**3. Project Methodology:**

. **Methodology**

The development of the autonomous robotic vehicle was carried out in structured phases, covering mechanical design, sensor calibration, embedded software development, and iterative testing.

**Hardware Design**

A two-wheeled differential drive robotic chassis was constructed, integrating essential components for autonomous navigation and decision-making. The key hardware includes:

* Arduino Uno R4 microcontroller – acts as the central control unit for all peripherals.
* IR lane-following sensors – detect the contrast between the lane and the background.
* Ultrasonic sensors (HC-SR04) – provide obstacle distance measurements for real-time avoidance.
* TCS3200 color sensor – a color-to-frequency converter used to detect the color of objects based on RGB reflectance.
* SBC Motor Driver 2 – controls the motors with suitable current and voltage for bidirectional motion.
* 12V LiPo battery with switch – powers the entire system, providing consistent voltage and current for reliable operation.

The mechanical frame, including chassis structure, sensor holders, and battery mounts, was designed using SolidWorks. This CAD-based approach ensured accurate placement, structural integrity, and modular design for component accessibility and replacement.

**Sensor Calibration and Integration**

All sensors were calibrated and tested before integration to ensure accurate data acquisition and system stability:

* IR Sensors: Tuned to detect lane boundaries using reflectance-based thresholding, optimized for the test surface.
* Ultrasonic Sensors: Configured with distance thresholds to trigger avoidance behavior when obstacles are within proximity.
* TCS3200 Color Sensor: Calibrated using reference color samples. The sensor uses photodiodes with RGB filters and outputs a frequency proportional to the intensity of each component. Color classification was achieved by comparing frequency ratios of red, green, and blue channels.

**Software Development**

Firmware was written using the Arduino IDE in C++, with a modular structure for sensor reading, motor control, and decision logic:

* Lane Following: Implemented with basic PID logic to maintain position within the lane using IR sensor input.
* Obstacle Avoidance: Ultrasonic data triggered directional changes when obstacles were detected within a predefined range.
* Color-Based Behavior: TCS3200 output was analyzed to determine object color and adjust behavior accordingly—e.g., stopping or rerouting.

**Testing and Iteration**

The system was tested under different physical and environmental conditions to ensure functionality and robustness:

* Sensor Accuracy: Each sensor’s performance was verified under varying lighting and surface reflectivity conditions.
* Navigation Robustness: Evaluated system behavior during lane exits, sharp turns, and reentry, ensuring consistent responsiveness.
* Environmental Adaptability: Testing included both indoor and semi-outdoor environments to assess sensor stability and overall system reliability.

Each iteration guided hardware and software refinements, with component placements and mountings reworked in SolidWorks for better alignment and stability, resulting in a reliable and efficient robotic system.