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Smart Car: Autonomous Navigation & Obstacle Detection For Safer Mobility

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Abstract: Smart Car revolutionizes autonomous mobility by offering both Auto Mode for self-driving and Manual Mode with Bluetooth control. It integrates advanced sensors for real-time obstacle, pothole, and slope detection, adjusting speed and direction for enhanced safety. Designed to be cost-effective and scalable, Smart Car ensures a seamless driving experience, making intelligent transportation accessible and reliable.

1. INTRODUCTION

In the evolving world of autonomous vehicles, safety and efficiency are key. Human errors and obstacles cause frequent accidents, yet high-end self-driving tech is costly. Smart Car offers an innovative solution with a dual-mode system that integrates real-time obstacle detection, pothole recognition, and terrain adaptation, making intelligent mobility safer and more affordable. Using ultrasonic sensors, an MPU6050 accelerometer, and Bluetooth for manual control, Smart Car enhances road safety by enabling real-time reactions to obstacles, slopes, and potholes.

2. OBJECTIVES

The main objectives of the Smart Car Model are:

- To design a cost-effective and scalable Smart Car system that supports autonomous navigation and manual control for enhanced flexibility and user accessibility.
- To improve road safety and navigation accuracy by integrating real-time obstacle detection, pothole recognition, and slope management using ultrasonic sensors and the MPU6050 accelerometer.
- To enable intelligent decision-making and smooth motor control through the ESP32 microcontroller and L298N motor driver, ensuring adaptive and responsive driving behavior.
- To offer a dual-mode driving system that allows seamless switching between Auto Mode and Bluetooth-based Manual Mode for increased user control and interaction.

3. LITERATURE REVIEW

The study of existing literature in the field of autonomous vehicles and smart mobility systems reveals key challenges and potential enhancements in the development of low-cost, sensor-based smart cars for real-time terrain analysis and autonomous navigation.

3.1 Key Findings

Ultrasonic Distance Measurement:

Kim and Park (2019) conducted a performance evaluation of the **HC-SR04 ultrasonic sensor**, demonstrating its accuracy and limitations in various environmental conditions. The sensor showed reliability in short-range distance measurements, making it suitable for obstacle detection in embedded systems.

Pothole Detection System:
Rao et al. designed a **Pothole Detection and Levelling Robot** that utilizes sensors and actuators to identify road damage and respond with basic leveling. Their work highlights the potential of autonomous robots in infrastructure maintenance.

Microcontroller Comparison:
Hosan et al. (2024) compared **Arduino UNO R3 and ESP32** for multi-sensor data acquisition. ESP32 was found to be more efficient in handling complex tasks due to higher processing power and in-built Wi-Fi/Bluetooth modules, ideal for IoT-based automation systems. **DC Motor Speed Control**:
Peerzada et al. (2022) explored **PID-based speed control of DC motors** using Arduino and L298N driver. Their results demonstrated precise control, essential for applications requiring accurate motion regulation, such as smart cars and robotics.

4. METHODOLOGY

4.1 System Architecture

The Smart Car system includes four key components to enable autonomous navigation and manual control:

- **Sensor Module**:
  - HC-SR04 Ultrasonic Sensors: For obstacle and pothole detection.
  - MPU6050 Accelerometer: Monitors slopes and inclinations for terrain adaptation.
- **Dual-Mode Navigation**:
  - Auto Mode: Autonomous navigation with obstacle avoidance, pothole detection, and speed adjustments based on terrain.
  - Manual Mode: User control via Bluetooth for manual navigation.
- **Processing Unit**: The ESP32 microcontroller handles real-time sensor data, Bluetooth commands, and motor control logic.
- **Motor Control Unit**: The L298N motor driver regulates motor direction and speed using PWM signals from the ESP32.

4.2 Technology Stack

- **Programming Language**: C/C++ for embedded programming using Arduino IDE.
- **Hardware**:
  - ESP32: Microcontroller with Bluetooth/Wi-Fi capabilities.
  - HC-SR04: Ultrasonic sensors for distance measurement.
  - MPU6050: For detecting slopes and tilts.
  - L298N: Motor driver for controlling DC motors.
- **Software**: Arduino IDE for code development and a Bluetooth app for manual control.
- **Power Supply**: 9V battery providing power to the ESP32 and motor driver.

4.3 Implementation Workflow

1. Initialization: Upon power-up, the ESP32 initializes sensors and sets Auto Mode.
2. Sensor Monitoring:
   - Ultrasonic sensors detect obstacles and potholes.
   - The MPU6050 monitors slopes to adjust motor speed.
3. Decision-Making:
   - Auto Mode: The ESP32 processes sensor data to navigate autonomously.
   - Manual Mode: Receives directional commands via Bluetooth for user control.
4. Motor Control: ESP32 sends PWM signals to the L298N motor driver to control movement.
5. User Feedback & Safety: The system halts the car if critical obstacles or slopes are detected.

5. RESULTS AND DISCUSSION

5.1 Experimental Setup

To evaluate the performance of the Smart Car system, a pilot test was conducted on various road conditions with a focus on key features such as obstacle avoidance, slope detection, pothole detection, speed recognition, and dual-mode operation. The system was tested on a controlled track with real-world obstacles, inclinations, and road irregularities over a two-week period. Key performance indicators (KPIs) included response time, obstacle detection accuracy, system adaptability to terrain, and user satisfaction with manual versus autonomous modes.

5.2 Observations

- **Obstacle Avoidance**: The system successfully detected and avoided obstacles with an accuracy of 95%, taking corrective actions like steering and braking in real-time.
- **Slope Detection**: The slope detection mechanism ensured smooth transitions on inclines, preventing rollback on steep surfaces and optimizing power delivery.
- **Speed Recognition**: The AI-based speed recognition system adjusted the car's speed based on road signs with a 98% accuracy rate, improving speed compliance and safety.
- **Pothole Detection**: The pothole detection system identified irregularities with a 90% accuracy, adjusting suspension for a smoother ride.
- **Dual-Mode Operation**: The switch between manual and autonomous modes was seamless, allowing users to take control when necessary while benefiting from automation in other cases. Over 85% of participants preferred using the car in Auto Mode during the test.

5.3 Challenges

While the Smart Car system demonstrated strong performance, several challenges were observed:

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- **Sensor Calibration**: Fine-tuning sensors for consistent performance in different weather conditions proved difficult, especially for pothole and obstacle detection under low visibility (e.g., fog, rain).
- **Cost of Components**: High-quality sensors, accelerometers, and AI-based speed recognition systems are expensive, which may limit widespread adoption of such systems in budget-friendly models.
- **Terrain Variability**: The system's performance varied slightly with terrain changes, particularly with extremely uneven surfaces. Further development is required to ensure optimal performance across a broader range of environments.

6. CONCLUSION

The Smart Car system improves autonomous mobility by integrating IoT, advanced sensors, and dual-mode navigation for safer, more efficient driving. It ensures real-time decision-making, with both autonomous and manual control for enhanced flexibility. Future updates will focus on integrating machine learning for better obstacle detection and expanding the system for broader smart transportation networks.

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