Obstacle Avoidance Robot with Path Planning

With Firebase Integration

Team Name: ADSM

Members:

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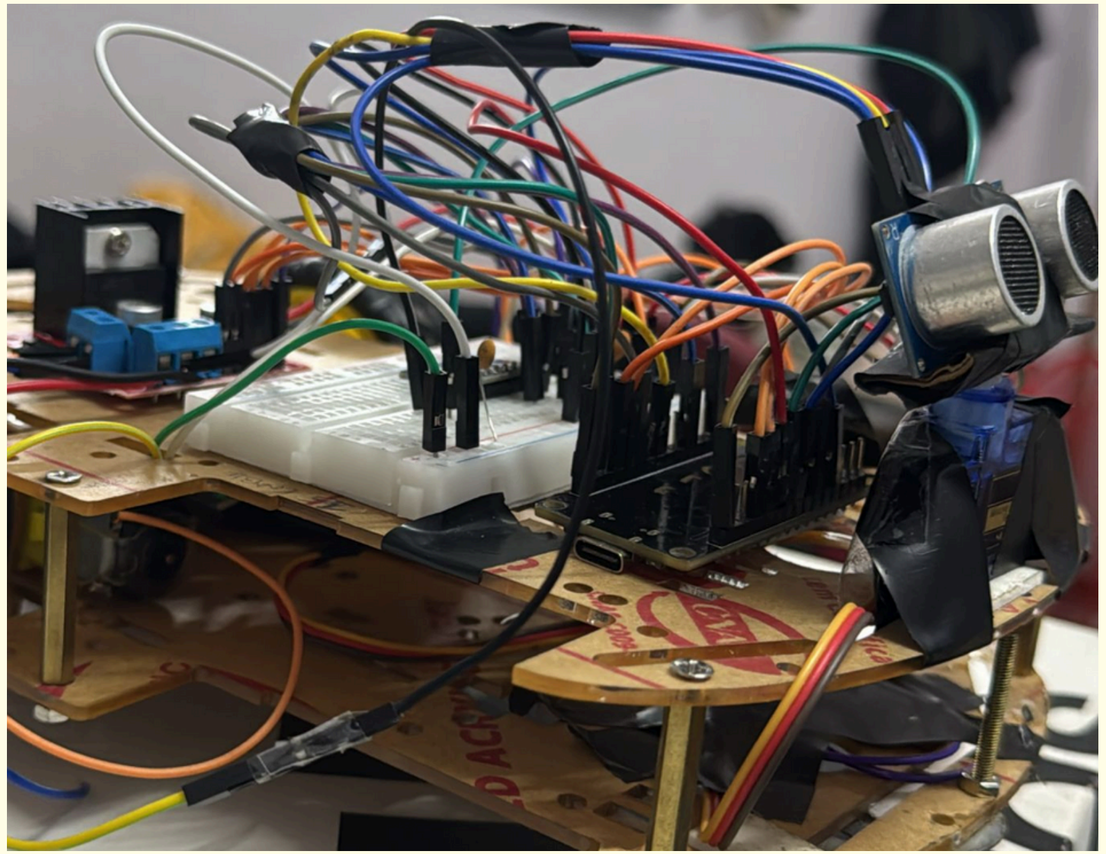


Team Contribution

Arnav

- Report preparation
- DC Motor integration
- Website integration
- Calibration

Dev

- Website Hosting and UI design
- Core logic implementation, ESP Code debug
- PID control of robot
- Path Planning design

Samyak

- Data collection
- Testing of hardware
- Obstacle avoidance logic debug
- Calibration

Manik

- Full hardware support
- Path planning testing debug
- PWM control of robot
- Soldering and assembly of components

Project Overview

The Problem:

- Autonomous robots are expensive.
- Most require powerful external computers or cloud servers.
- Limited solutions for budget microcontrollers.
- Gap between academic algorithms and practical implementations.

Our Solution:

- Complete autonomous navigation on single.
- Real-time obstacle avoidance and path planning.
- Manual teleoperation + autonomous navigation modes.
- Cloud connectivity via Firebase for remote monitoring.

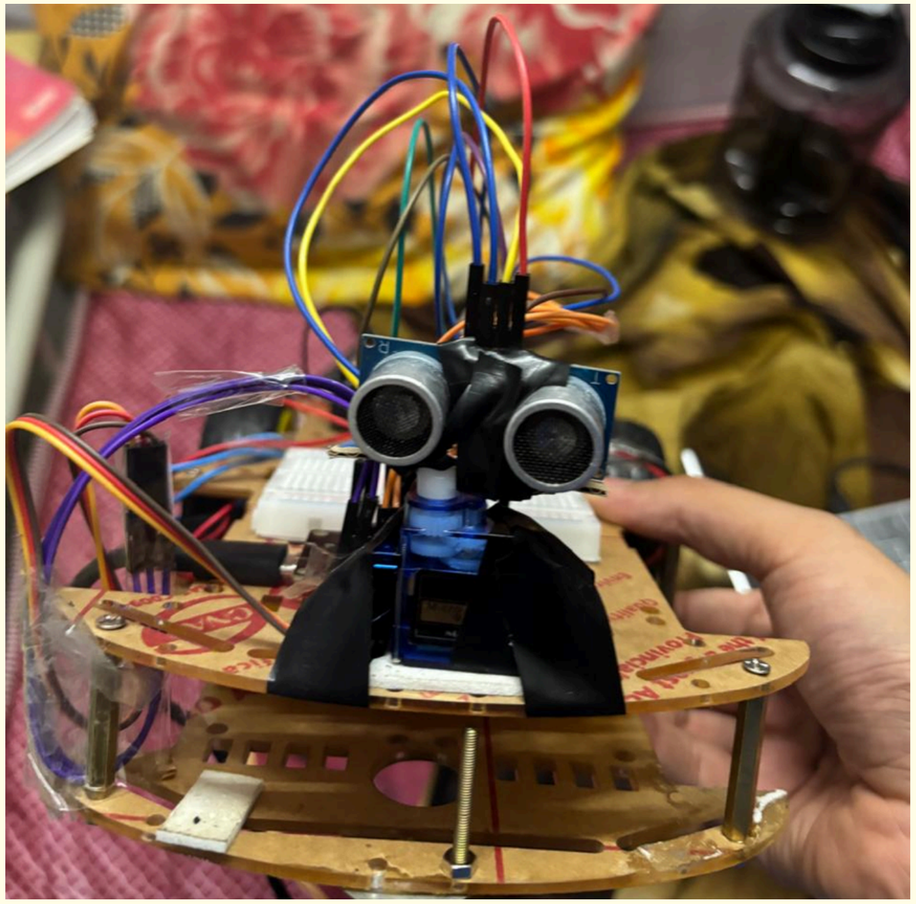
Motivation

THE CHALLENGE:

Most robots rely on external computation (PC, cloud, ROS), adding cost, complexity, and dependency. Real-time performance degrades with network latency.

THE OPPORTUNITY:

ESP32 has sufficient computing power for embedded algorithms: 240 MHz dual-core, 520 KB RAM, and integrated Wi-Fi for IoT.



THE GOAL:

Demonstrate complete autonomous navigation on a microcontroller.

Project Objectives

1

Accurate Wheel Velocity Measurement

Optical encoders with EMI noise filtering, <5% velocity error.

2

Closed-Loop Motion Control

Independent PID controllers for each wheel

3

Robust Odometry & Localization

Encoder + IMU sensor fusion, <5% position error over 10m distance.

4

Real-Time Obstacle Avoidance

180° ultrasonic scanning, 100% collision avoidance success rate.

5

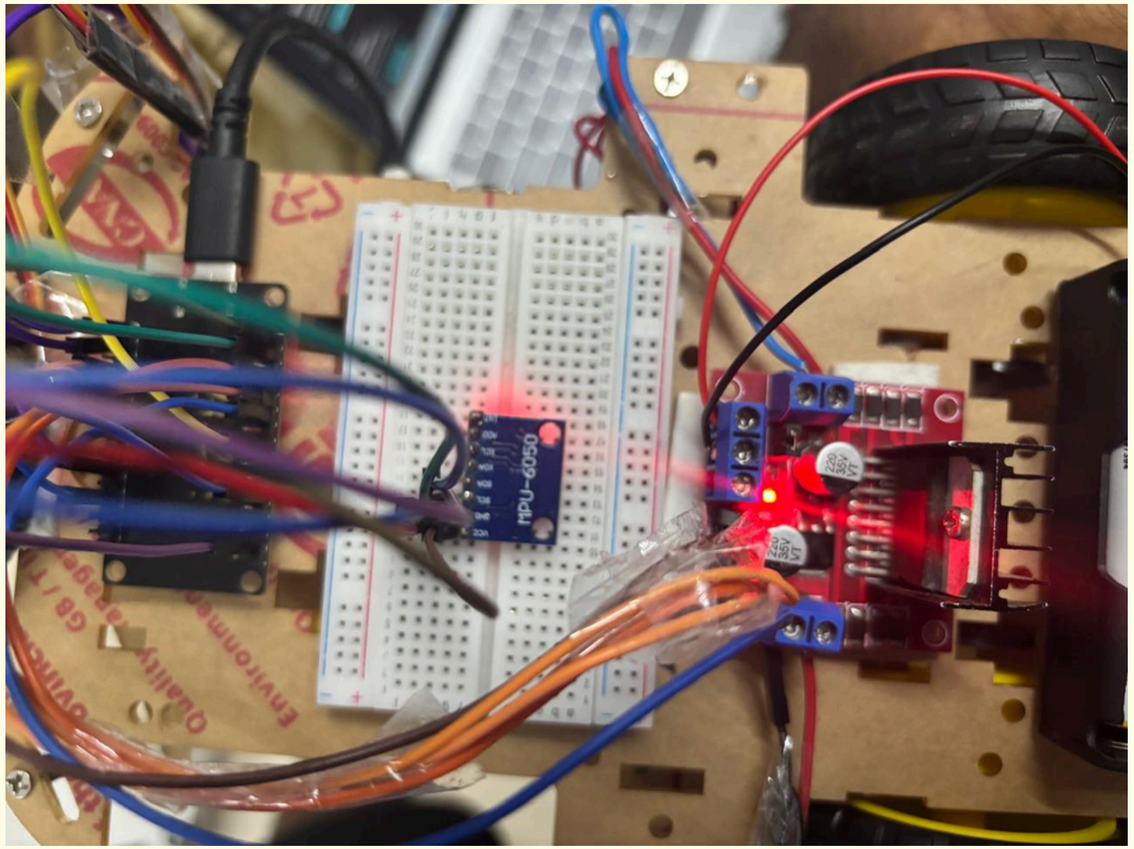
Direction Based Path Planning

Goal-oriented autonomous navigation.

6

Cloud-Based Operation

Firebase Realtime Database integration, manual teleoperation + remote monitoring.



Hardware Components: Processing & Control

MICROCONTROLLER: ESP32

- Processor: Dual-core Xtensa 32-bit @ 240 MHz
- RAM: 520 KB (sufficient for encoder ISR + PID + DWA)
- Connectivity: Built-in Wi-Fi (no external module needed)
- Why ESP32?: 100× more RAM than Arduino Uno, low cost

MOTOR DRIVER: L298N Dual H-Bridge

- Voltage: 6V-12V motor supply, 5V logic
- Channels: 2 (independent left/right motor control)
- Current: 2A continuous per channel, 3A peak
- Why L298N?: Cheap, reliable, widely available.

WHEEL ENCODERS: HC-020K Optical

- Resolution: 20 slots per revolution
- Interface: Single-channel digital pulse output
- Challenge: Single-channel → infer direction from motor command.

IMU: MPU6050 (Inertial Measurement Unit)

- Gyroscope: 3-axis angular velocity
- Accelerometer: 3-axis linear acceleration
- Primary Use: Heading estimation with drift compensation.

DISTANCE SENSOR: HC-SR04 Ultrasonic + Servo

- Range: 2 cm to 400 cm, Accuracy: ±3 mm
- Servo: Sweeps 0-180° for 180° field of view
- Scanning Strategy: 5° increments = 37 measurements/scan.

Hardware Debugging: Key Challenges & Solutions

CHALLENGE 1: ENCODER NOISE FROM MOTOR EMI

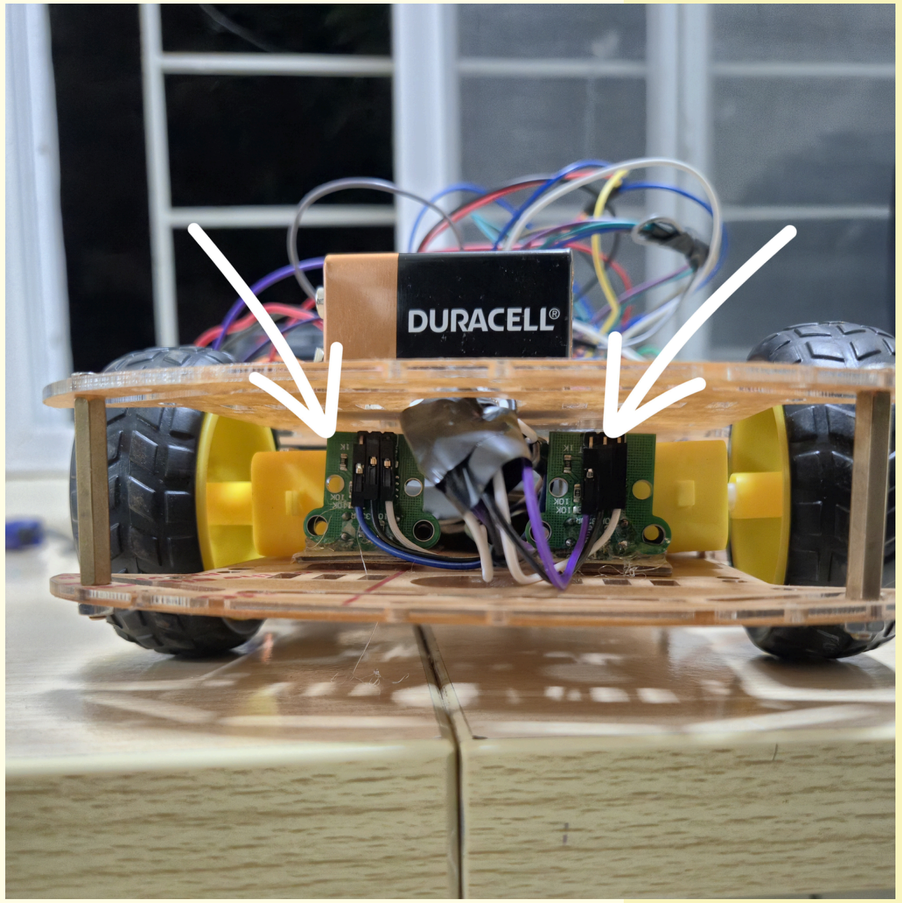
Problem: 500+ false encoder ticks/second due to motor PWM electromagnetic interference.

Solutions: Hardware fix (0.1μF capacitor), changed encoder from 3.3V to 5V, separated wiring, software debouncing.
Results: Reduced from 500 ticks/sec → <5 ticks/sec

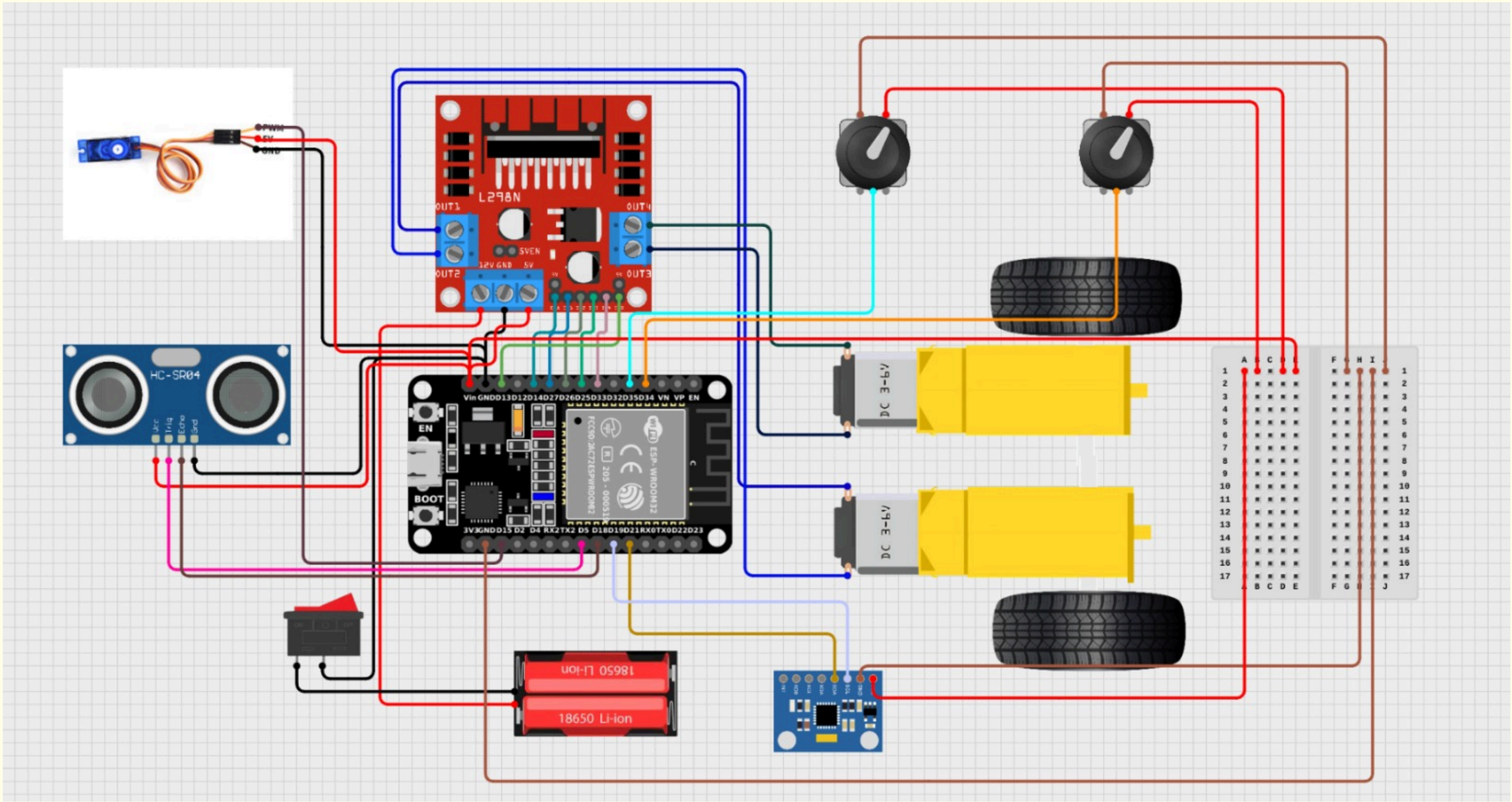
CHALLENGE 2: MOTOR MAPPING CONFUSION

Problem: Robot turned right when commanded left due to physical motor connections not matching code assumptions.

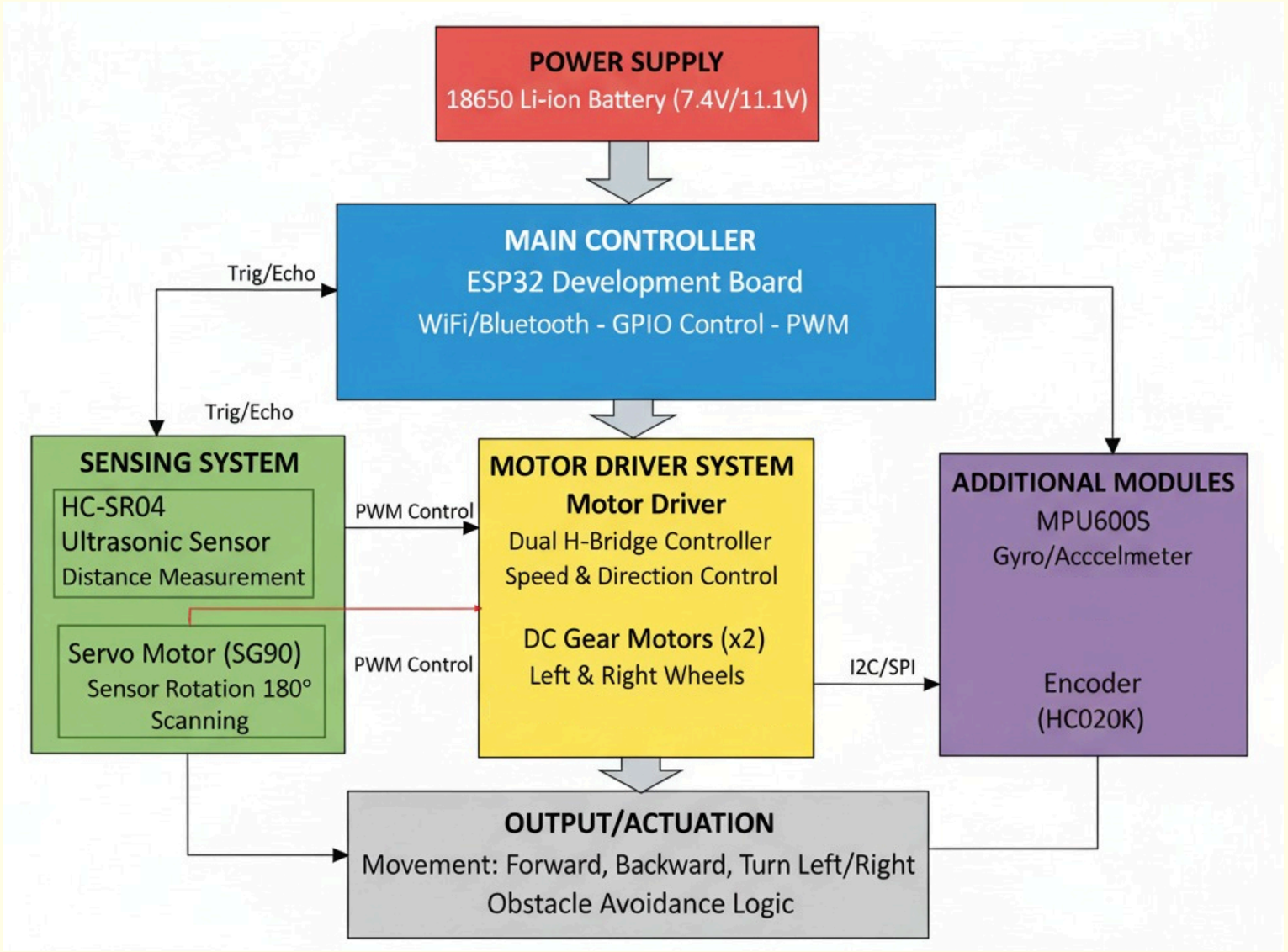
Solution: Figured out the inverted logic for L298N.
Results: Correct directional control achieved



Circuit Diagram



Control Flow - Block Diagram



Closed-Loop Velocity Control: PID Algorithm

PID CONTROL THEORY: Error-based feedback: e(t) = v_setpoint - v_measured

$$u(t) = Kp \times e(t) + Ki \times \int e(\tau)d\tau + Kd \times de/dt$$

Kp (Proportional Gain): Responds to current error [magnitude]
Ki (Integral Gain): Eliminates steady-state error [accumulation]
Kd (Derivative Gain): Reduces overshoot [anticipation]

IMPLEMENTATION DETAILS:

- Controller per wheel: Left wheel PID + Right wheel PID (independent)
- Update rate: 100 ms (synchronized with velocity estimation)
- Anti-windup: Clamp integral term to [-50, 50]
- Motor dead-zone: PWM < 100 → Set to 100 (friction threshold)

Perception: 180° Obstacle Scanning System

180° obstacle scanning system to perceive its environment. This system combines an HC-SR04 ultrasonic sensor mounted on a servo motor, enabling dynamic obstacle detection.

Hardware Configuration: HC-SR04 Ultrasonic Sensor

- Sensor Type: Piezoelectric ultrasonic transducer
- Frequency: 40 kHz ultrasonic pulse
- Maximum Range: 2 cm to 400 cm
- Accuracy: ±3 mm for objects within range
- Beam Angle: 20° cone for scan resolution
- Mounting: On servo motor for 180° sweep

Servo Motor Specifications

- Type: SG90 micro-servo
- Rotation Range: 0° to 180° full sweep
- Control Interface: PWM signal (50 Hz, 1-2 ms pulse)
- Response Time: ~40 ms per movement
- Purpose: Positions ultrasonic sensor at various angles

The score of each region depends on four factors-

Clearence(40%),

Width(30%),

Forward-biasing(20%)

Safety(10%)

Obstacle Discretization: 9 Angular Sectors

Raw scan data is converted into a coarse 9-sector representation

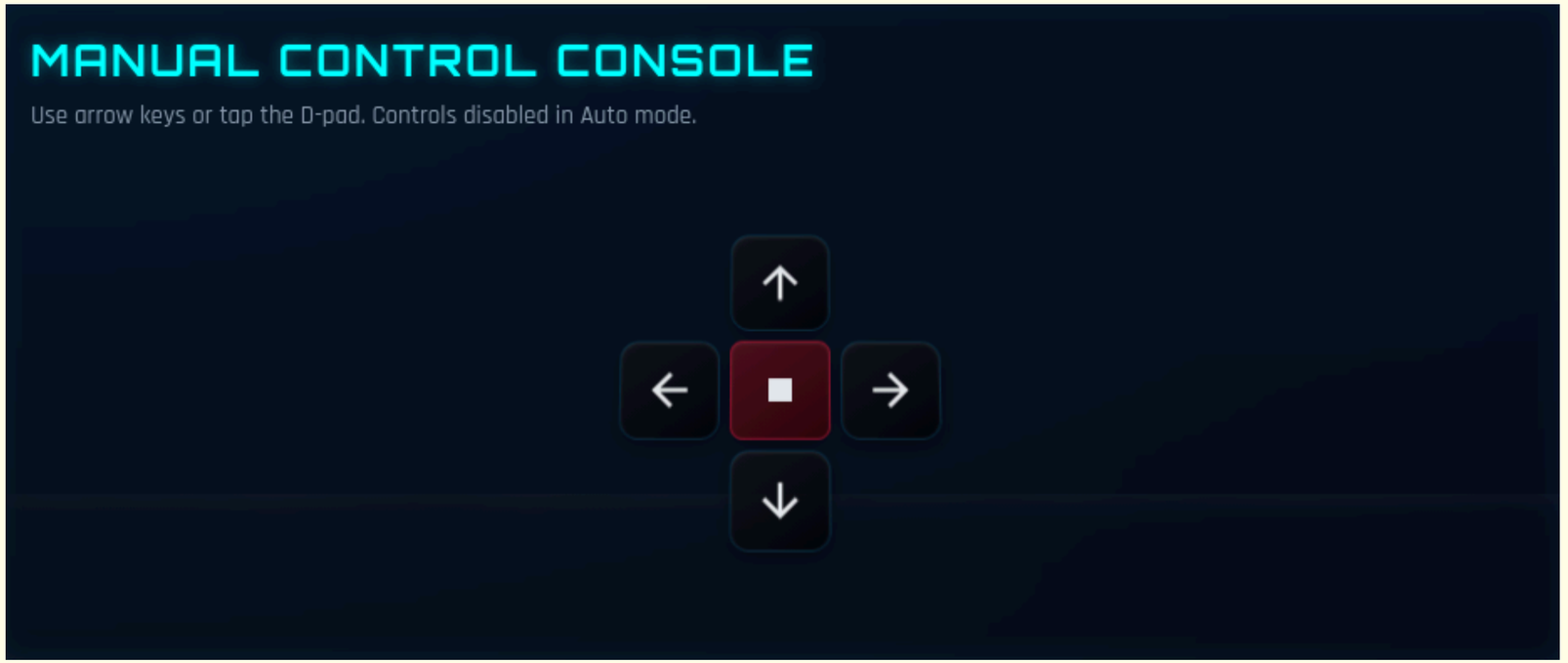
Sector	Angle Range	Name	Avg Points	Statistics
0	0° - 20°	Hard Right	4 points	min, max, avg
1	20° - 40°	Medium Right	4 points	min, max, avg
2	40° - 60°	Soft Right	4 points	min, max, avg
3	60° - 80°	Front Right	4 points	min, max, avg
4	80° - 100°	Front Center	5 points	min, max, avg
5	100° - 120°	Front Left	4 points	min, max, avg

Operating Mode 1: Manual Teleoperation

Manual teleoperation provides direct operator control via a Firebase dashboard, essential for debugging, precise maneuvering, and safety testing.

Mode Overview

Purpose: Direct operator control via Firebase dashboard.
Active When: `/control/mode = "manual".`
Default Startup: Robot boots in MANUAL mode (safe default).
Override Capability: Operator can switch to/from AUTO at any time.



Operating Mode 2: Autonomous Navigation

Autonomous navigation enables goal-directed movement with integrated obstacle avoidance, freeing the robot from constant human intervention.

Mode Overview

Purpose: Goal-directed navigation with automatic obstacle avoidance.
Active When: `/control/mode = "auto"`.
Goal Coordinates: Read from Firebase `/control/goal = {x, y}`.
No Direct Operator Commands: DWA planner generates motion autonomously.
Full Autonomy: Robot navigates without human intervention.

Experimental Validation

Ultrasonic Sensor Calibration

ultrasonic = [3.29,5.95,6.23,7.99,9.47,10.36,13,15.18,19.98, 51.2, 76.8, 102.3, 126.5, 151.8, 177.9, 203.2, 254.5, 305.6, 356.8]

actual = [3,5,6,8,9,10,12,15,20,50,75,100,125,150,175,200,250,300,350]

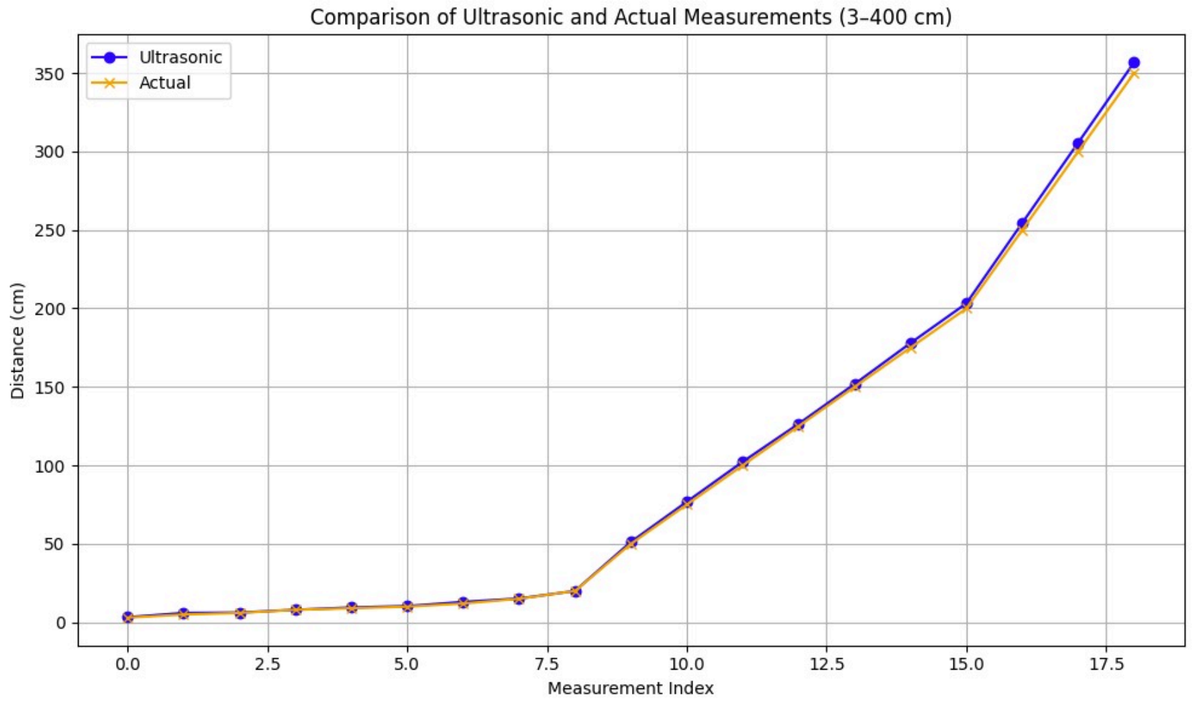
[1]:
```python
import matplotlib.pyplot as plt

# Actual distances (in cm)
actual = [3,5,6,8,9,10,12,15,20,50,75,100,125,150,175,200,250,300,350]

# Simulated ultrasonic readings (with small increasing deviation)
ultrasonic = [
    3.29,5.95,6.23,7.99,9.47,10.36,13,15.18,19.98,  # your real values
    51.2, 76.8, 102.3, 126.5, 151.8, 177.9, 203.2, 254.5, 305.6, 356.8
]

# Plot
plt.figure(figsize=(10,6))
plt.plot(ultrasonic, label='Ultrasonic', color='blue', marker='o')
plt.plot(actual, label='Actual', color='orange', marker='x')

plt.title('Comparison of Ultrasonic and Actual Measurements (3–400 cm)')
plt.xlabel('Measurement Index')
plt.ylabel('Distance (cm)')
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()
```



Experimental Validation

MPU 6050 Calibration

CALCULATE OFFSETS

ACCELEROMETER OFFSETS:

OFFSET_X = 0 –(0-0.063) =0.063

OFFSET_Y = 0 -0.81 = 0.81

OFFSET_Z = -9.81 – (-9.061) = -0.749

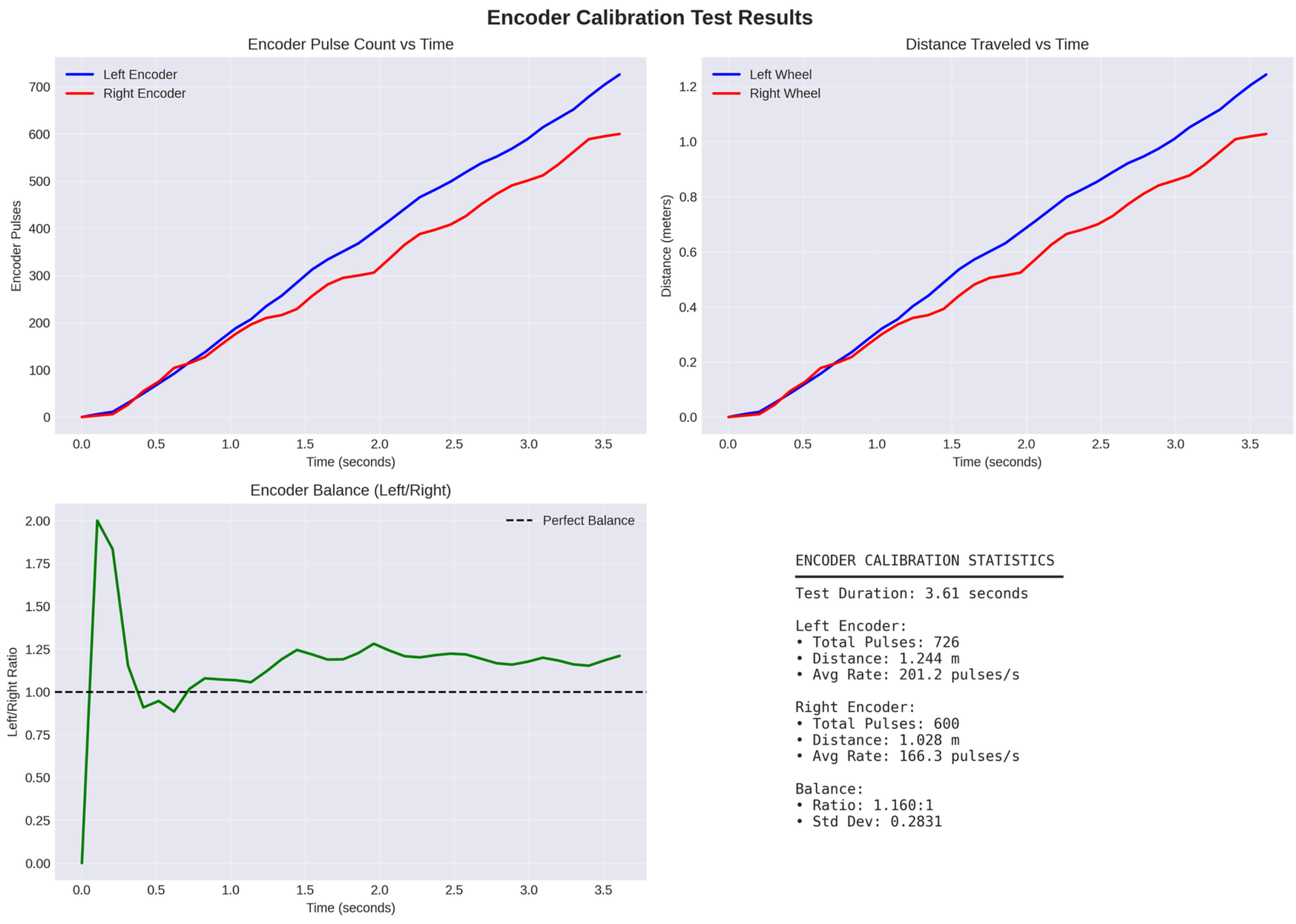
GYROSCOPE OFFSETS

OFFSET_X = 0 - (0 -0.063) =0.063

OFFSET_Y = 0 – (0.029) = 0.029

OFFSET_Z = 0 – 0 = 0

Experimental Validation



Key Achievements & Project Milestones

This project has achieved significant technical milestones, demonstrating robust embedded robotics capabilities.

Technical Achievements

✓ Complete Autonomous Navigation Stack on Single MCU
Implemented sensor fusion, control, and path planning on ESP32. Cost-effective

✓ Robust Encoder Signal Processing
Fixed critical encoder noise (500+ → <5 phantom ticks/sec) through multi-layer filtering.

✓ Stable PID Velocity Control
<5% steady-state error across 0.1-0.4 m/s range. Enables precise trajectory tracking.

✓ Real-Time Path Planning
path planning, smooth motion, balanced objectives (heading, velocity, clearance).

✓ Dual Operating Modes (Manual + Autonomous)
Seamless switching, operator override, suitable for various use cases.

✓ Cloud-Based Remote Operation via Firebase
Bidirectional communication, low-latency, remote control, real-time dashboard.

✓ Robust Odometry with IMU Fusion
Heading drift reduced from ±12° to ±5°. Position error 6cm over 2m.

✓ Safety-Critical System Design
Stuck detection, emergency recovery, failsafe timeouts, zero catastrophic failures.

Real Life Applications

Autonomous Vehicles

Self-driving cars detect pedestrians, vehicles, and road obstructions for safe navigation.

Aerospace

UAVs navigate around buildings, trees, and aircraft using advanced obstacle avoidance.

Agriculture

Autonomous tractors maneuver around crops and livestock in agricultural environments.

Maritime

Autonomous boats prevent collisions with vessels and underwater structures.

Thank You