MAPS: Autonomous Line Following Vehicle

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EXECUTIVE SUMMARY:

The Mobile Autonomous Path-Following System (MAPS) is a compact, autonomous robotic vehicle engineered to follow a black tape path on a white surface, detect and respond to obstacles, and recognize a designated finish line using integrated sensor systems. MAPS is activated via a touchless ultrasonic sensor and is capable of transporting a 250-gram payload without compromising performance.

At the core of the system is an Arduino Uno microcontroller, which processes input from two infrared sensors for path detection and an ultrasonic sensor for both obstacle avoidance and remote activation. PWM-based motor control enables fast and precise steering adjustments, while a 3D-printed chassis provides secure housing for components and allows for top-down access during development. The vehicle is powered by a single 9V battery, offering portability and ease of use.

MAPS was tested extensively and met all defined performance metrics. In its final stage, it demonstrated greater than 90 percent accuracy in line following, reliably detected and halted for obstacles within a 10-centimeter range, and consistently stopped at the finish line without error. The final prototype satisfies all client requirements and showcases effective embedded control, sensor fusion, and user-focused design within a lightweight, low-power system.

INTRODUCTION:

The project was developed under customer constraints established at the beginning of the semester. The objective was to design and prototype an autonomous robotic system capable of following a predefined path, detecting and responding to obstacles, and halting upon reaching a designated finish line using integrated sensors and motors. The primary challenge lay in creating a vehicle that could execute these tasks entirely on its own, without external input. According to the client requirements, the system also needed to be battery-powered, compact, and user-friendly to operate.

This project served as a platform to gain practical experience in sensor integration, embedded systems programming, and real-time control logic. The design was constrained by a limited power supply, tight spatial requirements for component placement, and variable ambient lighting conditions that could interfere with sensor performance. To guide development, a set of performance objectives was defined early in the process [A1]. These constraints were useful when considering design iterations throughout the semester.

INNOVATIVE DESIGN ELEMENTS:

MAPS' design incorporates a range of carefully selected components, each chosen to balance simplicity, functionality, and cost within the project's constraints. At the heart of the system is the Arduino Uno, selected for its versatility, extensive documentation, and ease of programming through the Arduino IDE. Line tracking was achieved using two digital infrared sensors positioned at the front of the chassis. These sensors were chosen for their fast response time and reliable ability to detect contrast between the black tape and the white background, enabling responsive steering corrections through conditional logic. Obstacle detection and touchless activation were handled by a single ultrasonic sensor, selected for its straightforward integration and accurate range detection within the required distance threshold.

Motor control was implemented using an L298N motor driver, which allowed for independent control of two DC TT motors and supported pulse-width modulation (PWM) for variable speed regulation. The TT motors were chosen for their ideal balance of torque and compact size and were paired with plastic wheels that offered sufficient traction and turning precision for simple mobility. A caster wheel was mounted at the front of the chassis to enhance maneuverability and provide passive stabilization during movement. All electronic components were mounted within a 3D-printed PLA housing, and wired according to the circuit diagram [C1]. A custom 3D-printed battery holder was designed to securely house a standard 9V battery, which powered the entire system for over an hour during testing. Standard male-male, male-female, and female-female jumper wires were used to connect all components, offering routing flexibility and quick replacements during debugging.

DESCRIPTION OF FINAL PRODUCT:

The final MAPS prototype is a lightweight, portable, battery-powered robot that autonomously follows a black tape line, detects obstacles, and stops at a finish line. It operates using sensor input processed by an Arduino Uno, with two IR sensors for line tracking and one ultrasonic sensor for both obstacle detection and touchless start. The vehicle's movement is driven by two DC motors controlled through an L298N motor driver, allowing for responsive directional adjustments.

All components are mounted on a custom 3D-printed PLA chassis designed for accessibility and durability. A rear-mounted 9V battery powers the system, secured in a printed holder for easy swapping. The top platform is tested to support payloads up to 250 grams. Overall, the final product meets the design criteria for autonomy, compactness, and usability, and performs reliably in standard indoor testing environments.

EVALUATION OF RESULTS:

MAPS was tested in a controlled indoor environment on paths with varying curves and a designated finish line. The robot consistently followed the black tape path with over 90 percent accuracy, demonstrating stable steering and minimal deviation during operation. In tests involving obstacle detection, the ultrasonic sensor reliably triggered a stop when objects were placed within a 10-centimeter range, and the robot resumed movement once the path was cleared. The touchless start mechanism using the same sensor also responded accurately to hand gestures without false activations.

Finish line detection was successful in all trials, with the robot stopping reliably when both IR sensors simultaneously detected black. The system operated for over an hour on a single 9V battery, exceeding the runtime requirement. Additionally, the robot maintained performance while carrying a 250-gram payload, with no noticeable impact on stability or steering precision. Overall, the prototype met all key functional metrics and behaved consistently across repeated trials, confirming the reliability of its sensor-based control system and mechanical design.

LESSONS LEARNED:

Through the development of MAPS, we gained valuable insight into the practical challenges of an engineering project. A major lesson was the importance of calibrating the IR sensors. Early tests showed inconsistent tracking performance, which we resolved by fine-tuning the detection thresholds to match our lighting conditions and tape contrast. This calibration significantly improved the car's ability to stay centered on the path and reduced erratic corrections.

We also learned how critical battery condition is to overall system reliability. Ensuring the 9V battery was at full capacity consistently led to stronger motor responses and more accurate sensor readings. In contrast, a partially drained battery introduced delays, weaker torque, and inconsistent behavior, making well-tuned logic and hardware appear faulty.

A third and equally important area of learning was coding and debugging. Much of the project involved iterative troubleshooting: testing individual behaviors, adjusting logic conditions, and rewriting control structures to improve reliability. For example, tuning how the system responded to object detection required continuous trial and error, along with critical verification of sensor states. This process taught us how to break down complex behaviors into testable blocks and reinforced the value of clear, modular code design.

Overall, the project emphasized the value of iteration, careful calibration, and persistent testing across both hardware and software components.

REFERENCES:

1. “Line Following Robot.” *Arduino Project Hub*, 7 June 2020, projecthub.arduino.cc/lightthedreams/line-following-robot-34b1d3.
2. hash includes electronics. “Line Follower Robot Using Arduino.” *YouTube*, YouTube, 27 July 2021, www.youtube.com/watch?v=5jh-5HGvC-I.
3. “ChatGPT.” *OpenAI*, chatgpt.com/. Accessed 1 May 2025.
    - for image generation and writing refinement

APPENDIX

Appendix A - Pairwise Comparison Chart:

	Accurate Autonomous Line Following	Obstacle Detection & Avoidance	Finish Line Recognition	Fast Response Time	Lightweight and Portable	Precise Steering Control	Score
Accurate Autonomous Line Following	x	1	1	1	1	1	5
Obstacle Detection & Avoidance	0	x	1	1	1	0	3
Finish Line Recognition	0	0	x	0	1	0	1
Fast Response Time	0	0	1	x	1	0	2
Lightweight and Portable	0	0	0	0	x	0	0
Precise Steering Control	0	1	1	1	1	x	4

Figure A1 - Pairwise Comparison Chart

Appendix B - Glass Box:

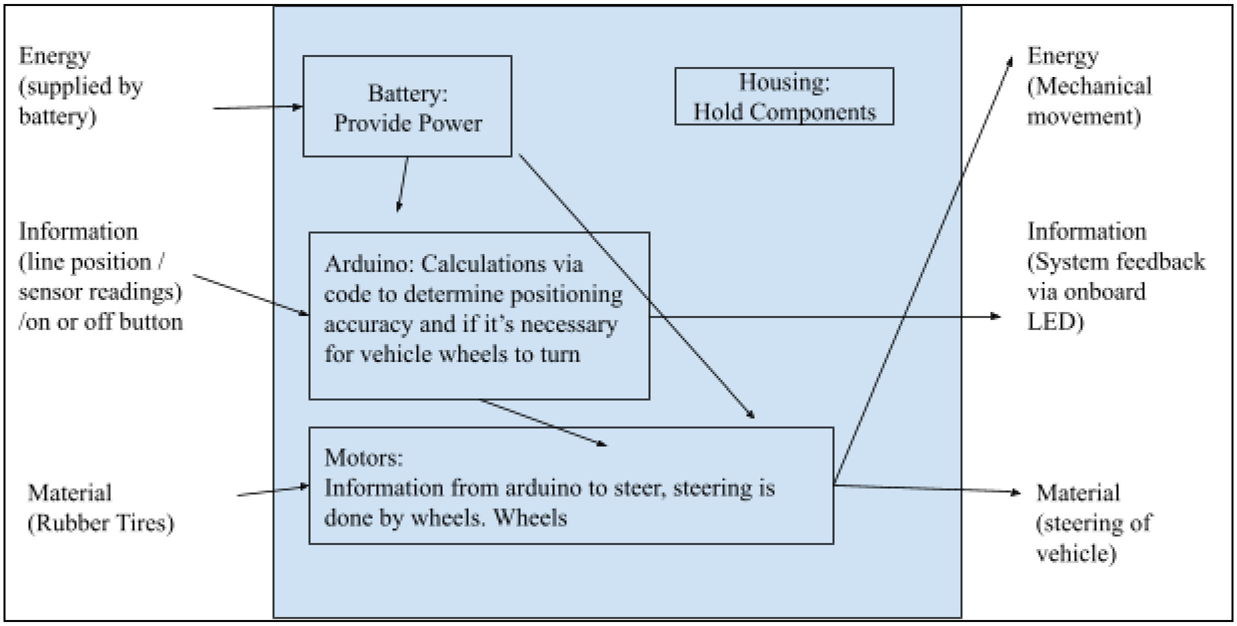

Figure B1 - Glass Box

Appendix C - Electrical Schematic:

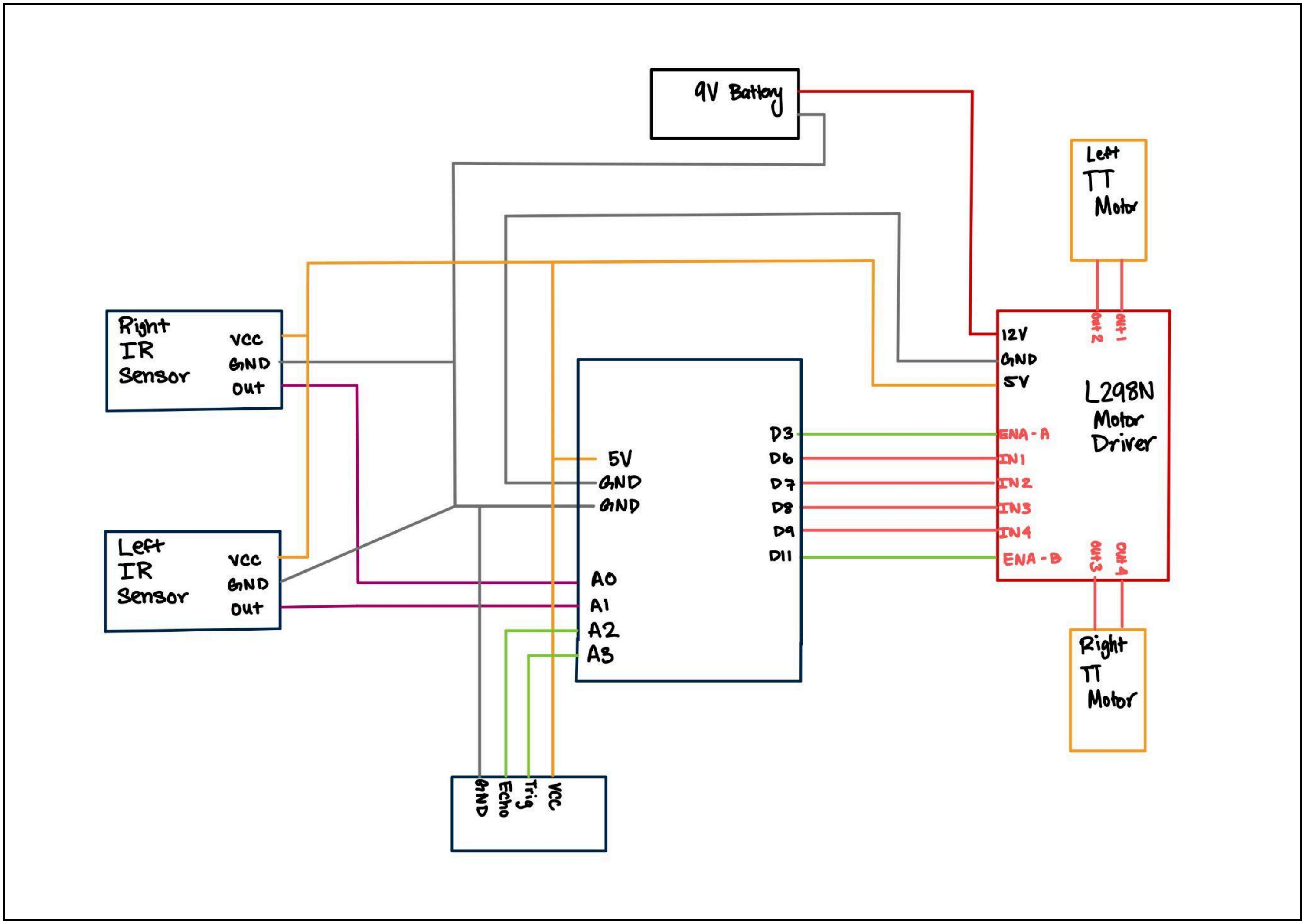

Figure C1 - Circuit Wiring

Appendix D - Code Flow Chart:

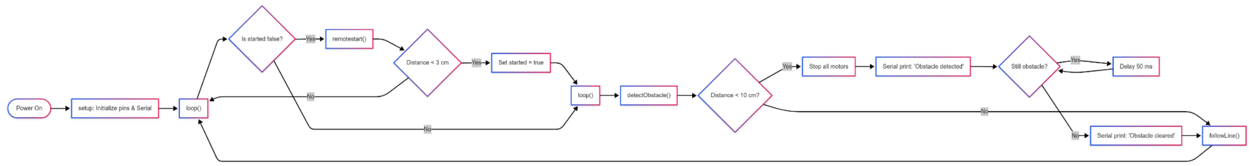

Figure D1 - Technical Code Flowchart of MAPS Control Logic

Appendix E - Computer-Aided Design:

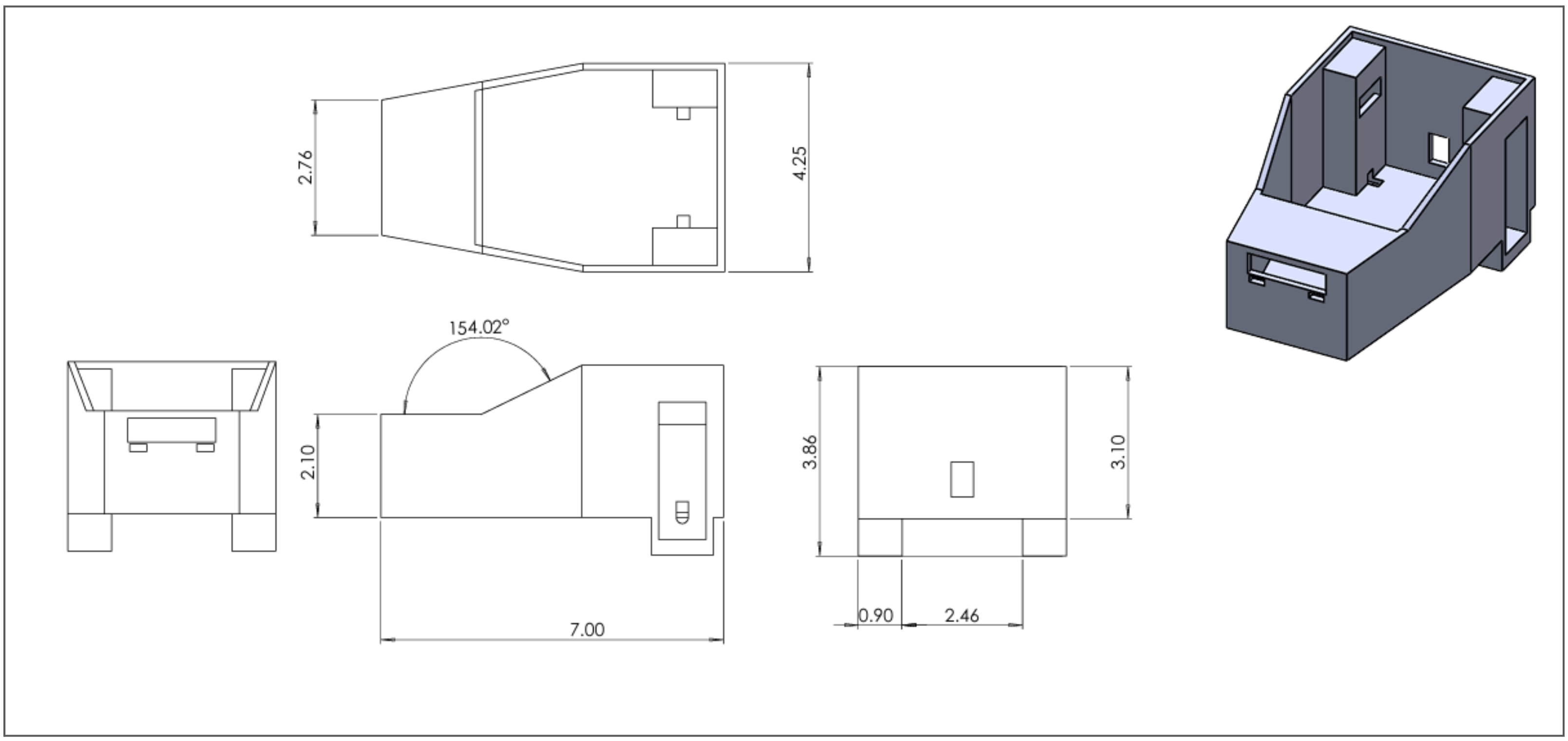

Figure E1 - CAD Drawings

Appendix F - Bill of Materials

Part	Quantity	Cost ($)
IR Line Following Sensor	2	1.76
Arduino Uno R3	1	8.99
9V Battery	1	1.60
HCSR04 USS Sensor	1	3.50
L298N Motor Driver	1	6.99
DC Gearbox Motor	2	5.90
Rubber Wheels	2	0.81
	Total	$29.55

Figure F1 - Full BOM

Appendix G - Power Budget

Part	Voltage	Current (mA)	Power (mW)
Arduino Uno	5	49.5	247.5
TT Motor x2	1.52	450	684
IR Sensor x2	9.94	18	178.92
US Sensor	4.97	19.7	97.909
Motor Driver	8.3	19.2	159.36
Power Consumption (mW)			1367.689
Battery Energy (Wh)	9V*0.4Ah		3.6
Time (h)	3.6Wh/1.368W		2.63

Figure G1 - Power budget of electrical components and calculating time in hours system should last

Appendix H - Plots Related to Testing

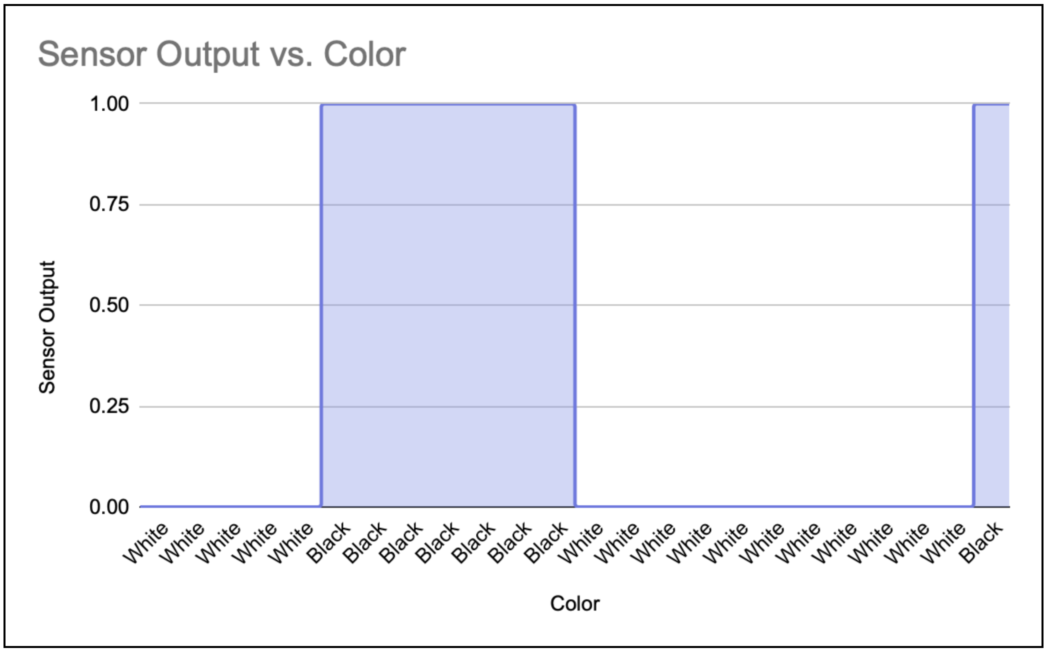

Figure H1 - Sensor Output vs Color: When the sensor detects black it outputs "1" and outputs "0" when failing to detect black

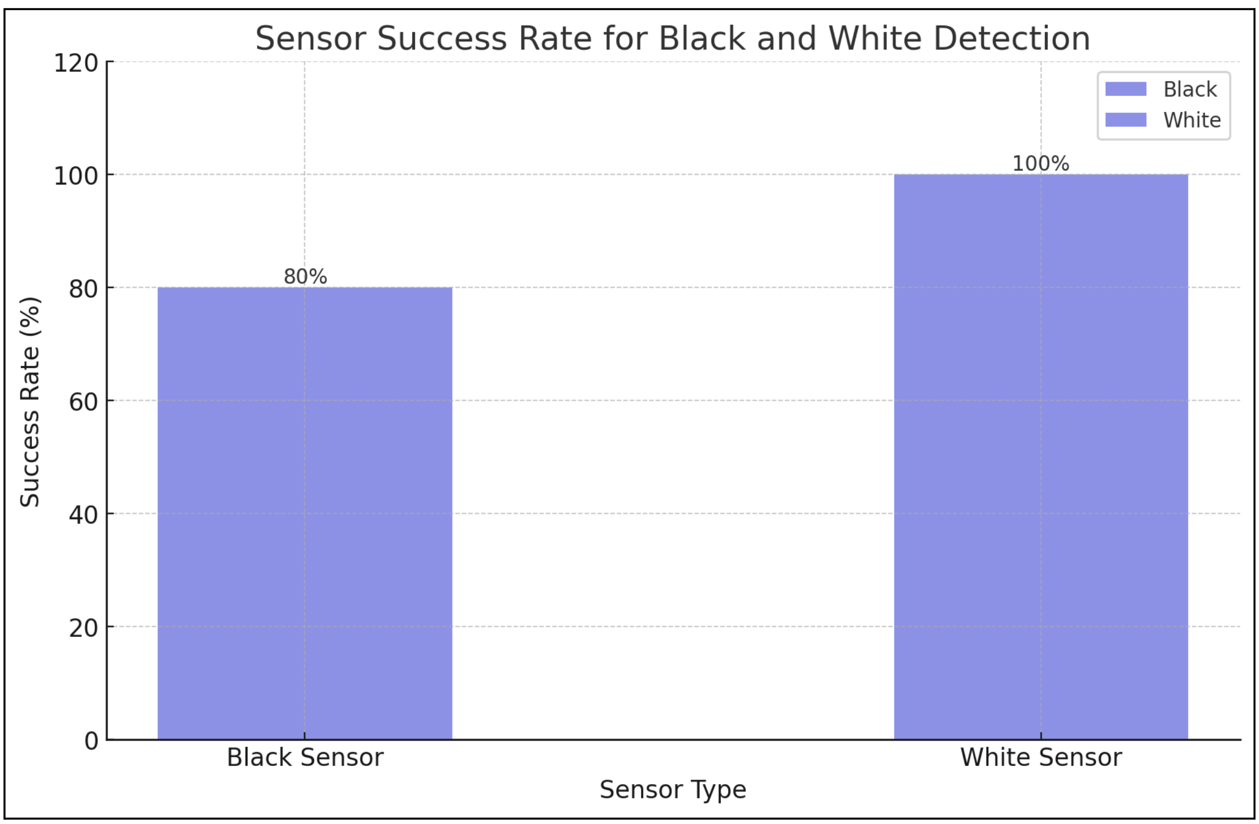

Figure H2 - Sensor Black and White Detection: Comparison of the white and black sensors identifying their respective colors

Appendix I - Morph Chart

Function/ Feature	1	2	3	4
Line detection	IR Sensor	Photoresistors	Camera connected to a computer	…
Speed Control	PWM	PID Algorithm	Bang-bang control	…
Obstacle Avoidance	IR Sensors	Ultrasonic Sensors	LIDAR	Bumper Switches
Driving and Turning	Servo Motor for steering	Skid steering	Pivot Turning	…
Housing	3D Printed	Metal sheets	Laser-cut wood	…

Figure I1 - Morph chart of our five most important functions

Appendix J - Objectives/Metrics

Objective	Metrics
Reliably follow 2cm wide black tape line	Avg Line Deviation of 0.5-1 cm from tape center
Smooth steering control being able to navigate down to 135 degree turns	Steering overshoot greater than 10 degrees in sharp turns
Detect an obstacle and stop being touching it	Cand detect obstacle up to 10cm away
Quickly able to adjust to track line changes	Control loop frequency of 10-20Hz and reaction time lower than 250ms
Detect the finish line and stop moving	Detection accuracy of 90% and false stop rate of 5%
Lightweight and portable design that is easy to trasnport	Weight of 0.5lbs and can be held in one hand

Figure J1 - The 6 most important objectives and metrics used in achieving them