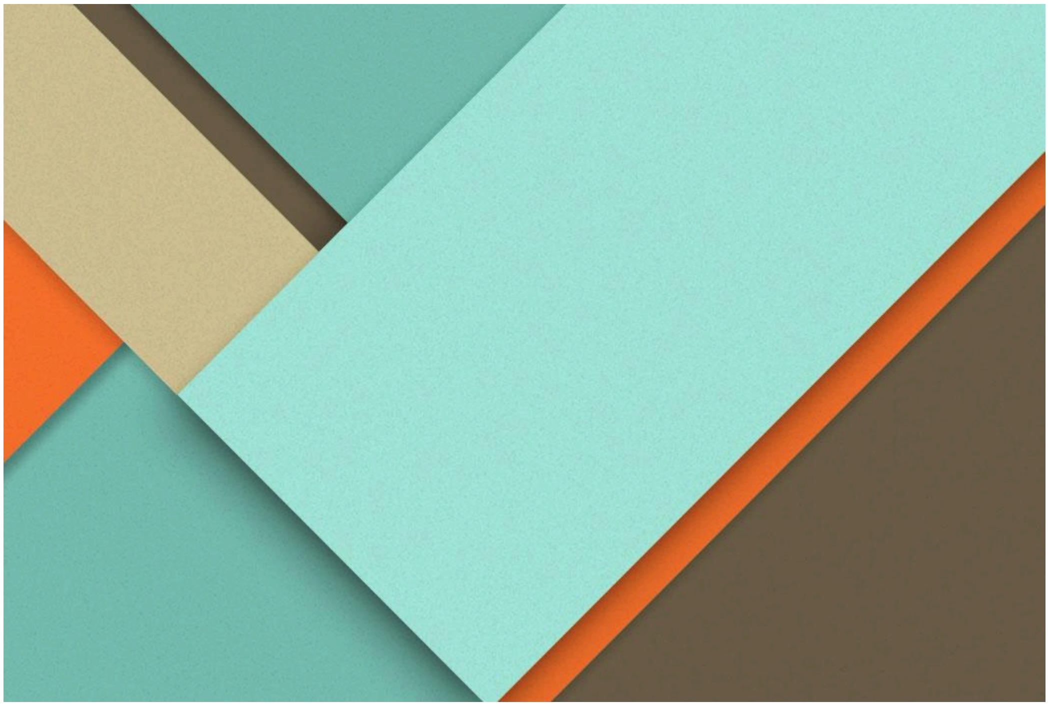

Small Scale Autonomous Racing Vehicles

<u>*Sponsored by Dr. Yaser P Fallah's Research Group (CAVREL)*</u>

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1 - Project description

1.1 - Background

We are a multidisciplinary team of five engineering students with a shared passion for robotics, automation, and intelligent systems. Our diverse backgrounds across several engineering disciplines allow us to approach challenges from different technical perspectives. Here's a breakdown of our team's composition:

- **Two Computer Engineering Students (Israel and Asa):** Our computer engineers specialize in hardware-software integration, embedded systems, and real-time computing. They have experience in developing low-level software, working with sensors, and using microcontrollers. They also have some experience in designing application-specific printed circuit boards. With experiences on both, the software and hardware side of things, they make the perfect bridge for interfacing the software that will run the project and the hardware that the project will be run on. Their background is crucial in designing and implementing some of the vehicles' systems, interfacing data acquisition from some sensors, and ensuring real-time processing necessary for autonomous navigation.

- **One Computer Science Student (Owen):** Our computer science student has a passion for artificial intelligence, machine learning, and computer vision. They are proficient in algorithms, data structures, and technical expertise that allow vehicles to make real-time intelligent decisions. They have also worked directly with small-scale autonomous vehicles, having published a research paper on autonomous vehicle platooning at the Vehicular Technology Conference (VTC 2024 - Fall). This student will focus on developing the perception, planning, and control components of the systems, enabling the vehicles to recognize objects, track lanes, and navigate independently at high speeds.

- **One Electrical Engineering Student (Casey):** Our electrical engineering student has a strong focus on circuit design, power systems, and signal processing. They bring expertise in sensor integration and power management, which are essential for the different components of the vehicles to receive power. This student will ensure that the systems remain efficient in terms of power consumption.

- **One Mechanical Engineering Student (Tevin):** Our mechanical engineering student brings expertise in dynamics, control theory, and mechanical design. They are responsible for designing and optimizing the physical chassis of the vehicles, ensuring they remain lightweight and aerodynamically efficient, while also handling the high speeds and rapid maneuvers required in a racing scenario. Their understanding of the vehicles' mechanical behavior, from suspension to aerodynamics, ensures that the autonomous control systems can interact effectively with the physical world.

As robotics and automation enthusiasts, the majority of us have chosen to minor in **Intelligent Robotic Systems**. This has equipped us with a deep understanding of how robots interact with their environment, make decisions based on sensor input, and perform complex tasks autonomously. Some of us have gained hands-on experience in building robots, designing control algorithms, and integrating machine learning into real-world systems.

1.2 - Motivation

Our motivation for choosing the Small Scale Autonomous Racing Vehicles project comes from several factors:

- Cutting-edge Challenge: Autonomous racing combines various complex domains such as computer vision, real-time decision-making, and control systems. The fast-paced environment of a race demands the highest level of precision and optimization, which pushes us to challenge our technical skills and innovate. Autonomous vehicles are a rapidly evolving field with applications in industries like automotive engineering, robotics, and Artificial Intelligence (AI) driven transportation. Working on this project positions us at the forefront of this technological frontier.

- Passion for Robotics: As students passionate about robotics, we see this project as an opportunity to bring together our knowledge in intelligent systems, sensing, control, and mechanical design. Building an autonomous vehicle that can navigate, make split-second decisions, and race on its own is the ultimate test of our combined knowledge and skills. This project allows us to apply what we've learned throughout our studies in a highly tangible and exciting way.

- Real-World Applications: Autonomous vehicles are shaping the future of transportation and robotics. By working on this project, we are contributing to the development of technologies that have the potential to revolutionize industries. Whether it's improving self-driving cars or enhancing robotics in industries such as logistics, manufacturing, or space exploration, the skills and experience we gain from this project are directly applicable to solving real-world problems.

- Interdisciplinary Collaboration and Professional Growth: This project allows us to collaborate across disciplines, combining expertise from electrical, mechanical, computer engineering, and computer science. Practicing this kind of complex collaboration now, especially with complex and relevant technologies and techniques like Light Detection and Ranging (LIDAR) and Simultaneous Localization and Mapping (SLAM), puts us a step ahead in preparing to work in the robotics industry. Performing well in this project and potential competitions that we plan on participating in, such as the F1Tenth Competition, also allows us to showcase our skills to potential employers and graduate schools.

- Community Contribution: One of our goals is to make this project available for anyone to use and learn from. We want to contribute to bridging the gap of knowledge when it comes to autonomous vehicles. We aim to create simplified detailed step-by-step instructions on how to replicate our final product. This way, anyone with basic robotic knowledge can learn and implement our project. One of our objectives to accomplish that goal is to work with the Institute of Electrical and Electronics Engineers (IEEE) and Association of Computing Machinery (ACM) chapters here at the University of Central Florida (UCF), along with some other chapters, to ensure autonomous vehicle racing maintains a presence at UCF.

1.3 - Related Work

For our Small Scale Autonomous Racing Vehicle project, some notable projects, communities, and existing products can serve as inspiration or reference points. These projects and existing products showcase a range of technologies in autonomous driving, artificial intelligence, machine learning, robotics, and control systems. Below are some relevant examples:

Indy Autonomous Challenge

- Overview: The Indy Autonomous Challenge is a global competition where university teams design autonomous race cars to compete on full-scale race tracks [1].
- Key Technologies: Autonomous driving relies on high-end sensors, such as Light Detection and Ranging (LIDAR), Radio Detection And Ranging (RADAR), and cameras. Autonomous driving also relies on deep learning for real-time perception, and control systems optimized for high-speed maneuvers.
- Relevance: Although full-sized, this project demonstrates the cutting-edge in autonomous vehicle racing, including the use of real-time Artificial Intelligence (AI) and control under high-speed conditions. Some competitors at the Indy Autonomous Challenge had started out with small-scale racing autonomous vehicles. Therefore we believe that the techniques used there can be scaled down to our project.

Gymnasium (OpenAI Gym) and Reinforcement Learning Projects

- Overview: Gymnasium (formerly OpenAI Gym) is a toolkit for developing and comparing reinforcement learning algorithms. Many projects use the Gymnasium environment to simulate and develop control algorithms for autonomous vehicles in racing scenarios[2].
- Key Technologies: Reinforcement learning, deep Q-networks (DQN), and policy gradient methods are applied to optimize the driving behavior of autonomous vehicles, especially for tasks that require real-time decision-making in dynamic environments[3].
- Relevance: Using reinforcement learning to optimize the driving strategy of our autonomous vehicle, especially in a competitive race, can be crucial for improving performance. Leveraging simulated environments like OpenAI Gymnasium can help us refine algorithms before deploying them on our vehicle.

Audi Autonomous Driving Cup

- Overview: The Audi Autonomous Driving Cup is a university competition where teams develop autonomous driving software on a 1/8th scale Audi car. The cars must navigate a complex environment with obstacles, stop signs, and intersections while following the rules of the road[4].

- Key Technologies: The cars use Light Detection and Ranging (LIDAR), ultrasonic sensors, and stereo cameras for object detection and navigation. Artificial intelligence (AI) and machine learning are used for path planning, while control algorithms ensure the cars make smooth and accurate movements.
- Relevance: This project involves building robust and efficient AI and control systems for small-scale autonomous vehicles, similar to our project's goals. The integration of sensors and control in dynamic environments makes it highly relevant.

F1Tenth Autonomous Racing Platform

- Overview: F1Tenth is a popular autonomous racing platform used in university courses and research. The platform consists of 1/10th scale autonomous race cars equipped with sensors (LIDAR, camera) and a robust software stack. Teams participate in races where the cars must navigate tracks autonomously at high speeds[5].
- Key Technologies: The F1Tenth cars use algorithms for Simultaneous Localization and Mapping SLAM, path planning, and control optimization. LIDAR and computer vision are used for localization and obstacle detection, while the framework Robot Operating System (ROS) is commonly used for communication and coordination between components.
- Relevance: This is one of the most directly applicable projects to our goal. The F1Tenth platform is designed specifically for small-scale autonomous racing and can provide a wealth of resources, both hardware and software, to support our project development.

NVIDIA JetRacer

- Overview: NVIDIA JetRacer is a small-scale AI-powered autonomous racing car built on the NVIDIA Jetson Nano platform. It comes with built-in support for AI-based driving and deep learning models[6].
- Key Technologies: JetRacer uses deep learning models for real-time object detection, steering, and obstacle avoidance. It also supports advanced algorithms for racing in dynamic environments using computer vision.
- Relevance: This platform is directly applicable to our project. It demonstrates how Artificial Intelligence (AI) models and real-time processing can be implemented on a small-scale car. The Jetson platform's compact size and powerful AI capabilities make it a similar solution for our racing vehicle.

Donkey Car (Open Source Self-Driving Car Platform)

- Overview: Donkey Car is an open-source Do it Yourself (DIY) platform for building 1/10th-scale autonomous cars. It's widely used in the maker community and by robotics enthusiasts to build and race small self-driving cars[7].

- Key Technologies: The system uses a Raspberry Pi for processing, a camera for vision, and a Remote Control (RC) car chassis for mobility. It employs deep learning for steering, throttling, and obstacle avoidance. Donkey Car uses TensorFlow and Keras to train models on driving data.
- Relevance: Donkey Car's open-source framework provides an excellent alternative for small-scale autonomous racing vehicles. We can learn from its existing framework, AI model, and control systems to build our vehicle.

1.4 - Goals and Objectives

Our primary goal is to build two small-scale autonomous race cars capable of competitively navigating an indoor racetrack in the presence of other race cars with the same goal. The primary objectives involved in completing this project are as follows:

- **Construction:** Our race cars must be durable enough to survive multiple races without crashing or short-circuiting.
    - Basic objectives:
        - Our two PCB boards must be capable of efficiently routing power from the battery(ies) to the main drive motor, the steering servo, the companion computer, the real-time flight controller, and all other sensors and electronic components. It must also be capable of preventing power surges.
        - Our System Status Indicator module must be capable of interfacing with the flight controller (Pixhawk 6C running PX4 firmware) and displaying different patterns of color in response to issues with the car (e.g. low battery).
        - The vehicle with the 1/6th scale motor must be capable of maintaining traction at speed despite the significantly greater torque.
    - Stretch goals:
        - Our RSO should be capable of teaching new members how to build autonomous race cars of their own even after our senior design project wraps up.
- **Software:** Our software system must handle all three key components of autonomous driving: perception, planning, and control [8].
    - Basic goals:
        - Our car must be capable of reactively following the contours of the race track before a full map is created without getting stuck in dead ends.

        - Our simultaneous localization and mapping (SLAM) module must be capable of taking in points from a LiDAR or depth camera and fusing them into a unified map representation in real time.
        - Our system must be capable of computing an optimal race line once the full race track is mapped, and the control component must be capable of pursuing that race line while avoiding obstacles.
        - Design the car's drivetrain and suspension system to execute the accelerations and velocities commanded by the autonomy software while being responsive to the conditions and layout of the race track.
    - <u>Stretch goals:</u>
        - Our control component should be capable of predicting changes in steering and speed simultaneously instead of being separate algorithms (model predictive control).
        - Our system should be capable of plotting multiple routes around obstacles and selecting the best one (rapidly exploring random trees).
- **Vehicle mechanics and dynamics:** Our vehicle must be designed and optimized to achieve high top speeds and exhibit good handling characteristics.
    - <u>Basic goals:</u>
        - Have an aerodynamically efficient aerodynamic package for the vehicle.
        - Have the car's drivetrain and suspension system be capable of executing the accelerations and velocities commanded by the autonomy software while being adequately reactive to a wide variety of conditions and track layouts.
        - Minimize the vehicle's weight and optimize the weight distribution to allow the vehicle to have good handling characteristics across a wide variety of conditions and track layouts.
    - <u>Stretch goals:</u>
        - Enable the vehicle's aerodynamic package, drivetrain and suspension systems, weight, and weight distribution to be variable to allow for a track-specific setup.
        - Create a parameter-based vehicle model that enables the user to determine a vehicle aerodynamic package setup, drivetrain and suspension system configuration, and weight distribution that would be optimal for specific track conditions and layouts.

- **Competition & Legacy:** Our project should leave behind a legacy of autonomous racing at UCF.
    - Basic goals:
        - Our cars must race at the F1Tenth grand prix in the closed and open categories.
        - Run workshops in cooperation with the Institute of Electrical and Electronics Engineers (IEEE) and the Association of Computing Machinery (ACM) to teach others about autonomous vehicle racing.
    - Stretch goals:
        - Start an autonomous racing registered student organization (RSO) at the University of Central Florida.

1.5 Description of features and functionalities

The vehicle will have a lightweight and durable chassis optimized for high-speed racing. The chassis will be constructed using materials that provide an optimal balance between durability and weight, allowing for excellent speed and handling performance. An aerodynamic will enable higher top speeds by reducing drag and maximizing efficiency. The high-performance drivetrain will deliver rapid acceleration and high top speeds, while a finely tuned suspension system will ensure optimal handling through a variety of corners. Together, these mechanical elements will enable the vehicle to handle a variety of racing conditions while maintaining agility and speed.

As the vehicle operates in a closed-loop system, sensors play a crucial role in gathering environmental data to facilitate autonomous decision-making. The vehicle will be equipped with Light Detection and Ranging (LiDAR) sensors, which emit and receive electromagnetic signals to determine the distance between the vehicle and surrounding objects[9]. This will aid in proximity sensing and collision avoidance. Complementing the LiDAR, an RGBD (Red Green Blue - Depth) camera will provide both color and depth information, enhancing the vehicle's understanding of its environment. This sensor system will also assist with real-time computer vision tasks. An Inertial Measurement Unit (IMU) will provide orientation and motion data, further improving localization and navigation accuracy. Together, the LiDAR, RGBD camera, and IMU will feed critical environmental and motion data into the vehicle’s SLAM algorithms. The SLAM system will enable the vehicle to simultaneously build a map of its surroundings and localize itself within that map, supporting dynamic obstacle avoidance and real-time path adjustments.

The vehicle will be equipped with a path-following functionality to navigate the race track map created by the SLAM algorithm. Once a racing line is calculated, the vehicle's control system will continuously track and follow this path, adjusting its speed and steering based on real-time data. The path-following algorithms will compute the optimal trajectory, factoring in the vehicle’s dynamic capabilities such as maximum speed, acceleration, and cornering abilities.

For versatility in operation, the vehicle will include an external control and communication system. This system will allow for manual control via a remote RC controller. While the vehicle is designed for fully autonomous operation, this feature provides flexibility for manual intervention or testing purposes. Additionally, real-time monitoring of the vehicle's key performance metrics will be enabled through onboard displays. These will include power monitoring, showing the status of the power distribution system and battery health, as well as speed monitoring to provide instant feedback on the vehicle's performance. These systems will help the team track critical information during testing and ensure the vehicle's safe and efficient operation throughout a race.

All of the vehicle's software systems, including ROS, SLAM, and path planning, will run on a high-performance computer equipped with a GPU. This setup will ensure that all processes, from sensor data acquisition to path execution, are performed with low latency, allowing the vehicle to make quick decisions and maintain high accuracy while racing around the track.

1.5 Division of Project Responsibilities

To successfully develop our two small-scale autonomous racing vehicles, we need to design, program, and integrate various subsystems to ensure the vehicles are fully functional. To optimize efficiency and capitalize on each team member's strengths, we will assign tasks based on individual expertise while maintaining close collaboration throughout the project. Below is an outline of the primary responsibilities assigned to each team member.

Tevin - Mechanical Engineering

- Vehicle Mechanics and Dynamics
    - Design, manufacture, and integrate mounting solutions for sensors and electronics.
    - Design and assemble the chassis and vehicle frame using appropriate manufacturing techniques.
    - Design an efficient aerodynamic package for the vehicle.
    - Ensure through design that the drivetrain and suspension can handle accelerations and velocities commanded by the autonomy software.
    - Optimize the vehicle's weight and weight distribution for good handling across varying track conditions.
- Overall Physical System Testing
    - Test the aerodynamic efficiency of the vehicles.
    - Assist in physical testing and troubleshooting of the assembled vehicles, focusing on mechanical performance (suspension response, vehicle speed, vehicle handling, etc.).

Casey - Electrical Engineering

- Power Distribution System
  - Design and implement the power management and distribution system, ensuring proper power delivery to all components.
  - Take charge of overall electrical architecture.
  - Calculate and budget the total power requirements for the vehicle (motors, sensors, compute units, etc.).
- Electrical Safety Monitoring
  - Design and program a monitoring module in the power management and distribution system
  - Design a battery management system (BMS) that monitors and protects the batteries from overcharging/discharging.
  - Ensure safe and efficient power delivery, including voltage regulation and protection circuits.

Asa - Computer Engineering

- System Status Indicator Module: Hardware
  - Design and fabricate a printed circuit board (PCB) that interfaces with the vehicle's sensors and subsystems, routing data to the status module
  - Interface components such as microcontrollers, sensors, and communication modules, to enable real-time data collection and transmission.
  - Ensure that the hardware is power-efficient by selecting low-power components and designing circuits that minimize energy consumption
- System Status Indicator Module: Software
  - Filter and process the incoming data to highlight critical metrics, such as power usage/issues and any system anomalies.
  - Develop a user interface for visualizing status information
  - Program the system to trigger alerts or warnings when critical thresholds are reached

Owen - Computer Science

- Overall High-Level Vehicle Programmation
  - Develop a script that initializes the subsystems required for the autonomous section of the vehicle.

- Race Line Computing
    - Develop algorithms that compute the optimal race line based on track data and vehicle dynamics.
    - Factor in, vehicle capabilities (e.g., maximum speed, steering angle) and track conditions (such as sharp turns, and straightaways) when computing the race line.
    - Continuously update the race line in real-time as the vehicle navigates the track, ensuring responsiveness to dynamic obstacles or changes in track conditions.
- SLAM (Simultaneous Localization and Mapping)
    - Implement SLAM algorithms to enable the vehicle to build a map of its surroundings and localize itself within that map.
    - Fuse sensor data (such as LiDAR, camera, IMU) to continuously update the vehicle's position and orientation in real time.
    - Ensure that the SLAM system can function in dynamic environments, where obstacles and features may change over time.
    - Optimize SLAM for real-time performance, ensuring low latency and high accuracy.

Israel - Computer Engineering

- Vehicle Steering
    - Design and implement the steering control system to ensure accurate and smooth turns during racing.
    - Integrate feedback from sensors and planning algorithms to adjust the steering dynamically.
- Follow the Gap Algorithm
    - Implement the "Follow the Gap" algorithm, which involves steering the vehicle towards the largest visible gap in the surroundings, ensuring collision avoidance while maintaining speed.
    - Identify open gaps from sensor data (such as LiDAR point clouds) and calculate the safest path for the vehicle through them.
- Project Website Development
    - Design and program a user-friendly website for our project to introduce the project and present the description and goals for the project.

    - Publish detailed instructions, software code, and downloadable files for anyone interested in the project
- Project Management and Coordination
    - Coordinate tasks across team members, ensuring that deadlines are met and dependencies between tasks are managed.
    - Maintain clear communication between team members to ensure all components are integrated smoothly.
    - Track progress on the design, development, and testing of each vehicle subsystem.

2 - Technical specifications

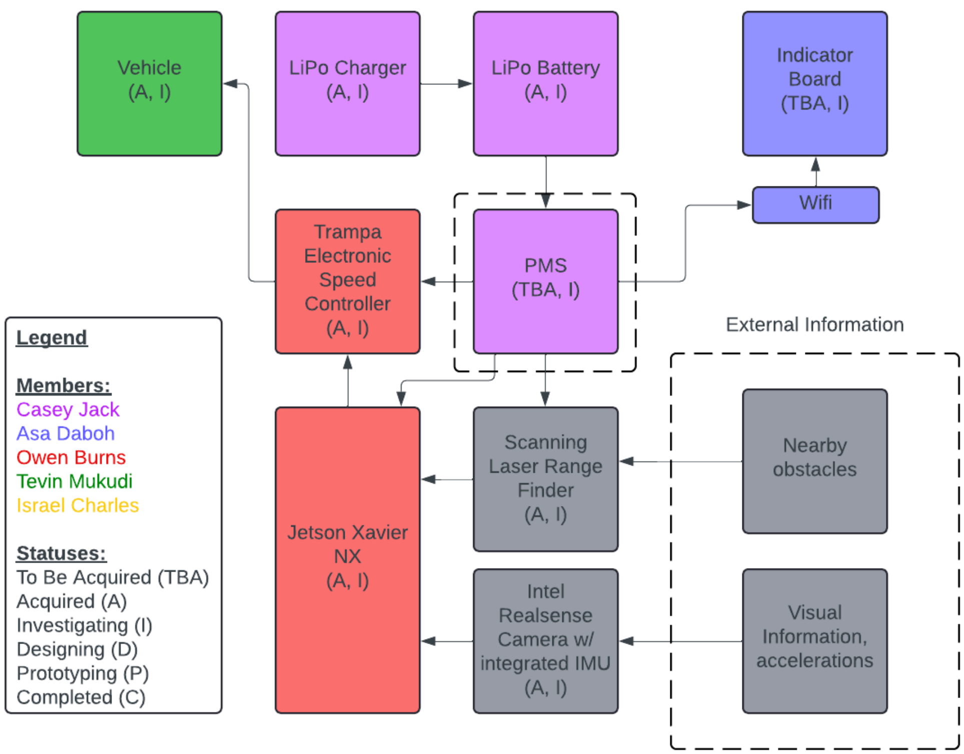
2.1 - Key Specification Table

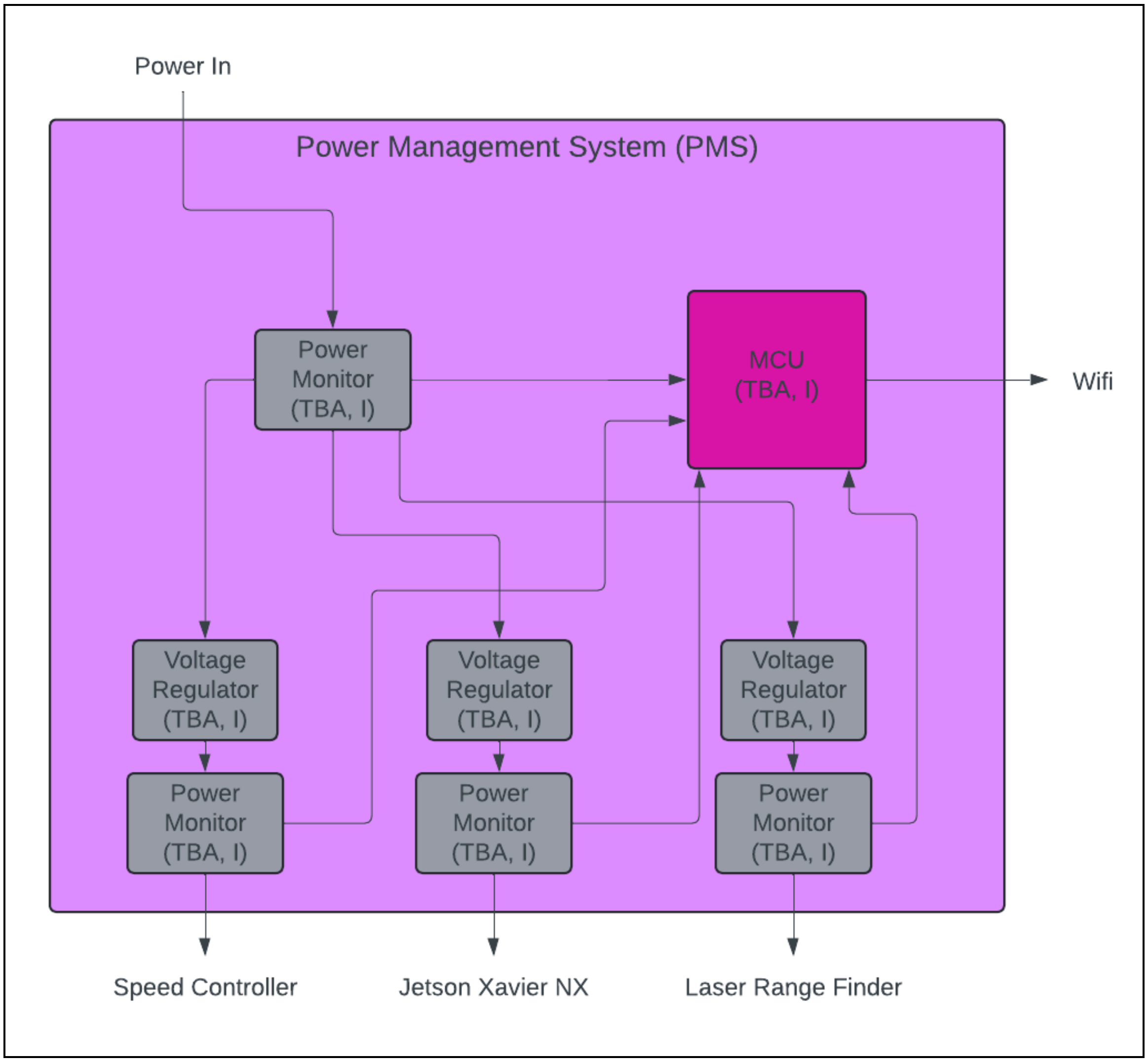
Item	**Parameter**	**Specification**
Vehicle	Max speed	>15 mph
Sensor communication	Latency	<100ms
Race line following algorithm	Average path point computation speed	< 250 milliseconds/point
Indicator board	Number of statistics on display	5
Power distribution board	Efficiency	>60%
Vehicle software odometry estimations	Accuracy	± 15cm
Battery	Runtime	>10 minutes
Vehicle Suspension	Response frequency	>1.5hz
Vehicle	Maximum roll angle at all racing conditions	7 degrees
Vehicle	Aerodynamic efficiency (coefficient of drag)	< 0.4
Battery	Capacity	> 5000mAh
Power distribution board PCB	Number of layers	2
Model Predictive Control	Overshoot	< 20%

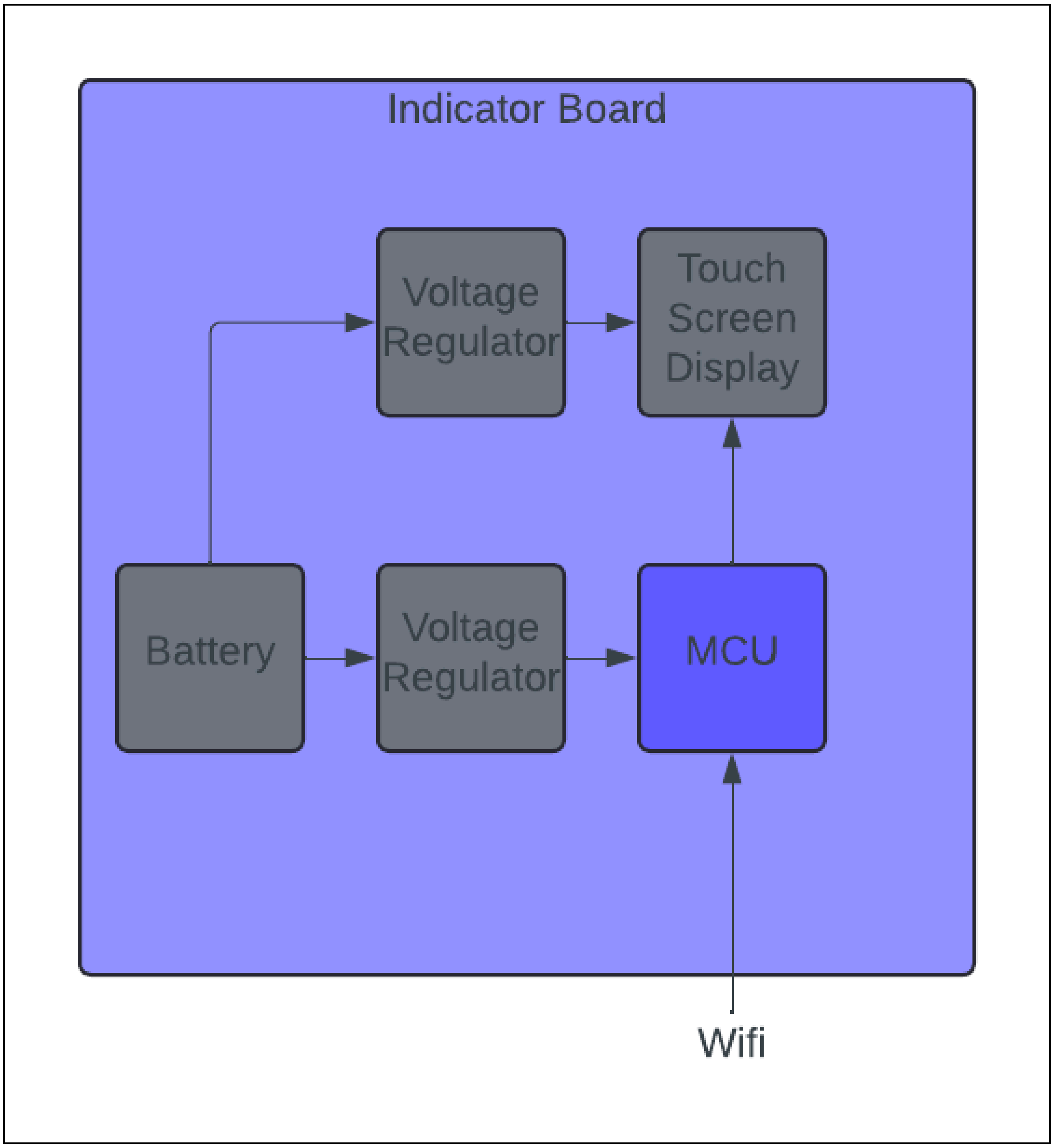
Set-point tracking		
Model Predictive Control Set-point tracking	Rise-time	< 1 second

Table 1: Key Specifications

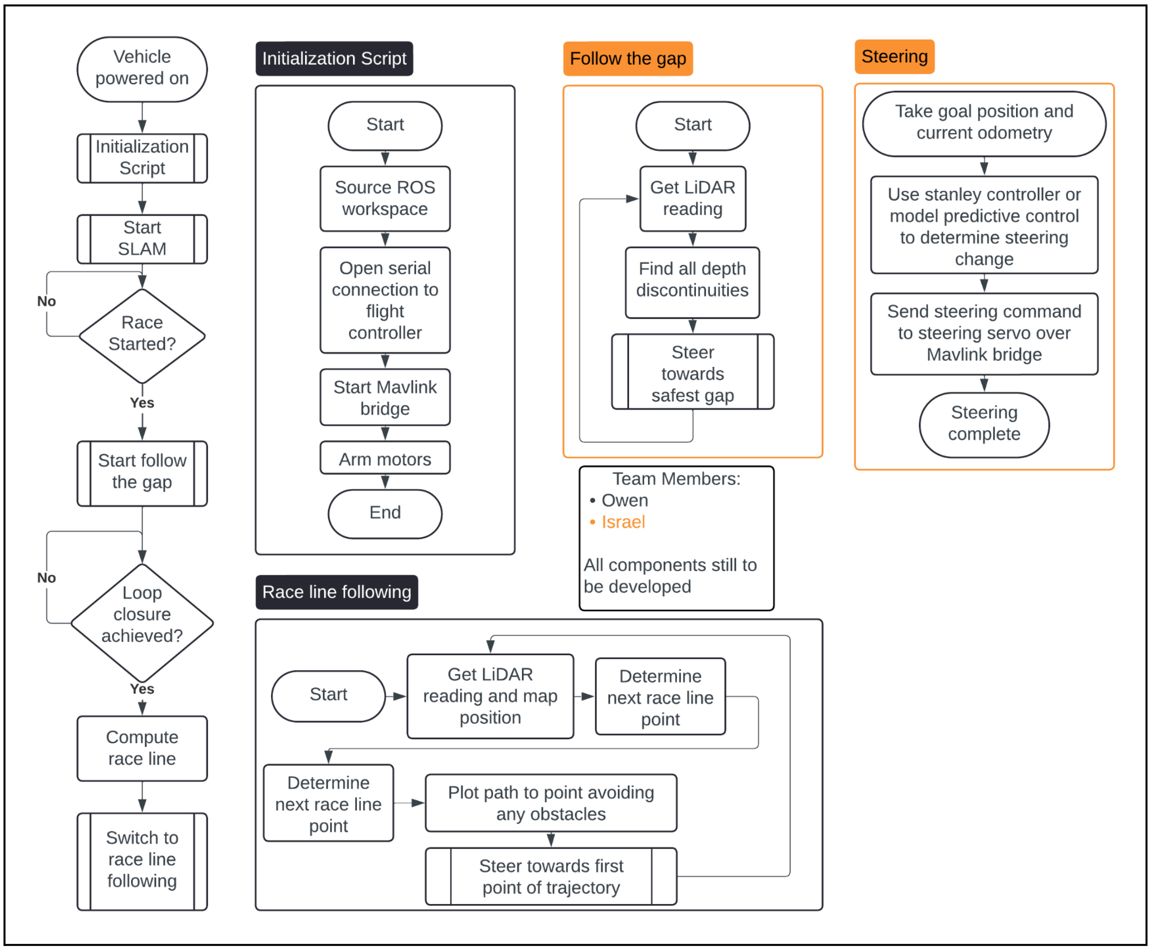
2.2 - Hardware Block Diagram



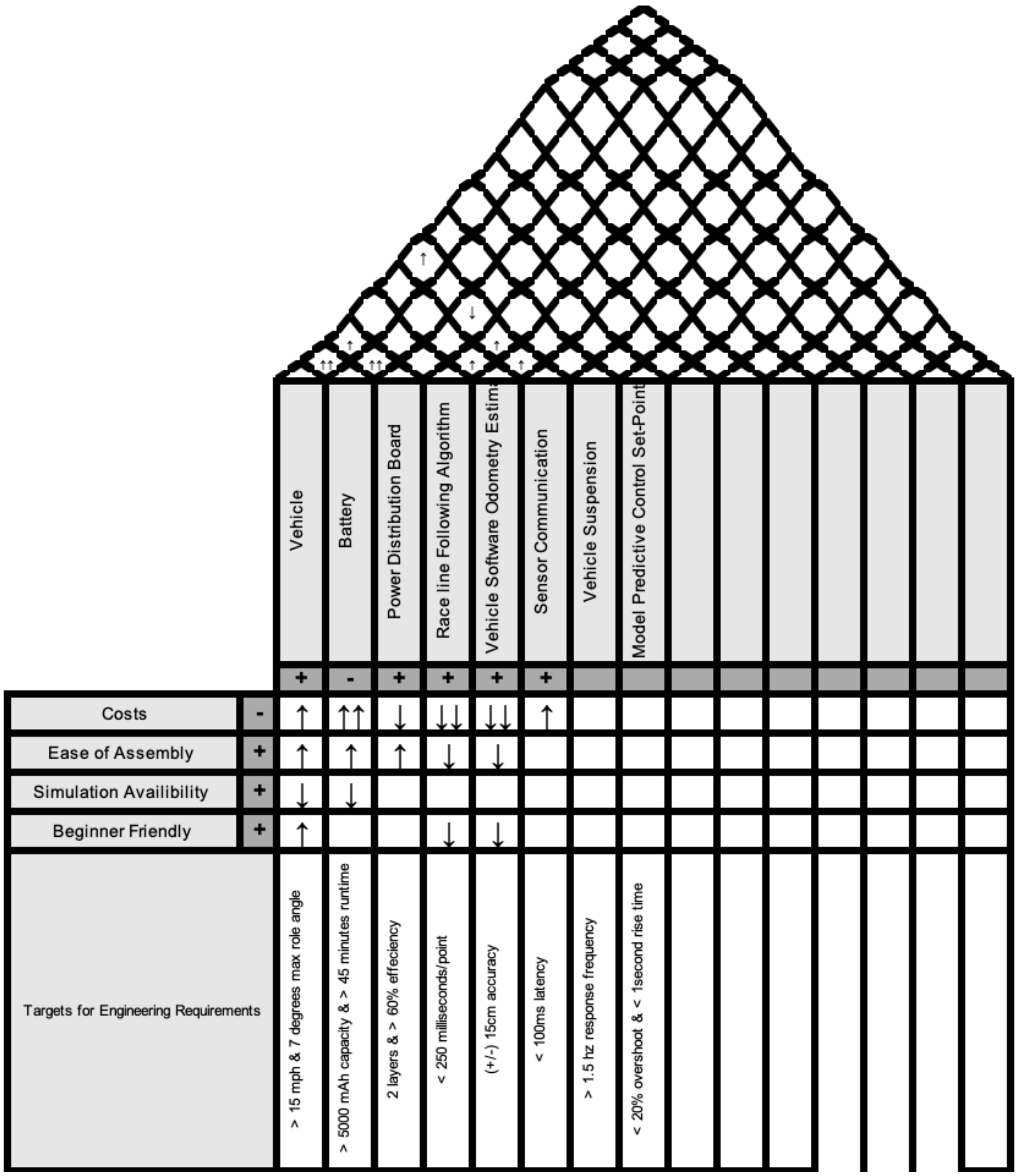

Power In
Power Management System (PMS)
Power Monitor (TBA, I)
MCU (TBA, I)
Wifi
Voltage Regulator (TBA, I)
Voltage Regulator (TBA, I)
Voltage Regulator (TBA, I)
Power Monitor (TBA, I)
Power Monitor (TBA, I)
Power Monitor (TBA, I)
Speed Controller
Jetson Xavier NX
Laser Range Finder


Indicator Board
Voltage Regulator
Touch Screen Display
Battery
Voltage Regulator
MCU
Wifi

2.3 - Software Block Diagram



2.4 - House of Quality



3 - Administration

3.1 - Project Milestones

In order to achieve the project milestones at appropriate times, it is integral that the group meets at least once a week and maintains constant communication to verify that goals are being accomplished. The following milestones are purely tentative and subject to change as seen fit by participating group members.

Senior Design 1

Start Date	End Date	Task	Description
8/19/24	8/22/24	Form group	Form team and get acquainted with group members
8/19/24	9/19/24	Research/ familiarization	Familiarize with software being used and study autonomous vehicle techniques
8/22/24	9/5/24	Requirement analysis	Define system requirements (hardware and software)
9/9/24	9/26/24	D&C revision	Prepare to turn in divide and conquer document revision (due 9/27 @ noon)
10/25/24	10/25/24	60-page draft report	Submit 60-page draft report (due 10/25 @ noon)
9/12/24	10/31/24	Hardware setup	Obtain hardware and begin testing components; begin building vehicle
9/12/24	10/31/24	Algorithm development	Setup simulation environment and begin implementing algorithms in said simulation; optimize algorithms
11/8/24	11/8/24	60-page report revision	Submit 60-page report revision (due 11/8 @ noon)
11/7/24	11/26/24	Real-world testing	Build real track, implement all hardware and software on track; refine algorithms based on real-world data
11/26/24	11/26/24	Final report/ mini demo video	Submit final report and mini demo video (due 11/26 @ noon)

Senior Design 2

Start Date	End Date	Task	Description
1/6/25	2/27/25	Real-world testing	Continuation of real-world testing that began

		(continued)	the previous semester (as needed)
2/20/25	4/3/25	Documentation/ presentation	Compile detailed documentation of system design, algorithms, and performance specs; create final report and prepare a live demonstration (if possible)
4/1/25	4/3/25	Live presentation	Present and demonstrate all findings/deliverables

3.2 - Budget and Financing

As a multidisciplinary project, the costs span several categories, including hardware, software, testing, and logistics. Below is a breakdown of expected expenses.

Bill of Material for Known Expenses

PART NAME	Unit(s)	UNIT COST	TOTAL
Chasis and Power Related			
Traxxas Slash 4X4 "Ultimate" RTR 4WD Short Course Truck	1	$ 499.95	$ 499.95
2 Lipos and Charger Combo	1	$ 239.95	$ 239.95
TRX to XT90 Adapter	2	$ 9.99	$ 19.98
TRX ID Connector Converter	2	$ 5.99	$ 11.98
LiPo safety bag like the Aketek Silver Large Size Lipo Battery Guard Sleeve/Bag for Charge & Storage.	2	$ 9.99	$ 19.98
Barrel Jack to Pigtail	1	$ 4.97	$ 4.97
Bullet Adapter 4mm Male 3.5mm Female	1	$ 8.99	$ 8.99
VESC 6 MkV	1	$ 258.00	$ 258.00

VESC ppm cable	1	$ 4.02	$ 4.02
Sensing and Computing Related			
Jetson Xavier NX	1	$ 659.00	$ 659.00
Hokuyo UST-10LX Scanning Laser Rangefinder	1	$ 1,670.00	$ 1,670.00
Intel RealSense D345i (optional)	1	$ 234.00	$ 234.00
Short (~1 ft) A USB-to-microUSB cable - Pack	1	$ 7.98	$ 7.98
Sony DUALSHOCK 4 Wireless Controller for PlayStation 4	1	$ 57.99	$ 57.99
Antenna	1	$ 8.99	$ 8.99
Micro SD Card 32 GB	1	$ 13.60	$ 13.60
NVMe SSD Card 250 Gb	1	$ 45.99	$ 45.99
Miscellaneous			
M2 - M5 Socket Head Assortment Kit	1	$ 24.09	$ 24.09
M2 - M4 Standoff Kit	1	$ 23.00	$ 23.00
HDMI emulator	1	$ 14.00	$ 14.00
Header Pins Pack	1	$ 8.99	$ 8.99
Air Duct Material (for creating a race Track)	8	$ 31.99	$ 255.92

Total: $4092

Estimated Budget Breakdown for Additional Expenses

Miscellaneous Electronics

- Power Distribution Board: $30 - $50
- Voltage Regulators: $10 - $30
- Wiring, Connectors, and PCB Development: $50 - $100
- Total: $90 - $180

Mechanical Components:
- Custom Frame or 3D-Printed Parts: $50 - $200
- Mounting Materials and Fasteners: $20 - $50
- Total: $70 - $250

Logistics and Miscellaneous
- Marketing/Presentation Materials: $50 - $100
- Unexpected Costs (spare parts, repairs): $100 - $200

Total Estimated Budget:
$4,730 - $5500

Financing: Dr. Yaser Fallah has agreed to provide us with financial support for our entire project. He will cover the costs mentioned above

3.3 - Declaration

We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have utilized LLM for drafting, outlining, comparing, summarizing, and proofreading purposes.

4 - Appendices

4.1 - Appendix A

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