constraints based on broader considerations.
15) The robot shall not use radiative wireless power transfer technology.
    - The safety hazards caused by radiative wireless power transfer violate IEEE Code of Ethics I.1. Radiative transfer is only usable for power consumption under 10 milliwatts [5]. The power consumption of the entire robot is likely to exceed this amount, making radiative power transfer too dangerous of an option to pursue [6].
16) The robot shall abide by the applicable FCC regulations regarding wireless charging methods outlined in parts 15 and 18 of the standard.
    - This standard applies to wireless charging devices depending on operating frequency. FCC Parts 15 and 18 list the power limitations and RF exposure requirements for wireless power transfer for different frequency bands [5].
17) The robot shall abide by NEC 310.15(B)(16) when sizing any conductors for the project [7].
    - This standard outlines the allowable ampacities of insulated conductors up to 2000 volts. The project will be well under this voltage and is therefore applicable. The standard will need to be followed for the safety of the design team and potential users by ensuring all wire is appropriately rated for the load [7].
18) The team shall abide by the IEEE Code of Ethics at all times.
    - This standard outlines how each team member will conduct themselves and hold the team accountable. Although this standard does not apply directly to robots, it is important for the team to consider these ethical obligations in this process just as professional engineers do [8]. Specific examples are given in ethical considerations.

Constraints will be referenced throughout the remainder of the document as CX, where C represents the constraint and X represents the constraint number.

III. Statement of Ethical, Professional, and Standards Considerations

Since the project put forth by the team will have impacts on future students, the ethics, professionalism, and standards should be considered to ensure the safety and intended effects for anyone who works with the robot.

A. Ethical

The team has the responsibility to abide by the IEEE Code of Ethics. The following examples could pose ethical considerations. In the power subsystem, batteries are used to power the robot, so when the battery needs to be replaced, proper protocols for battery disposal should be upheld for the integrity of the environment [8]. For the chassis, unique parts will be created to minimize waste, and scrap material will be disposed of properly to promote sustainable development practices [8]. Additionally, the software being used throughout the different subsystems for analysis, modeling, documentation, coding, etc. will be legally downloaded and will not breach licensing or copyright agreements. Code from others will be properly accredited when used [8]. The team has also identified the inability to use radiative wireless power transfer as a binding ethical consideration because if the method is used harm will occur to surrounding personnel. This is identified in constraint 15 above. Additionally, radiative power transfer methods are likely to be a safety hazard given the power requirements of the robot and that radiative transfer is often not allowable over 10 mW for safety [5]. Given this and that the IEEE Code of Ethics requires that engineers do work that is safe for humans, only nonradiative power transfer methods will be investigated.

B. Standards

To ensure robot safety and reliability, the robot must meet all applicable standards. Some of the standards for the robot come from the SECON competition requirements. One such requirement is that the robot must have an emergency stop button easily accessible on the outside of the robot for the power to the motors to be cut in an emergency [1]–[3]. The requirements for emergency stop buttons in robotics are also outlined in NFPA 79–10 [7]. The primary legal standard that is applicable to the power systems of the robot are those applicable to wireless charging. The Federal Communications Commission (FCC) is the primary regulatory body that sets the standards for wireless charging, laid out in FCC Parts 15 and 18, setting limitations on power, frequency, etc. to ensure safe wireless power transfer [5]. Finally, when sizing wires for power distribution subsystem the NEC standard outlines the allowable ampacities of insulated conductors up to 2000 volts. The standard will need to be followed for the safety of the design team and potential users [7]. In order these constraints are C7, C16, and C17.

C. Broader Impacts

The robot will directly affect future IEEE SECON robotics groups as mentioned in the problem statement. The impact on the team may be beneficial or could be a hindrance depending on the new specifications given for future years. If the goal of the project is achieved, though, future teams will perform very well in the competition which will bring more recognition to Tech's IEEE student branch. More recognition could lead to new members and more funding. Although the impact of goal success on future groups is primarily positive, future competitors would not have as much exposure to the engineering process of the robot's base. Upcoming users would rely on the user manual and technical documentation to understand the composition and integration of the robot. Beyond the intended team impact, the design could be a beneficial teaching tool for the basic functionalities of an autonomous vehicle (which could be used by Tech in camps or future classes). Wireless charging may also impact future teams by either making charging easier to sustain or adding an extra level of complication to the system that future teams must parse through. The robot could also be adapted for use in other competitions in the event that Tech takes on a new robotics competition. Though the robot would not be tailored to the event, the basic systems may be adequate to get a new design started.

D. Constraints Derived from Broader Considerations

Regarding future teams' exposure to the robot base design, the team has imposed constraint C14 to ensure a proper user manual is created. Documentation is an important factor to consider because integration could be as difficult as creating a new base if proper documentation is not provided. Thus, the team will ensure that all design and information needed for future teams' complete understanding is provided within the user manual.

If wireless charging is implemented, this will be the secondary form of charging for the robot. The primary form must be wired charging because wireless charging is not practical in competition. This is due to the use of wireless charging is for future teams to run hours of test trials without the hassle of charging the battery or following the robot with a slack wire. Additionally, the vision for wireless charging is to have some type of mat to place under the practice board. Using this mat would not be allowed at the competition because alteration to the official boards is not allowed and it is unknown if a power source will be accessible from the official boards [1]–[3]. Therefore, the team has imposed constraint C6.

IV. Block Diagrams

The robot has been divided into five main subsystems which are described below in more detail and shown in Fig. 1. The next sections explain each of the subsystems and how they plan to meet the requirements and constraints previously explained.

A. Chassis

The chassis subsystem is very different – due to its physical nature – from all other subsystems. However, this subsystem is still extremely important. The chassis will fulfil one of the most important constraints of the project:

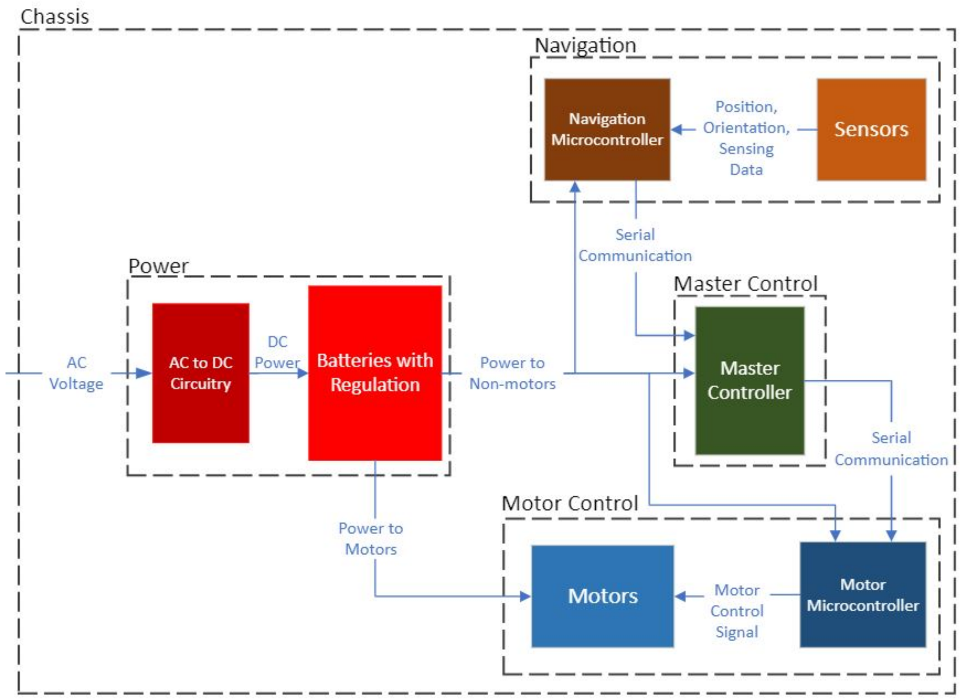

Fig. 1: Overarching Block Diagram

modular customization for future SECON teams. Without modular customization the project would be nearly useless. The following Fig. 2 outlines the components that will allow this goal to be achieved with a further breakdown of how each step will be accomplished. It is important to note that the block diagrams will have no true output compared to other subsystems, again, due to the physical nature. Each lighter shade in the block diagram represents a deeper layer of components. The black dashed sections represent different subdivisions of the sub system, and each will be explained below. This will allow for the system to be further separated for signoffs. Two overarching problems are aimed to be solved for the chassis to have modular customization. The chassis must possess the ability to have custom dimensions while meeting the payload requirements and be plug and play adaptable. The first function will be achieved through utilizing extruded aluminum with T – Channels to construct the frame of the robot. The second function is for the chassis to be plug and play adaptable. There are a total of four subdivisions that the team has identified to achieve this capability: easily moveable trays, attachments for DC motors, sensors, and start/stop buttons, and wire organization.

1) Chassis Frame - Extruded Aluminum: At the customer's request, extruded aluminum will be utilized to customize the dimensions of the robot. Extruded aluminum can be cut to any length, and the T-channels allow for attachments points on all four sides of every rod so components can be attached and moved if needed. The rods also fulfil the payload requirements of the project due to the material's properties. From this subsystem, the overarching chassis layout will be determined based on constraints and logical component placement. Testing to verify functionality will be performed during the design and testing stage.

Input: Dimension, strength, and modularity requirements

Applicable Constraints: C3, C4

2) Trays: The goal of this subsystem is to create plug and play modules for the robot. The trays will be 3D printed and made custom to hold other subsystem components, keeping the robot unified and organized. The movement will be made possible by making trays that attach and slide through the T-channels on the extruded aluminum. While designing the trays, it will be important to consider the parameters of the tray's mounted components (dimensions and operation requirements) to design the most effective layout and design. Additionally, the trays must be able to move two inches from the stock design without rewiring. The two-inch flexibility will be accomplished by allowing extra wire to be stored within a central wire tray that will extend when needed. The adherence to constraints will be tested through the design and testing phases of the project.

Input: Design with T-channel connectors, appropriate amount of excess wire, and component design parameters

Applicable Constraints: C4

3) Attachments: The attachments will be 3D printed seats that are designed to the dimensions and operational requirements of the selected DC motors, sensors, start switch, and stop button of the project. For example, a line-following sensor

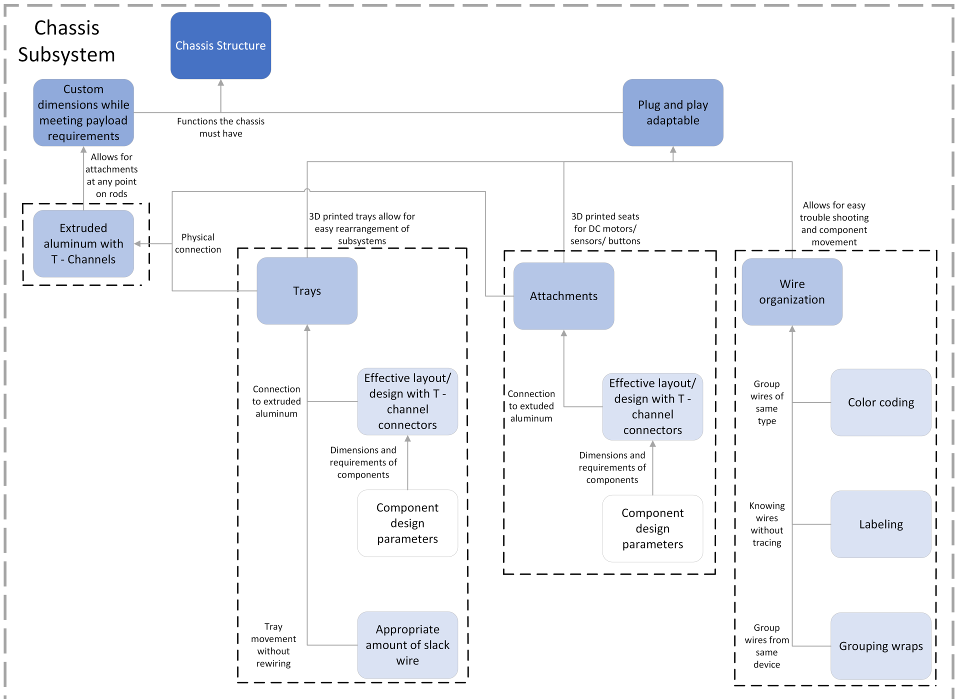

Fig. 2: Chassis Block Diagram

will need to face the ground at a specific distance from the floor in order to be accurate. The start and stop buttons need to be easily reachable to make the robot accessible at initialization and in case of an emergency. Additionally, these attachments will have a T-channel connector integrated into the design for easy connection to the extrusion rods. Overall, the objective is for these attachments to hold components in the correct position, but also allow for easy mobility or accessibility across the robot. The effectiveness and ease of the attachments will be verified during the design and testing phase of the project.

Input: Effective design with T- channel connectors and component design parameters

Applicable Constraints: C1, C4, C7

4) Wire Organization: Wire organization is an extremely important constraint because without it, components get shorted, troubleshooting takes much longer, and wires become significantly harder to trace. Thus, wire organization will be achieved through color coding for quick recognition. In addition to color coding, labels will be placed on either side of the wire to easily identify wires from drawings and trace wires across the chassis. The wires from a single component will also be grouped and wrapped together to make organizing within a main wire tray easier. Although not directly accomplishing plug and play features, wire organization will allow for easy movement of subsystem trays and easy location of component connections if rewiring is needed. These will indirectly impact plug and play features by making ease of use better for the user. The best version of each will be determined during the design and construction phase.

Input: color coding, grouping wraps, and labels

Applicable Constraints: C4

B. Motor Control

A microcontroller in the motor control subsystem controls the movement of the wheels. Communication from the master controller tells the motor controller the direction and magnitude of the necessary motion, and the motors are sent a signal to act according to the high-level directions from (Fig. 3). The robot needs to be able to move in a controlled way to ensure that future teams can complete tasks requiring precise movements. A block diagram showing the motor control subsystem is shown below.

1) Microcontroller: The microcontroller will be made to have subroutines to traverse hills and move in all directions as necessary. The way that the robot needs to move will come from the serial communication from the master control. Additionally, all decisions made regarding products and design will be documented in the user manual.

Input: Serial communication from the master control, 7-12V DC

Output: Control signal

Applicable Constraints: C9 - C11, C14

2) Motor Drivers: The type of motor driver will be documented as well as the different control signals and associated voltages in the user manual.

Input: Control Signal, motor DC voltage

Output: Regulated DC voltage

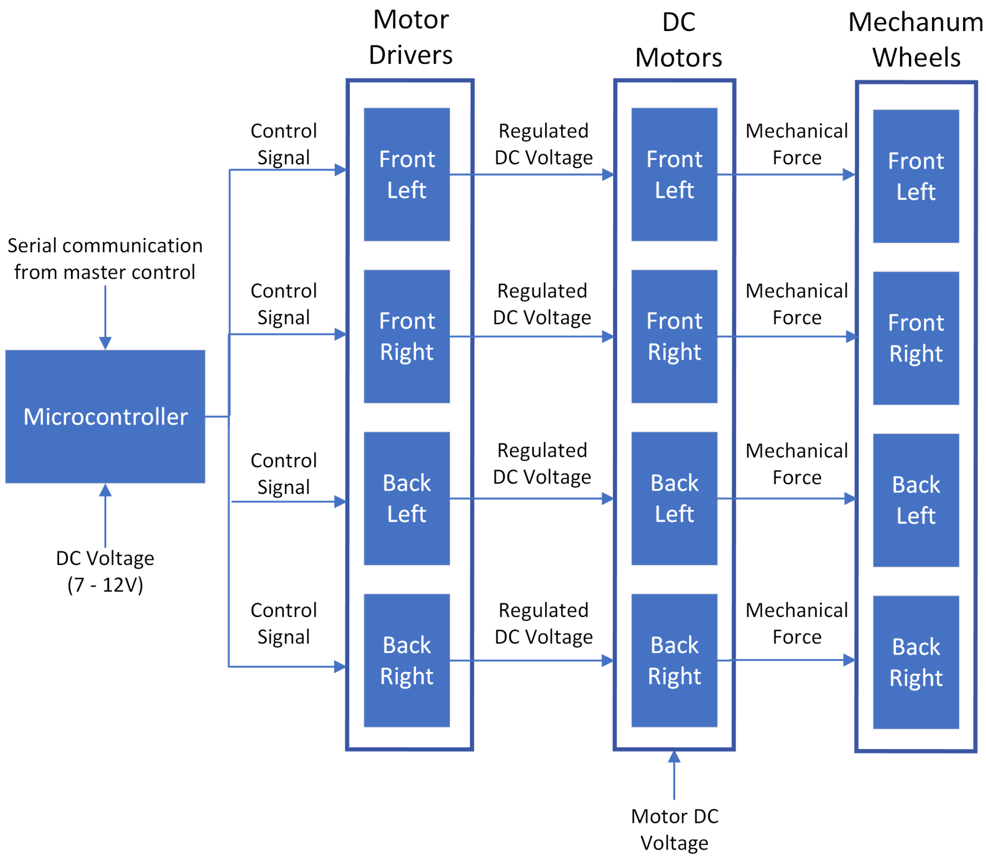

Fig. 3: Motor Control Block Diagram

Applicable Constraints: C14

3) DC Motors and Mecanum Wheels: The DC motors and wheels will be chosen where they will be able to move the robot at the top speed of 2 feet per second. Additionally, all decision processes and design will be included in the user manual.

Input: Regulated DC voltage
Output: Mechanical force
Applicable Constraints: C13, C14

C. Sensing

The sensing subsystem will provide data to master control depicting the physical phenomena the robot autonomously reacts to. The subsystem is composed of four smaller subsystems: line following, orientation, location, and object detection. Real-time sensor data will be read by a microcontroller dedicated solely for the sensing operations of the robot. The local microcontroller will transmit data back to the master control using serial communication protocol.

1) Line Following: The purpose of the line following subsystem is to detect where the robot is travelling in reference to a line painted on the arena floor. The line-following subsystem will be implemented in a modular format so future IEEE SECON competitors can easily alter it to fit their needs. A reflectance sensor array will produce raw data based off of where the robot lies on the line. The reflectance sensor uses photoresistors and capacitors to measure the time delay in order to get an accurate distance. A hardware or software filter will be used to make the data more functional. The line sensor readings provide the master control with data to control the robot's movement. The data on where the robot is in reference to the observed line will allow the master control to make robot maneuvers to stay within 2 inches of the desired location. The line sensing module must produce valid data on both flat ground and slopes. Although the line sensing subsystem will not be propelling the robot up and down the inclines, the system must produce valid data over the incline and decline so the master controller can make the correct maneuvers. Information regarding coding conventions, code structure, design thoughts, design implementation, and other important notes will be included in the user manual regarding the line following subsystem.

Input: Physical phenomena read as voltage by sensor
Output: Serial data to the master control
Applicable Constraints: C9 - C12, C14

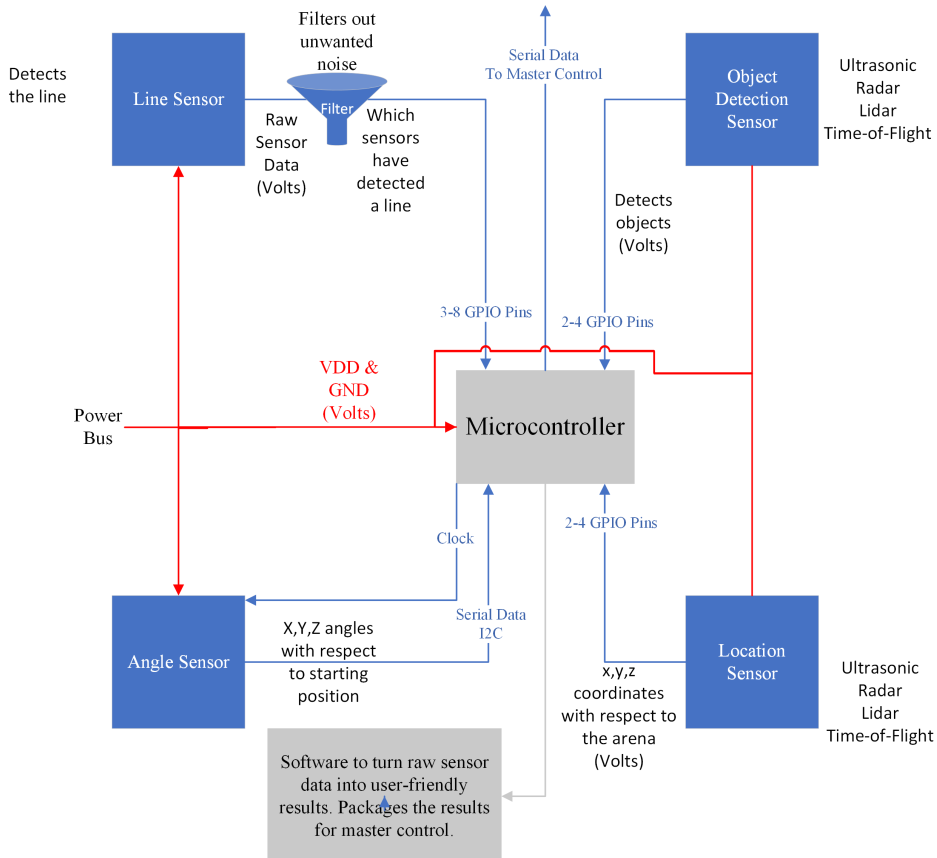

Fig. 4: Sensing Block Diagram

2) Orientation: The purpose of the orientation subsystem is to detect the robot's directional heading. The orientation module will use a sensor to track the robot's movement, and the raw data generated by the sensor will be transmitted to the microcontroller using serial I^2C protocol. The orientation subsystem reports the angle displacement of x, y, and z in reference to the robot's starting orientation. Knowing the vector displacement angle in each of the three coordinate ranges will aid the master control in traversing the arena. It will also help future teams complete tasks that require the robot to turn in a specific manner. Information regarding coding conventions, code structure, design thoughts, design implementation, and other important notes will be included in the user manual regarding the orientation subsystem.

Input: Physical phenomena read as voltage by sensor
Output: Serial data to the master control
Applicable Constraints: C9 - C11, C14

3) Location: The purpose of the location subsystem is to mark the robot's physical location in the arena. The location module will use a sensor that sends raw data about the robot's physical location to the navigation microcontroller to analyze in order to move and control the robot autonomously. The data reports the robot's physical location within 2-inch tolerance in the arena. The serial data is then sent to master control to be used to locate robot's coordinates relative to the arena.

Input: Robot's coordinates relative to the arena
Output: Serial data to the master control
Applicable Constraints: C4, C10-12, C14

4) Object Detection: The purpose of this subsystem is to detect objects in the arena. The object detection module will use a sensor that sends raw data about an object being detected to the navigation microcontroller to analyze in order to move and control the robot to avoid the object. This serial data is then sent to master control to be used for object avoidance.

Input: Detects object
Output: Serial data to the master control
Applicable Constraints: C4, C10, C11, C14

D. Power

The power system of the robot provides the electrical backbone for the rest of the project. Without a reliable method of power supply and distribution to the robot components, the robot will be unable to complete any functions. A block diagram providing an overview of the power systems of the robot is shown below.

1) Wireless and Wired Charging: The wired and wireless charging subsystems shown in Fig. 5 above will be designed

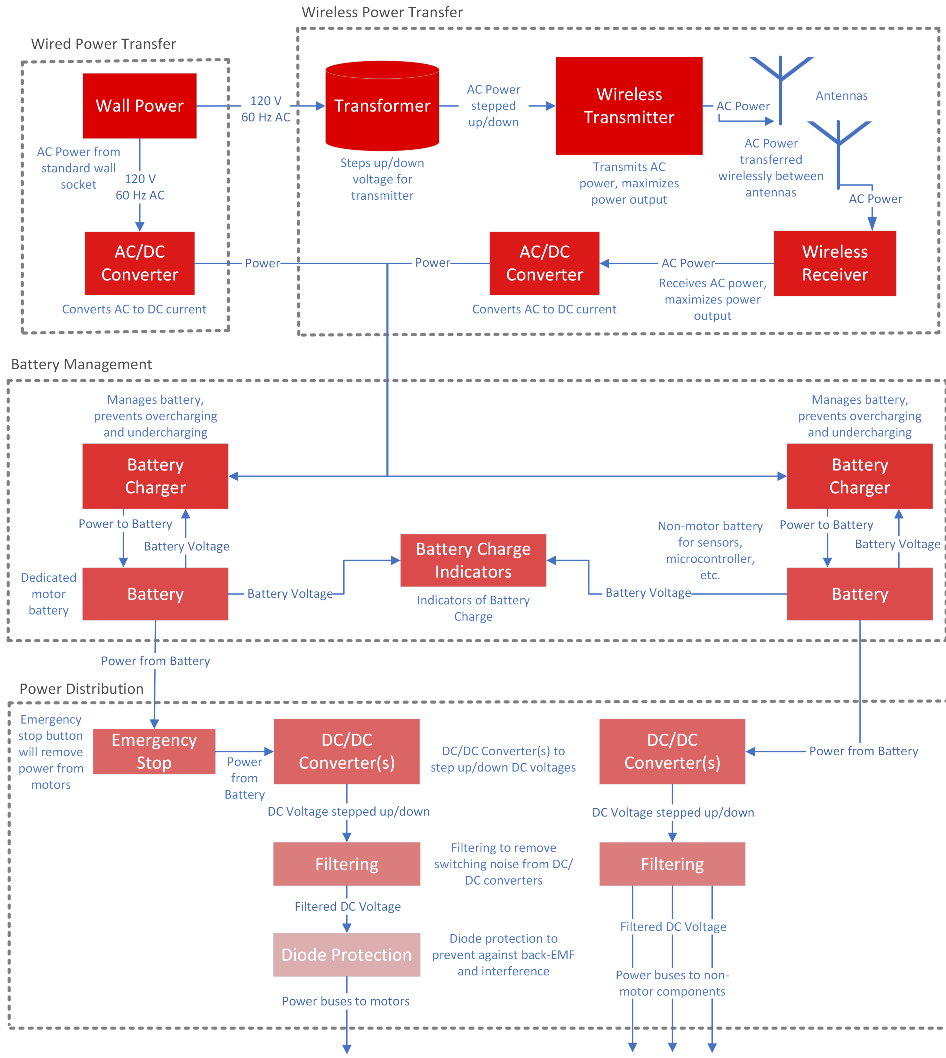

Fig. 5: Power System Block Diagram

based on the power requirements of the robot. The applicable standard to the wired power transfer subsystem is the NFPA requirements on wire sizes for different ampacities, and the primary standards for wireless power transfer are FCC Parts 15 and 18, which regulate wireless power transfer frequencies and power [5], [7].

Input: 120 V 60 Hz AC voltage from standard wall socket.
Output: Power to battery management circuitry.
Applicable Constraint: C5, C6, C15 - C17

2) Battery Management: The battery management subsystem manages and regulates the charging of the batteries. One of the most important parts to the battery management is the isolation of the two batteries, one for the motors and one for the non-motor components in order to prevent interference between power buses resulting from the motor. The applicable standard to this subsystem listed is the NFPA requirements on wire gauge and ampacity and will be taken into account to avoid power failures resulting from wire current capacity.

Input: Battery voltage and current.
Output: Power from battery.
Applicable Constraints: C5, C7, C8, C17

3) Power Distribution: The power distribution system is the subsystem responsible for delivering the batter power to all of the hardware of the robot. There are separate power buses for the motor and non-motor hardware in order to reduce interference from the DC motors to the rest of the power buses. There will also be an emergency stop button that when pressed will open the power bus to the motors, while keeping the power bus to all non-motor hardware closed. This cuts all power to the motors until the button is reset. This is done as a safety precaution in the case of motor malfunctions.

Input: Power from batteries.
Output: Power to motors and power rails.
Applicable Constraints: C4, C7, C8, C17

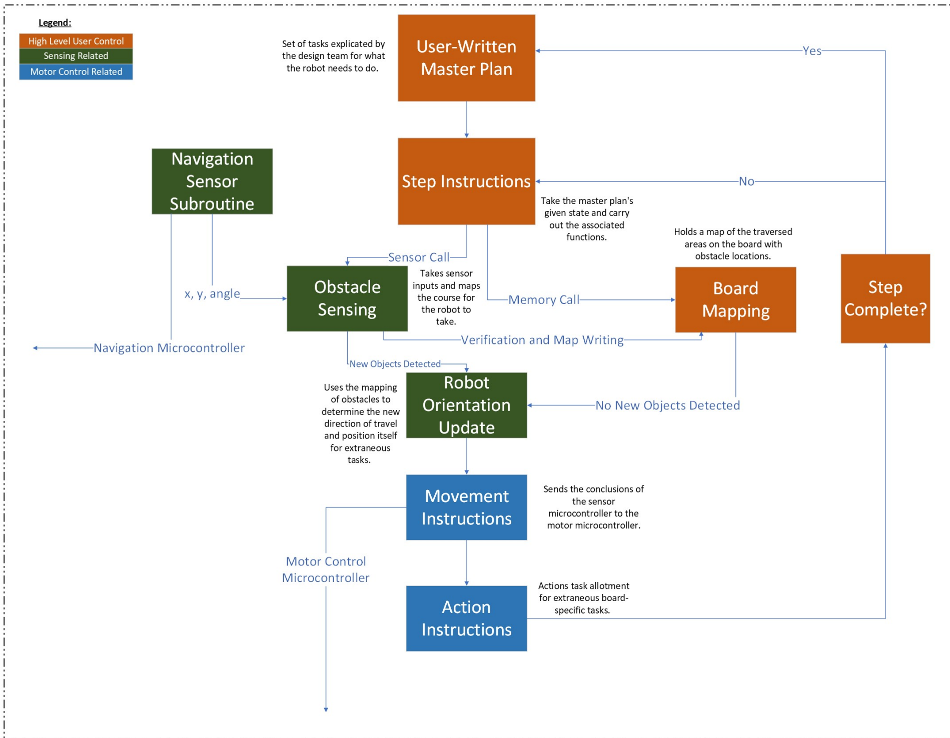

Fig. 6: Master Control Block Diagram

E. Master Control

Inputs: Serial bus from sensing, input power, and peripheral inputs (start button and alternate start method)

Outputs: Serial bus to motor control, serial bus to peripheral task items (specified by future teams)

Applicable Constraints: C2, C10 - C13

1) Planning: At the highest level, the master controller will hold the user-defined tasks written as functions to keep the overarching plan clean and readable. As individual functions are called, the tasks will be executed by loading system variables (goal location, goal altitude, task steps, etc.) and prompting the other systems connected to the master controller. Once the prompted steps are complete, the system will load the next instructions detailed in the specific function and do another iteration of the navigation and peripheral commands. Once the entire function has been completed, the system will step out of the function and move on to the next step. The process will continue until the system has run all its functions and finished the run, which satisfies C3.

2) Navigation Command: Once the goal variables have been set, the master controller will prompt the map and sensor inputs. The sensor input will run in a subroutine (read continuously by the system) so that the position is known at any given time. If the sensor system discovers an object in the path, it will update the map and then continue carrying out its given specifications as explained in C10. If the sensors do not detect a new object, the robot will proceed on the directed path using its map (satisfying C11). By utilizing a map, the system can continue operating at high efficiency without having to continuously rescan discovered areas. The navigation system will also receive a chassis angle from the sensors which will help determine how much power the motor controller should send to the motors and how much time the specified power should be applied to satisfy C9.

3) Peripheral Control: Once the robot arrives at its destination, it will most likely have tasks to complete. Having a step dedicated to the peripheral tasks (tasks that are outside the basic movement and sensing of the robot) gives future teams the ability to adapt the robot to their specific needs for each step.

V. Timeline and Work Breakdowns

The Gantt chart shown in Fig. 7 in the Appendix shows the general tasks for the detail design. Each task can be followed individually and is assigned to the person best suited to the task. While the deadlines can change due to unforeseen circumstances, each task to be completed near the projected end date as a checkpoint to ensure progress is being made.

VI. Conclusion

Adaptable, generic, and user-friendly are the overarching goals of the SECON hardware competition robotic platform. By implementing fast, centralized charging, plug-and-play sensors and chassis, and efficient power allocation, the design product will provide future teams with all the necessities to begin work on higher-order robot functionality. The robust robotic platform outlined in this conceptual design will provide future students with peace of mind in their robotic systems, knowing that the basic robotic functionalities have already been tried and tested rigorously. Moving forward, the detailed design of the subsystems will be generated according to the timeline and work breakdown established within this document.

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VII. APPENDIX

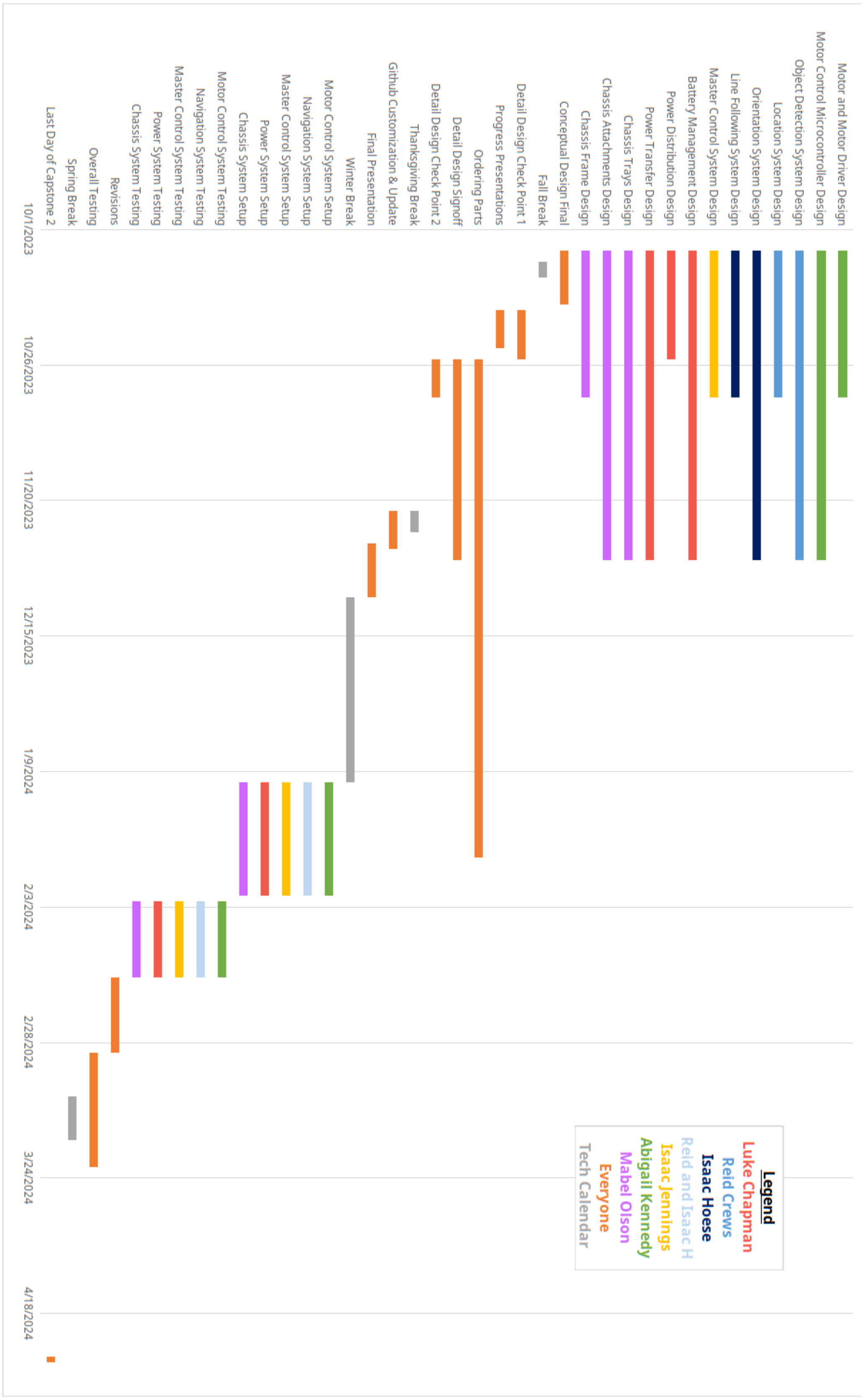

Fig. 7: Gantt Chart