Self-Calibrating Multi-Sensor Smart Parking System

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Abstract:

This project presents a Self-Calibrating Multi-Sensor Smart Parking System designed to detect parking slot occupancy with high accuracy using ultrasonic, Hall-effect, and LDR sensors. The system uses an ESP32 microcontroller for real-time processing and IoT connectivity, while an OLED display provides instant on-site status updates. A key feature of this system is its automatic self-calibration mechanism, where baseline sensor values are recalibrated periodically to adapt to environmental changes such as lighting, dust, and temperature. Sensor fusion ensures reliable detection, significantly reducing false positives. The system operates both offline and via an IoT dashboard, making it suitable for smart cities, malls, campuses, and residential parking. The prototype offers a low-cost, scalable, and maintenance-free solution for modern parking challenges.

Keywords:

Smart Parking, Sensor Fusion, ESP32, Self-Calibration, IoT System

I. INTRODUCTION

A. Background of Study and Motivation

Urban environments face continuous challenges in managing limited parking spaces. Drivers often struggle to find available slots due to the absence of real-time information. Existing systems that use a single sensor face accuracy issues caused by ambient light variations, magnetic interference, dust accumulation, and temperature changes. Moreover, manual recalibration leads to high maintenance costs.

To overcome these limitations, a multi-sensor, self-calibrating parking system is required.

B. Literature Review

Recent research focuses on smart parking using single-sensor technologies such as ultrasonic sensing or infrared detection. However, these systems fail under certain lighting or environmental conditions. Sensor fusion approaches using magnetic + optical or ultrasonic + camera systems have been proposed to improve reliability. IoT-based parking systems using ESP32 and NodeMCU have gained popularity due to their low cost and WiFi capability. Recent works also emphasize self-learning algorithms to reduce manual intervention. However, a low-cost, multi-sensor fusion system with automatic recalibration is still limited in existing literature.

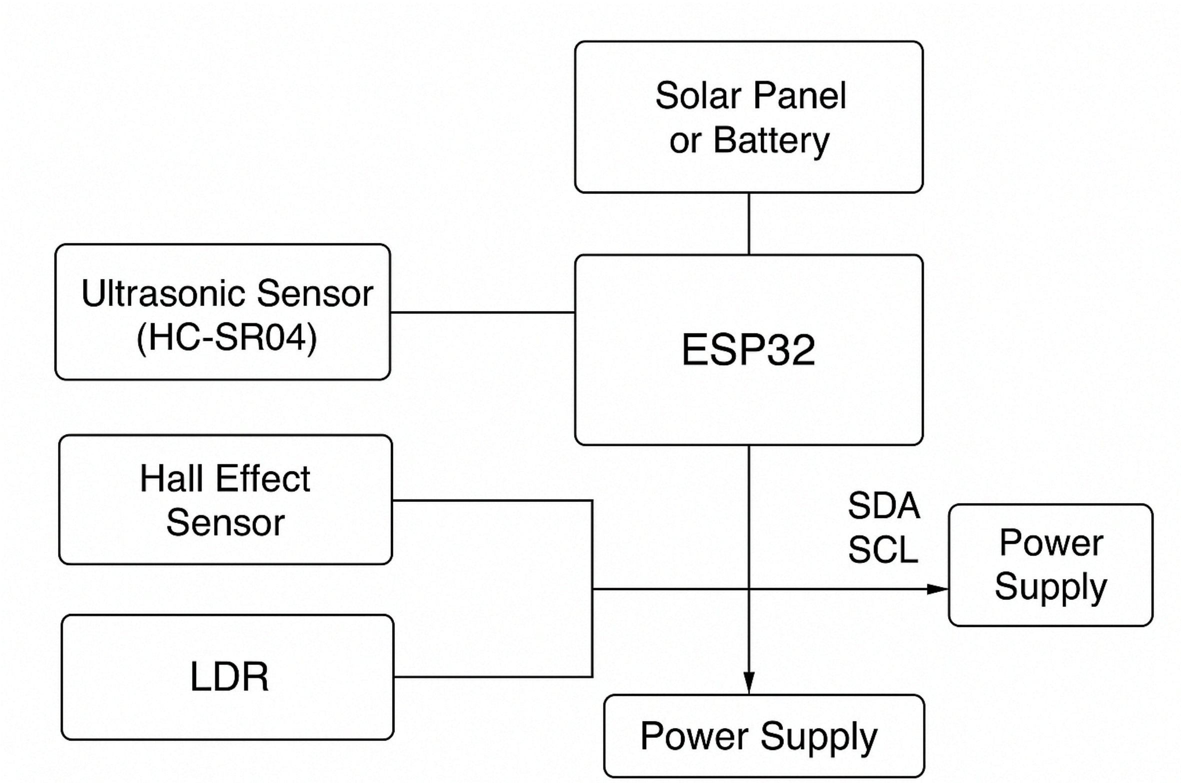
C. Research Objectives

- To design a smart parking system that integrates ultrasonic, Hall-effect, and LDR sensors.
- To implement sensor fusion for accurate vehicle detection.
- To develop a self-calibrating algorithm that adjusts baseline values automatically.
- To build a low-cost and scalable system using ESP32.
- To provide real-time status through OLED display and IoT dashboard.

II. METHODOLOGY AND MODELING

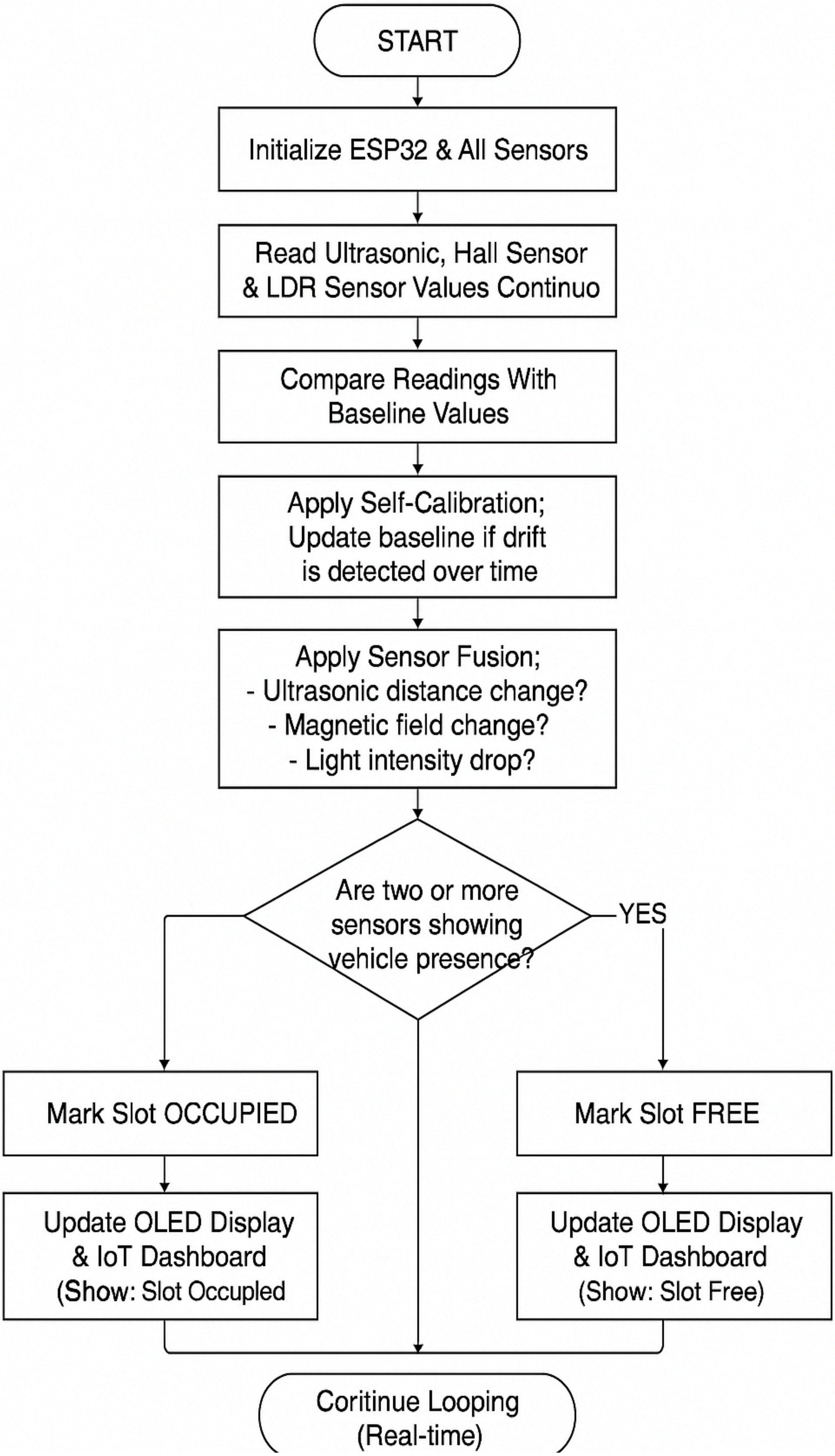
A. Block Diagram of the Proposed Model

Sensors → ESP32 → Sensor Fusion Algorithm → Self-Calibration Module → OLED Display + IoT Dashboard



B. Flow Chart

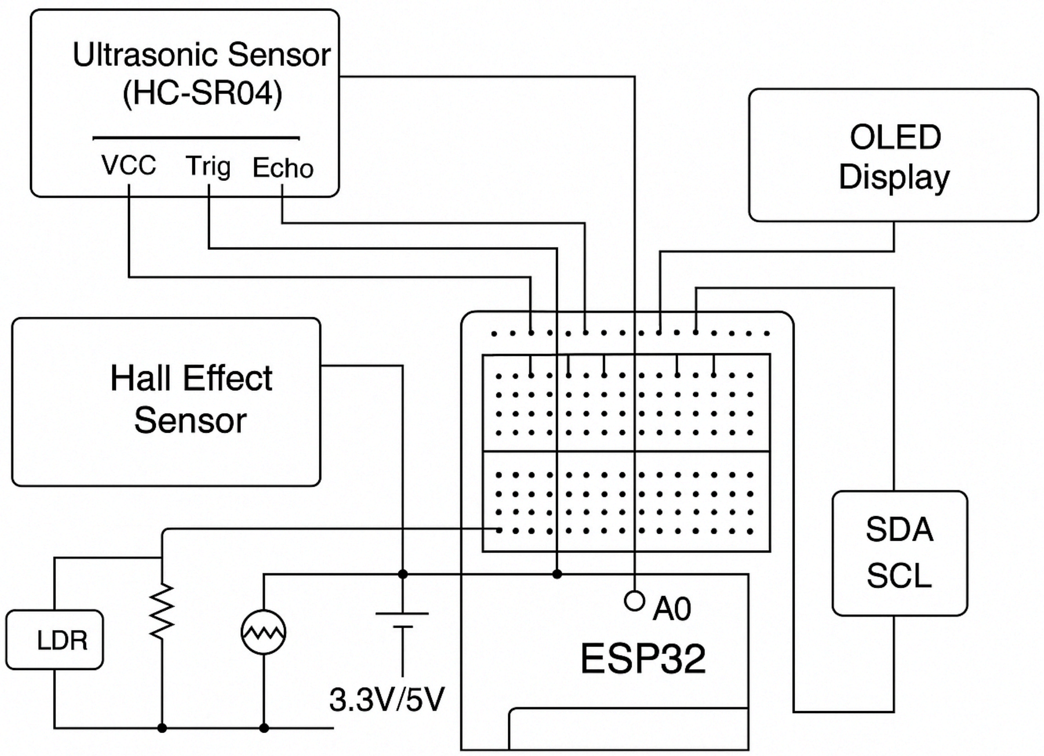
Start → Read sensors → Compare with baseline → Apply sensor fusion → Occupied/Free? → Update display & IoT → Auto recalibrate → Repeat


START
Initialize ESP32 & All Sensors
Read Ultrasonic, Hall Sensor & LDR Sensor Values Continuo
Compare Readings With Baseline Values
Apply Self-Calibration; Update baseline if drift is detected over time
Apply Sensor Fusion; - Ultrasonic distance change? - Magnetic field change? - Light intensity drop?
Are two or more sensors showing vehicle presence?
YES
Mark Slot OCCUPIED
Mark Slot FREE
Update OLED Display & IoT Dashboard (Show: Slot Occupied
Update OLED Display & IoT Dashboard (Show: Slot Free)
Coritinue Looping (Real-time)

C. Circuit Diagram of Proposed Model

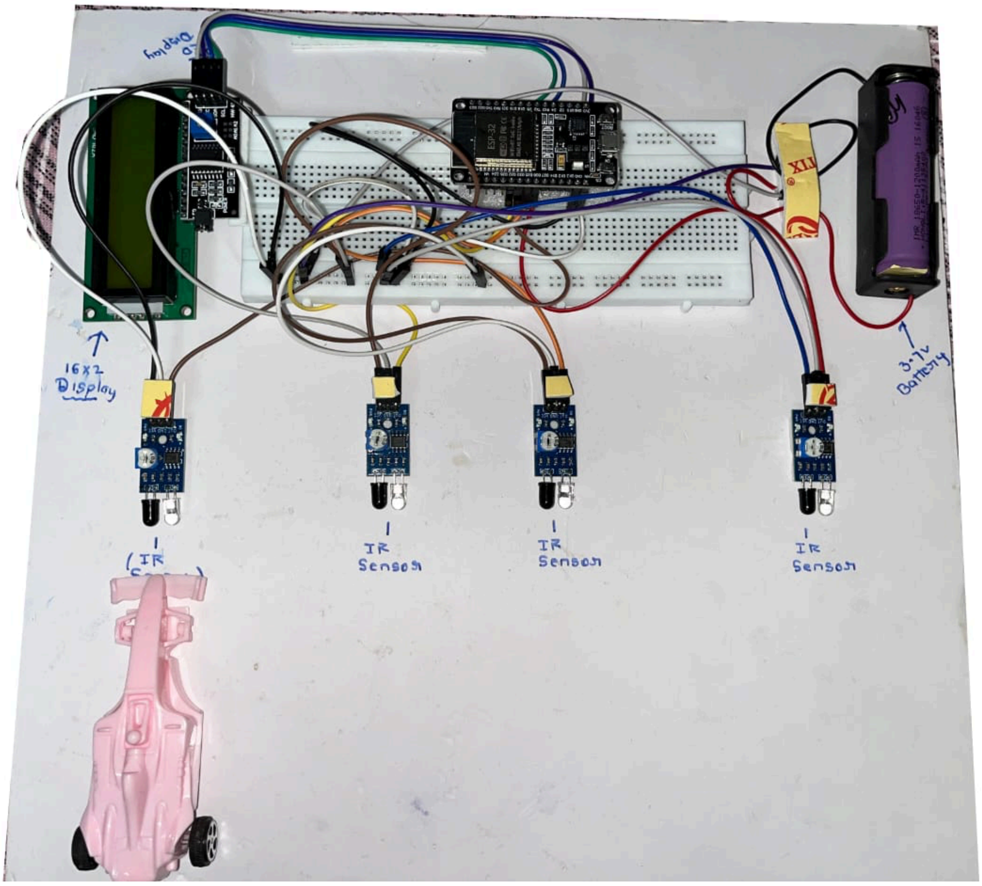
Connections Used:

- Ultrasonic Sensor → Trig to D4, Echo to D5
- Hall-effect Sensor → Analog pin D34
- LDR Sensor → 3.3V → A0 (via resistor divider)
- OLED Display → SDA (D21), SCL (D22)
- Power → 3.3V/5V from ESP32 or external source

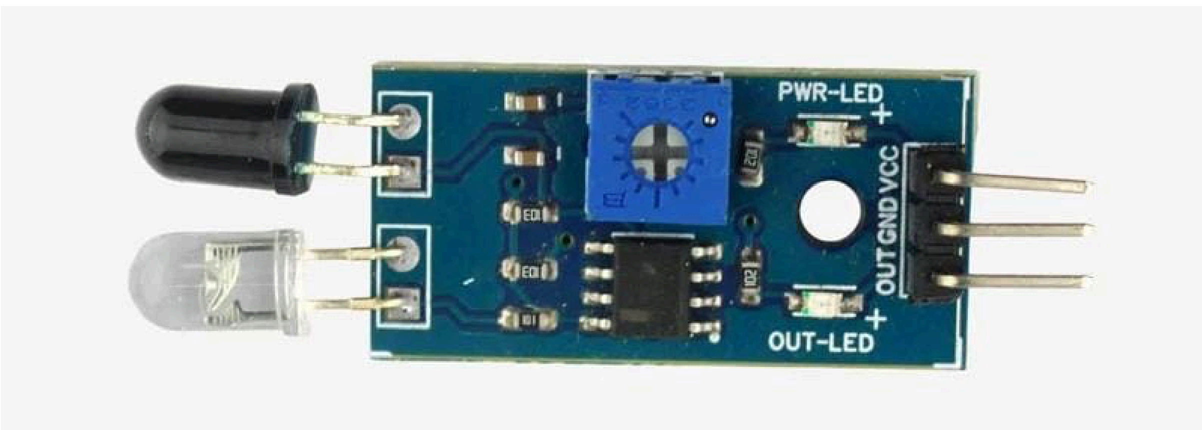


D. Layout of Proposed System (Images of Hardware Prototype)

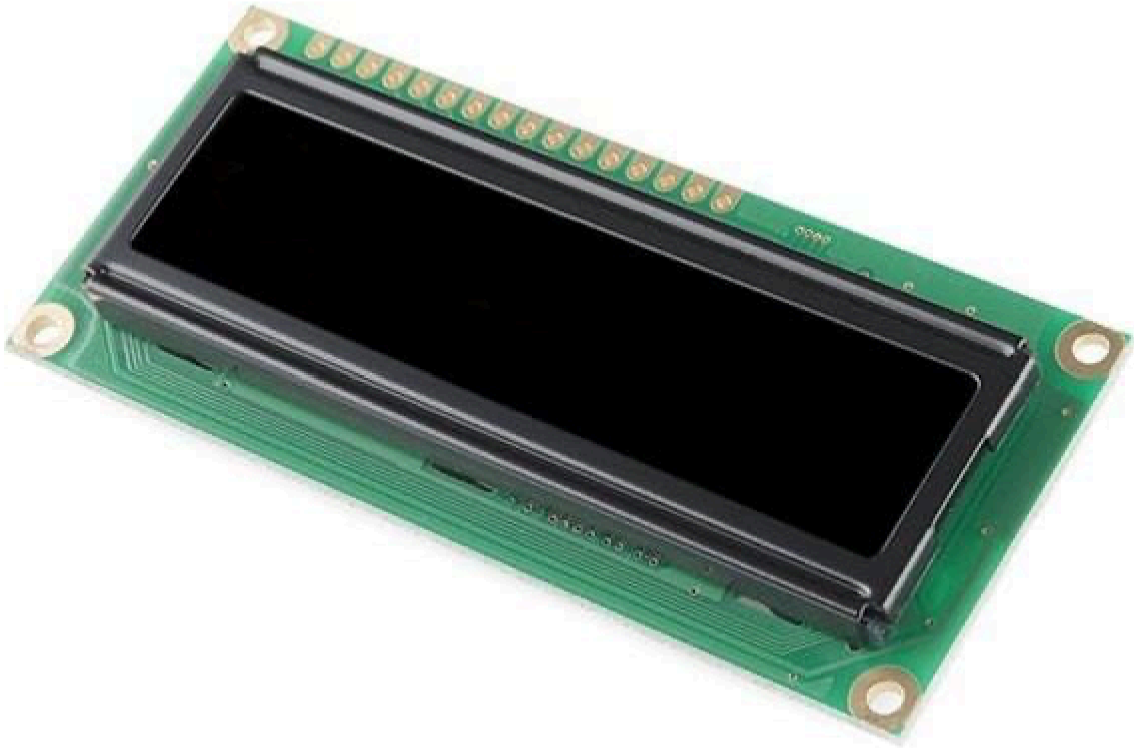
- Image of assembled prototype:



- Sensor module image:



- OLED display image:



III. RESULTS AND DISCUSSIONS

Experimental Results

The system detects vehicle presence when all three sensor readings deviate significantly from their baseline values:

- Ultrasonic distance reduces
- Hall-effect sensor detects magnetic disturbance
- LDR voltage drops due to blocked light

When the vehicle leaves, readings return to normal, marking the slot as **Free**.

Dashboard / Output

- OLED instantly displays **Occupied** or **Free**.
- IoT dashboard shows live slot status and updates every few seconds.

Comparison Table:

Feature	Existing Single-Sensor System	Proposed Multi-Sensor System
Accuracy	Moderate	Very High
Environmental Adaptability	Low	High
Maintenance	Requires manual calibration	Self-calibrating
Cost	Medium	Low
IoT Support	Sometimes	Fully supported
False Positives	High	Very Low

IV. CONCLUSION

The Self-Calibrating Multi-Sensor Smart Parking System successfully integrates ultrasonic, Hall-effect, and LDR sensors to deliver high-accuracy vehicle detection. The ESP32 ensures efficient processing and IoT connectivity. The self-calibration algorithm eliminates the need for manual adjustment, making the system maintenance-free and reliable under varying environmental conditions.
The project demonstrates a cost-effective, scalable, and energy-efficient solution suitable for smart cities, malls, colleges, and public parking spaces. This technology has the potential to reduce traffic congestion and improve urban mobility.

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