Modular IEEE Robot Platform Project Proposal

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I. Introduction

Each year, Tennessee Technological University (Tech) participates in the Institute of Electrical and Electronics Engineers (IEEE) Southeastern Conference (SECON) hardware competition. The competition asks participants to create a robot that can perform various tasks, and competitors are scored based on their robot's capability to complete tasks as quickly as possible. In past years, Tech has placed well, but the same problems have arisen each year that have inhibited wins: choppy navigation, shorted cables, and battery depletion are just a few of the many problems teams have repeatedly faced in previous competitions. Our team sets out to fix the besetting problems that teams face each year not by competing in SECON, but rather by building a generalized platform that will optimize the basic robotic functionality for future teams. Sensing, movement, and centralized charging are the top priorities in the team's design, all fitted together in a modular, adaptable framework that can be manipulated to fit most – if not all – IEEE hardware competition specifications. No longer will teams have to spend countless hours learning and designing movement systems or hoping everything works after rewiring a battery mid-competition. Our design will take care of these basic competition necessities and leave the custom tailoring to the competition team.

A. Outline

The following proposal will break the project down into three major sections: the problem, solution, and current resources. In the problem section, the specific design issues will be addressed, and the problem will be brought into clear resolution via background, constraints, standards, and previous literature. The background section explains the issues that have been experienced in past competitions due to previous SECON constraints. Many of the problems expressed by the customer were derivations of the same constraints. The constraints are written as a series of "shall statements" that provide insight on what the project shall do once completed. After summarizing the problem, the solutions are considered. The solutions section discusses the critical unknowns of the project, possible solutions to the problem or its parts, and the measures by which the solutions can be tested to determine success or failure. Additionally, the solutions section considers the broader implications of the project on the design team, SECON competition, and Tennessee Tech IEEE student branch. The resources section follows the solution and provides a list of personnel skillsets, necessary software applications, a theoretical budget, and a timeline of the design process. Following the project specifications is the conclusion that summarizes the entire project and gives final thoughts on the outlook of the work to come.

II. The Problem

Each year, the SECON capstone team faces the same operational problems: motor control, navigation, and battery management. While the groups find solutions to these issues, the invested time designing the systems detracts from the time spent on more challenging tasks and specifications. To create a sound robot platform for future teams, four issues need to be addressed: navigation control with location tracking, precise motor control, integrated battery charging, and adaptable modules. The team will address each of these issues in accordance with the standards and constraints set forth by stakeholders.

A. Background

Fig. 4 (shown in appendix) describes the four major issues in a top-down analytical model. Each subsystem will help address a part of the major issues.

1. Navigation control with location tracking: Although the tasks for competitions change yearly, there are two main arena layouts that have been seen consistently. The first is a barrier-based board layout with a centrally lined path as seen in the 2024 arena layout (Fig. 2) [1]–[3]. The second is a non-barrier-based board layout that has distinguished zones and no trackable line as seen in the 2023 arena layout (Fig. 1). Either of these layouts could include inclines, declines, obstacles, and much more. Having two general layouts allows for a sensor set to be general enough to navigate both. Additionally, the sensor set needs to be sufficiently able to understand the robot's precise board location. Being able to confirm the location allows for more effective use of time.
2. Precise motor control: Time is a large factor in many of the hardware competitions. Each run has a 3-minute limit.

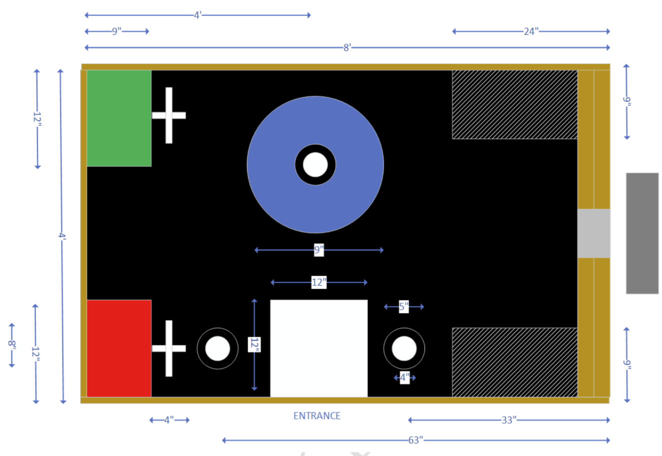

Fig. 1: 2023 IEEE Competition Layout [2]

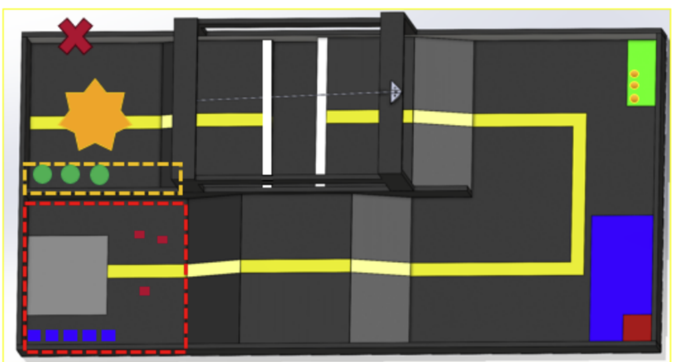

Fig. 2: 2024 IEEE Competition Layout [3]

Therefore, it is necessary for the robot to be supplied with enough power capacity and possess precise and effective motor control to be able to complete as many tasks as possible.

3. Integrated battery charging: Every year, the SECON team faces problems with their battery system at competitions: the battery takes a long time to charge and must be disconnected from the robot to do so, meaning valuable practice time is lost. Upon reassembly, components are often short-circuited which causes stress from wasted time, energy, and money to fix the issue. Therefore, it is essential for the robot platform to possess a charging system that is well integrated with all other systems and considers the user's needs.
4. Adaptable modules: It is important to consider how future teams' competition requirements will change. Therefore, the robot created will need to be adaptable in size while still adhering to competition requirements. The sensor sets should be easily interchangeable based on the requirements of the competition. Additionally, the placement of components and wheels should be as plug and play adaptable as possible as well.
5. Customer Requests: The customer requested several specific ideas or components to be used. The following section explains specifically why these requests were made through the unique attributes each component offers: the components explicated were extrusion rods, mecanum wheels, DC motors, back EMF, and a "clean" and "dirty" power bus. Extrusion rods (shown in Fig. 3) will allow components to be adjusted along the D-channels. The rods are created of 6063-T5 aluminum alloy which has a yield strength of 110 MPa, or 1217 kg/cm2 which will be sufficient for all SECON robotic needs [4]. Mecanum wheels have a unique tread that utilizes rollers to move in a dynamic pattern. Moving each wheel independently can produce diagonal and side-to-side movement while keeping all wheels straight. These attributes will allow a full range of movement. DC motors are used because of their controllability and starting torque compared to AC motors. DC motors start rotating at approximately 1 volt of potential, so the steady state off position must have a voltage less than 1 volt to ensure none of the motors are active. Once enough voltage is applied to a DC motor, back electromotive force (EMF) is created in the opposite direction [5]. Without protection, back EMF can damage circuit components. The "clean" bus is for control devices and to reduce voltage drops due to back EMF and is kept isolated from the "dirty" bus. The "dirty" bus is for power devices and to manage large currents.

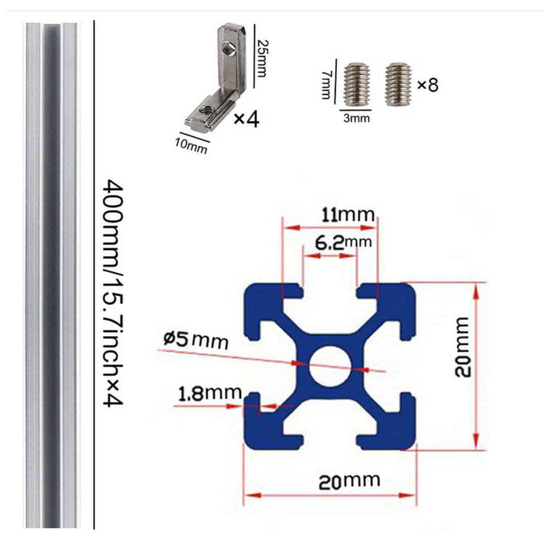

Fig. 3: Extruded Aluminum Rods for Chassis [6]

B. *Specifications*

The customer for the project, Professor Jesse Roberts, provided a list of requirements for the robot. Using the verbal requirements, the team formulated a list of specifications.

1) Chassis Specifications: The body and frame of the robot base must adhere to the rules of the IEEE SECON hardware competition [2] [3]. As a result, the robot can be no larger than 1 foot in length, width, and height. The robot created in this project will be under 12 inches in length and width and

6 inches in height. Professor Roberts also requested that the frame's dimensions be customizable. In addition to custom dimensions, the frame must be able to withstand at least 5 pounds of payload capacity. Mecanum wheels will be used at the customer's request to achieve dynamic turning capabilities.

2) Navigation Specifications: The robot must have the ability to navigate a 4-foot by 8-foot plywood arena with differing layouts in order to properly orient itself. All the navigation techniques will be modular to give full customization to the SECON team. A sensor set for each of the identified layouts will need to be selected in a modular format to achieve navigation success. Having sensors in modular form will allow teams to choose which navigational techniques they need for the specific project, leaving them more space to implement unique competition designs. Navigation accuracy should allow the robot to locate itself in the arena within a 2-inch tolerance.

3) Power and Bus Specifications: Professor Roberts requested that there be a "clean" and a "dirty" bus to better handle the effect of noise on the microcontroller. In addition to the bus work, the customer specified that the battery must be configured to charge without removal. Therefore, a port must be present on an external wall of the robot. Additionally, it was requested for wireless charging to be explored as time permits. Specific battery ratings and size will be based off the cumulative power needs of all system components determined in future modeling.

C. Constraints

The following section outlines the statements that must be accomplished by the team and defines the scope of the project. These statements will be used to determine the project's measures of success.

The team shall:

1. design a robot with a single start button. Once activated, the robot will begin navigating its environment.
2. design a robot that possesses an allocated data input point for an alternative start method.
3. design an autonomous robot that has customizable dimensions with the stock design only occupying up to one-half of the allowed cubic foot (1 ft x 1 ft x 6 in).
4. design a robot platform whose modules are plug-and-play adaptable for different IEEE competition requirements.
5. design a robot that possesses 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.
6. evaluate wireless charging as an option for charging the robot.
7. design a robot to possess a single emergency stop button that is accessible and stops all robot movement without removing power to essential processors.
8. design the power bus in such a way that the DC motors do not inhibit robot operation.
9. design a robot that can travel inclines and declines up to 25 degrees.
10. design a robot that can turn 360 degrees left and right and move forwards and backwards based on sensor inputs.
11. design a robot whose navigation system controls movement; knows its location within a two-inch tolerance; and possesses a maximum speed of 2 feet per second.
12. create a user manual that explains all functions and capabilities of the robot.
13. abide by all standards listed under section II.D of this document.

D. Standards

This section outlines the standards that are applicable to the project and must be always adhered to.

IEEE Code of Ethics: 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.

NFPA 79-10: NFPA 79 section 10 outlines emergency stop system requirements for industrial machinery. The emergency stop pushbutton will be based on the code outlined in this standard [7].

FCC Part 15 and 18: 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 [8].

IPC J-STD: This standard outlines soldering requirements for component leads, terminations, wires, PCBs, etc. [9] [10]

NEC 310.15(B)(16): This 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 [11].

E. Difficulties/Challenges

The main challenges associated with the design are the constraints on time and budget with time being further perpetuated by the knowledge gap of the team. In terms of the subsystems, much of the hardware interfacing will require extensive research to ensure optimal performance and connectivity amongst all peripherals and processors. Optimizing the process will also have two key challenges that must be overcome: for one, optimization must be balanced with the team's budget. The team cannot utilize high-quality products if those products are extremely expensive. The IEEE team has a limited budget, so if the robot is too expensive to maintain, it will not be useful to future teams.

Secondly, optimization must be balanced with generalization. Since the team is building a platform for future robots, the systems cannot be hyper-optimized for one mode of navigation. Though some competitions may benefit from high-level sensing and navigation, the project goal is to create something highly adaptable so future teams can optimize the system to fit their needs. In essence, the goal is to create a system that is proficient at everything, not outstanding in just one way.

F. Existing Solutions

Previously, the existing solution was for teams to create a robot from scratch. Motor control, battery management, sensing, and navigation would only have been the first step. Instead of spending an entire year designing these systems well, teams would put together a system that worked well enough to maneuver and then begin working on other functions. Sometimes, the robot does well to make it to the end of the track. Starting from scratch each year is a very inefficient solution to the stated problem. Another solution is to purchase a base robot platform from a third-party source. Base robot platforms are not a new concept, and many designs could be purchased from online vendors (Amazon, VEX Robotics, Superdroid Robots, etc.). None of these kits, however, are optimized for the SECON hardware competition, meaning many of the subsystems would need to be redeveloped for the specific purposes needed in the competition. Modifications that may be necessary include changing mechanical dimensions, adding additional sensors that are more suited to the requirements of the competition, power system modifications to improve battery life and robot performance, etc. In order to meet the specifications and perform the tasks in the SECON competition, a robot also needs very robust parts, but most premade robots are either made with cheap parts or are too expensive to justify [12], [13]. Additionally, many premade robots also utilize concepts well beyond the scope of undergraduate design (concepts like neural networking), so making deep edits to the original base would be as complicated as starting from scratch [12], [13]. Therefore, having a platform designed in-house will lead to much greater success and affordability for years to come.

G. Summary of the Problem

The tasks at hand are derived entirely from the shall statements and, thus, will serve as a guide for the project solutions. Three major tasks have been developed that must be properly attended to: power, navigation, and chassis design. Power and navigation are further broken down into three subsystems to make the project more feasible. Each of these basic systems will be critical to create an efficient, generic platform for future teams to build upon.

III. Solutions

The following sections propose potential solutions to the shall statements, address how the team aims to achieve them, and acknowledge constraints that may hinder those results.

A. Critical Unknowns

For the team to fulfill the solutions listed in this document, all critical unknowns need to be evaluated and mitigated as much as possible. The largest unknown comes from changing competition requirements: as time progresses, the SECON hardware competition will evolve. It is critical that the team understands that the design will eventually become obsolete, but the benefits will affect the immediate years to follow its completion. Future teams may also have different skills sets that may not benefit from the platform that is created. These critical unknowns will be heavily considered in the decision-making process.

The critical unknowns that apply to the sensing functionality of the robot strongly depend on the choice of sensors. Because of this, the first critical unknown is the choice of sensors since we do not know what sensors will be most advantageous and easily integrated into the rest of the system. Once the sensor choices are decided, the unknowns will be restricted to the sensor specifications (bandwidth, response time, dynamic range, physical range, etc.). These unknowns will be answered through review of the applicable documentation and experimentation.

There are also several critical unknowns that apply to charging and power management. Primarily, the power requirements are currently unknown. The power, voltage, and current requirements will dictate various components of the robot, and additional loads applied by future teams must also be considered. The feasible amount of wireless power transfer is a related unknown. As such, wireless charging may not be practical for the requirements.

Finally, the critical unknowns related to the control system primarily hinge on the limitations of computing hardware. The team will be using the Jetson Nano as the central controller and will likely use smaller controllers (such as Arduinos) for some peripheral tasks. Because the hardware and computational limitations of these microcontrollers are unknown, a strict goal for modularity cannot yet be identified. This includes but is not limited to the computation speed, the number of possible threads, the number of ports available, and any limitations of the robot operating system.

B. Survey of Possible Solutions

The following section will outline multiple solutions for each robot subsystem. Although there are multiple solutions to each component, the team will use this document to select which solution is the most appropriate given the feasibility, constraints, and specifications laid out in the previous sections.

1) Charging: Various charging solutions are presented below that optimize centralized charging as mentioned in the shall statements. The first option would be to have a charging port on the robot. This would adhere to the constraint and can allow the robot to be used during charging. One drawback to this design is the need for a charging wire. During use while charging, the team would have to follow the robot with the slack wire to prevent entanglement. Secondly, the robot could be charged wirelessly with a charging mat placed underneath the game board. Wireless charging would make the system more convenient for cycling charging and testing, but there are some important concerns about wireless charging. Wireless charging creates more heat than wired charging. The two types of wireless charging – radiative and non-radiative – each have concerning attributes. Radiative wireless charging must be transferred using 10 milliwatts of power or less because of radiated energy safety concerns [14]. Non-radiative charging options are limited by charging distance. Broad issues of wireless charging include slow charging speed and high cost to implement.

2) Effects of DC Motors on Power Bus: DC motors produce back EMF on a power bus when they are turned off. This causes issues with any other component connected to the bus. Keeping the buses separate can be done in a few different ways. One method to do so is to keep the grounds of the two buses separate (i.e., two power sources will be used). By keeping the dirty and clean bus grounds separate, there is much less potential for interfering signals to travel from the dirty bus through the grounding conductors to the clean bus. Another method to utilize is decoupling capacitors at power and ground connections to filter out any interference caused by the dirty bus or coupling between the two buses. A final method of keeping the two buses from interfering is to have filtering circuitry in the clean bus that will block any prominent frequencies in the dirty bus [5].

3) Modularity: Modularity is a vital component of the project. The robot systems will be mounted on individual bracket systems and grouped into 'blocks' that can be manipulated into different shapes or sizes depending on the specifications of the competition at hand. The robot will be designed to take up a flat, 1 foot by 1 foot base, however, the system could – in theory – be adaptable to smaller sizes as well (note that the height of that space will differ). Other configurations would be possible as well with a block design because each piece can be rearranged into a new configuration. If components must be stacked, additional extrusion rods must be added. It is important to note, however, that there will be benefits and tradeoffs to the configuration of the system due to exterior manipulations such as charging and connecting leads or cables.

4) Navigation: The SECON hardware competition follows the same basic format every year. The team must autonomously traverse a 4 foot by 8 foot area while performing a set of tasks to earn points. However, the arena format is different for every competition. No matter the type of arena, the robot must have a set of sensors to navigate, so there will be two sets of navigation tools to correspond to the two basic types of arenas. Furthermore, the input data from these sensors will be used to control the movement around the arena.

In the case of a track with a line to follow, the robot is meant to move along the line within specified tolerances. To follow the path, the robot will need to be able to sense where the line is and navigate along it using sensors. In this case, an infrared line tracking sensor or a robotic vision system could be used to detect where the line is to keep the robot on track [15] [16]. It will be necessary for the robot to detect objects in front of it to prevent unwanted collisions. An additional sensor such as ultrasonic, bump, lidar, magnetic field, time-of-flight, or capacitive proximity could be utilized [17]–[20].

The other type of arena seen at SECON does not have a line to follow but instead the robot is free roaming within the entire 4 foot by 8 foot space. The robot will need to be able to sense the objects in the arena as well as the walls to get an accurate location of itself and objects for navigation. Some possible sensors for identifying the walls and objects are ultrasonic, bump, lidar, magnetic field, time-of-flight, and capacitive proximity sensors [17]–[20].

5) Chassis: Utilizing the extrusion rods brings two possible solutions: 3D printed internal rails, and individual trays. To move the internal components of the robot, 3D printed trays can be implemented so that all contents in the tray move as one unit when shifted about the extrusion rod. Trays will prevent the components from being shorted or damaged when moved. The individual tray method would require all external and internal components to be shifted independently, so problems may arise with wheel alignment when modified later since each wheel may not be precisely 90 degrees from the others. Improper alignment may cause navigation errors when maneuvering about the board.

C. Measures of Success

The following measures of success parallel the constraints listed above. Each measure specifically fulfills the requirements stated in its specified statement only.

1. The start button must be an easily reachable button on the exterior of the robot. After this button is pressed, the robot must autonomously begin navigating its environment without any further input from the user. For this to be considered successful, this must be completed for ten out of ten trials.

2. To prove that the input has not been allocated for any other use, the alternate start method input point will be specified in the user manual and pinout schematics.
3. The robot platform must be within the physical constraints of one-half of a cubic foot to leave room for specialized development. This may be distributed unevenly due to the different shapes and sizes of components used but will roughly take the shape of a 1 ft x 1 ft x 6 in rectangular prism. The area and dimensions will be measured with a ruler for verification.
4. For the robot platform to be considered plug and play adaptable, the platform's flexibility will be measured by having 4 inches of maneuverability on the front wheels and components that can be relocated within 2 inches of the base configuration without rewiring. Each wire will be grouped and labeled to be identified when moving around the components. There will also be two sensor sets – one for line following and one for free roaming – that are plug-and-play adaptable with high-level code structures used for software adaptability.
5. The battery (or batteries) must be able to be charged without being removed from the body of the robot. Charging could be done through a dedicated port on the outside of the robot or wirelessly through wireless power transfer. For the system to be considered robust, all hardware and software must perform their function as expected without critical failure. To be successful, the robot must have a 5 pound payload and at least a 2 hour runtime before needing to be charged. Also, the robot must run while charging for 10 out of 10 trials.
6. Wireless charging will be researched, and feasibility evaluated. The decision on whether or not to use wireless charging will be provided with written justification.
7. The emergency stop button must be easily accessible on the outside of the robot platform chassis. When pressed, all power operations must be suspended to the motors while maintaining power to the essential processors. To be successful, the voltage will be measured on each of the motors to be 0 ± 0.5 volts and the processors will be visibly checked to see if they are receiving power via light indicator for 10 out of 10 trials.
8. Waveform measurements will be taken of systems adjacent to the power bus to show that noise has not interfered with their operations. The back emf from the motors will be measured before and after the filter is added to the buses, and it should have decreased at least 80 percent for it to be successful.
9. The robot will traverse an incline and decline of 25 degrees on a practice SECON board to ensure its functionality, and it will be able to successfully complete this 10 out of 10 times.
10. The robot will be tasked with maneuvering a mock SECON competition that will test its ability to follow lines, navigate around obstacles, and maneuver in the four cardinal directions. To be successful, the robot will need to successfully maneuver the course 10 out of 10 times.
11. The robot's maximum speed of 2 feet per second (comparable to previous SECON robots' speeds) will be tested while carrying a 5-pound payload for 10 out of 10 trials [1]. The navigation system will be successful when it has reported its location within the 2-inch tolerance for 10 out of 10 trials.
12. A user manual will be assembled at the end of the project. For the manual to be successful, it will detail each subsection's functions, explain how to adapt the systems, and provide weaknesses for future teams to improve upon. To test how well-written the manual is we will use feedback given by people outside of the team on how well they understood the robot. To pass the manual as successful, it will be reviewed by 20 people and should have a 70% passing rate.
13. Following the conclusion of the project, the robot will comply with 100% of the applicable standards through a review and justification process.

IV. Broader Impacts

The generalized robot platform will improve engineering impact for future capstone students since it would diminish the need to create new power, sensor, and motor control systems year after year. IEEE SECON robotics groups would have the potential for greater competition success by not needing to recreate the base of the robot. The added time to address the robot's unique functions would allow the team to complete more of the competition's tasks and, consequently, obtain a higher score. A more successful performance could result in more visibility for the department, school, and design team. Visibility would also aid involvement in the TN Tech IEEE student branch.

Although the impact on future groups is primarily positive, future competitors would not be as exposed 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.

Wireless charging could also greatly impact results because – to the team's knowledge – it has not been previously used in the hardware competition and may provide a performance advantage. Great caution must be exercised, however: if the charging process is not safe for all personnel involved, then the robot may be barred from competing and disqualified. Additionally, if the charging process is not compatible with the competition's provided electrical source, then in the best-case scenario the robot could not properly charge. In the worst-case scenario, the team could cause a major electrical hazard.

As engineers, the team has the responsibility to follow the IEEE Code of Ethics including the safety and welfare of the public and environment. Also, the team has a responsibility to abide by the rules of the IEEE competition and avoid designing anything that may be interpreted as deceitful to the overseers of the competition. The team strives to avoid harming anyone involved in the competition or otherwise to the best of our ability. The team also has a responsibility to ensure that all the work presented is independently and originally generated.

V. Project Feasibility

A. Personnel and Skill Sets

To create a successful base model robot, skills with motor control, navigation sensors, and battery charging are required. While each member of the team shares some basic circuit analysis and coding skills, some of the key skills of the team members will be crucial in having a successful project.

- Luke Chapman: Python, KiCad, Ansys HFSS
- Jackson Crews: Qelectro Tech, Solidworks, Matlab
- Isaac Hoese: Power system analysis, python, GUI-Tkinter, SQL
- Isaac Jennings: C, C++, Assembly, LTSpice
- Abigail Kennedy: Ladder Logic, Logicad, Automation
- Mabel Olson: Autocad, Mechatronics, Sensors

B. Necessary Software

There is a need for softwares for specific sections of this project including electrical drawings, 3D design, software, and electromagnetic simulations. The following softwares have been identified as necessary: KiCad, AutoCAD, ROS, and Ansys Electronics.

KiCad is an open-source electronic schematic and printed circuit board layout design software. This will be an important software for us when we are designing printed circuit boards for the robot platform [21]. AutoCAD is a computer-aided design (CAD) software for 2D and 3D design. This software or an alternative CAD software will be necessary for designing the physical structure of the robot platform [22]. Robot Operating System (ROS) is a set of open-source libraries designed for development of operating systems for robotics systems [23]. This is what will be used for the development of the main operating system and software base for the robotic platform. The Ansys Electronics suite includes Ansys HFSS, Maxwell, and other electromagnetic simulation software. These softwares are for different types of electromagnetic simulations and modelling and may be used on this project depending on whether wireless charging is pursued. If wireless charging is attempted, then Ansys HFSS or Maxwell will be used for simulating power transfer [24].

C. Budget and Timeline

The budget described will serve as an estimate for the project's initial design. As the project furthers, the estimated amount will fluctuate. The proposed budget will act as the financial feasibility metric and aid in determining the project's full scope. Each component listed has a unit price range. The total component price is calculated by multiplying the quantity of each component by the lower- and upper-unit price. The final estimated budget of the project will have a 25 percent error margin added to compensate for unknown future expenses. Table 1 in the appendix shows the proposed budget for the project.

The timeline is an essential factor to consider for feasibility. The team must carefully align the schedule with the due dates of various project sections, including the final due date. Each member must be able to work in parallel to complete work by the deadlines to complete significant subsections. The team has a tentative schedule for both semesters of capstone, shown in Fig. 5 in the appendix, outlining planning, design, testing, and implementation to ensure the project is completed promptly.

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 envisioned in this proposal 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.

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VIII. Appendix

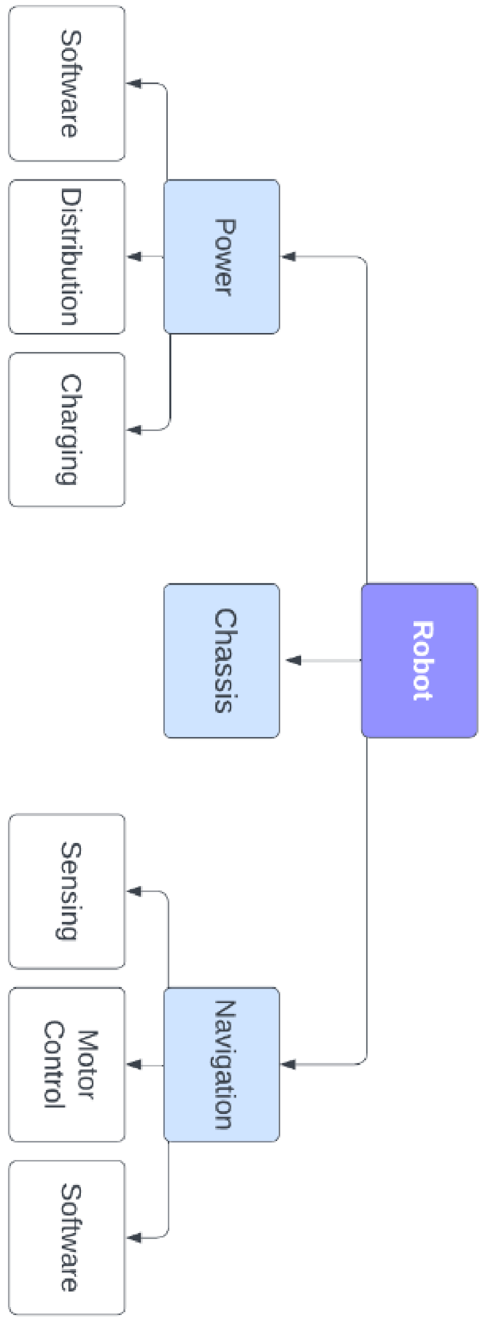

Fig. 4: Main Systems

Table 1: Proposed Budget

Proposed Budget						
Sub-System	Item	Qty.	Unit Cost		Total Cost	
			Low	High	Low	High
Power Regulation	Microcontroller	1	$35	$150	$35	$150
	Battery	2	$100	$150	$200	$300
	Battery Charger	1	$30	$50	$30	$50
	Emergency Stop	1	$10	$15	$10	$15
Total					$275	$515
Navigation	Line-Follower	2	$5	$50	$10	$100
	Gyroscope	2	$7	$40	$14	$80
	Compass	2	$1	$3	$2	$6
	Bump Sensor	1	$6	$8	$6	$8
	Sonar Sensor	4	$4	$30	$16	$120
Total					$48	$314
Chassis	Wheels	4	$10	$20	$40	$80
	Extrusion Rods	4~12	$3	$5	$12	$60
	Charging Port	1	$2	$5	$2	$5
Total					$54	$145
Motor Control	Brushless Motors	4	$5	$60	$20	$240
	Microcontroller	2	$20	$30	$40	$60
	Motor Drivers	2	$9	$20	$18	$40
	Motor Encoders	1	$13	$23	$13	$23
Total					$91	$363
Miscelaneous	Surface Mount Components	N/A	N/A	N/A	$50	$200
	Wire Supplies	N/A	N/A	N/A	$50	$100
	Printed Circuit Boards	10~15	N/A	N/A	$60	$80
	Switches	5	$8	$10	$40	$50
	Fuses	5	$1	$7	$5	$35
	Materials for Test Arena	N/A	N/A	N/A	$100	$200
Total					$305	$665
System Total					$773	$2,002
Margin/Redundancy					25%	25%
Final Total					$966	$2,503

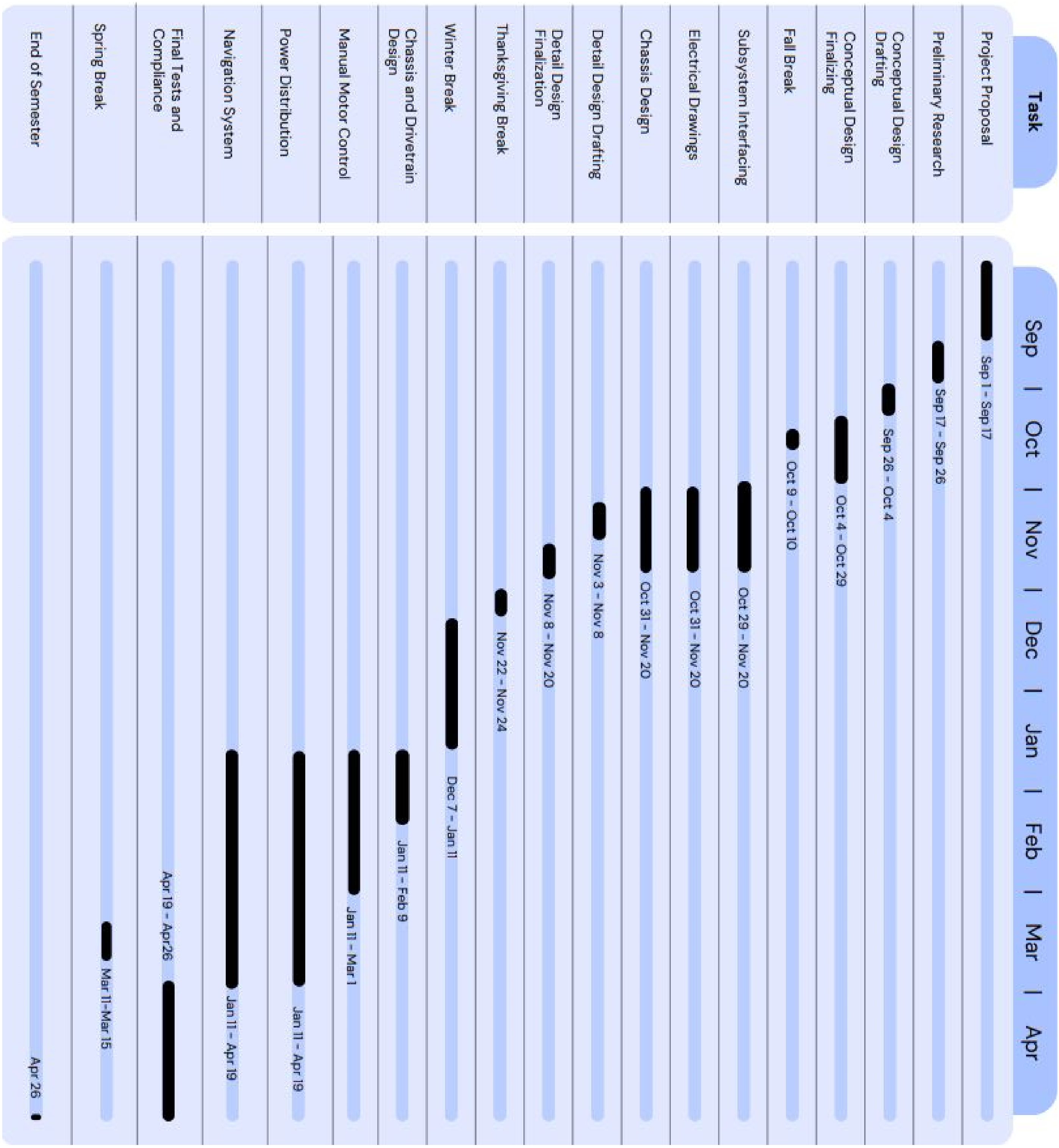

Fig. 5: Gannt Chart