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Hybrid Smart Parking System Enriched with IoT

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Abstract

Urban zones demand progressive parking methods that emerged as a response to increasing requirements for efficient parking operations. Traditional parking operations run improperly, thus creating both highway delays and fuel inefficiency and ecological degradation. The Internet of Things technology demonstrates the development of a smart parking system that both grows Internet of Things (IoT) capacity and delivers real-time parking status announcements. ESP32 microcontrollers together with Infrared Sensor (IR) sensors process data through cloud storage to show live updates about vacant parking spots. The interface operates from the local host web server to transmit real-time data through its system. Within the graphical user interface, users see green to indicate free parking spaces while red marks occupied parking slots. The system creates an obstructive function that restricts users from picking empty parking spaces during times of use by others. The dedicated parking area integrates Wireless power transmission technology components practical for providing Electromotive Force based (EMF)-based electricity charging service through copper coil conductors. The ESP32 module sends slot status data through its mobile hotspot connection, which ensures uninterrupted data delivery. The created system enhances efficient parking searches while reducing energy consumption and optimizing space distribution and delivers additional performance advantages. The integration of IoT and cloud computing with wireless charging protocols enables smart city infrastructure growth to create a sustainable, enhanced parking solution, according to research findings.

Keywords: Smart parking, IoT, ESP-32, IR Sensors, Real-time monitoring, Cloud computing, Wireless power transfer, EMF

INTRODUCTION

Dense traffic zones in public areas experience significant parking management issues that result in major traffic congestion problems. The absence of real-time parking slot development results in extended waiting periods and higher gas usage during congested traffic. Road vehicle users cannot access real-time parking spot data through conventional parking methods because system space utilization management performs poorly. Because the current system space utilization management performs poorly and lacks technology integration, road vehicle users cannot obtain real-time parking spot data through traditional parking methods [1, 2].

Conventional parking systems usually rely on static signage or manual monitoring, neither of which effectively reflects the current occupancy levels. Therefore, drivers sometimes rely on guessing or experience, which is problematic in densely populated urban areas where parking availability fluctuates rapidly. This mismatch between supply and demand worsens traffic and puts commuters under needless stress. Additionally, the lack of smart parking

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infrastructure prevents city officials from gathering important information that may be utilized to improve traffic distribution and urban planning. Examining parking trends, periods of high demand, and peak utilization without digital monitoring technologies is challenging. This restricts towns' ability to implement automated guiding systems, reservation systems, or dynamic pricing schemes that could simplify vehicle mobility [3, 4]. Additionally, poorly parked vehicles and congested streets can cause delays for emergency vehicles and public transit systems.

The implementation of Internet of Things (IoT) technology enables self-operational parking systems based on data exchange networks that are linked to monitoring systems through cloud-based algorithms. The combination of wireless networks between sensors and microcontrollers through IoT components maintains the open visibility of real-time parking availability for all users. The system operation becomes simpler owing to decreased traffic problems, which result in better resource management [5].

IoT technology enabled Strategic Performance Measurement System (SPMS) to track vehicles through operations between ESP32 microcontrollers and IR sensors. The system transmits real-time data to a cloud server that is accessible via a local host web application. The web application displays the available parking spots through its graphical interface.

AIM AND OBJECTIVE

Aim

A hybrid smart parking system needs to be developed using IoT technologies to achieve real-time monitoring between parking slot availability and wireless charging features for better efficiency and sustainable smart city progress. The suggested hybrid system intends to integrate wireless electric vehicle charging capabilities within allocated parking spots, in addition to real-time slot monitoring. Vehicles can be recharged while parked thanks to this integration, maximizing time efficiency and promoting the use of environmentally beneficial transportation options. Additionally, the system aims to reduce fuel use, carbon emissions, and traffic congestion caused by drivers searching for parking in crowded urban areas.

Enhancing data analytics capabilities to track usage trends, charging needs, and peak occupancy hours is another goal of this study. These findings will help city officials and planners make data-driven choices regarding resource allocation and infrastructure expansion. Other key goals are security, scalability, and dependability, which guarantee that the system can adjust to upcoming technological developments and expanding urban needs [6]. The overall goal of this hybrid smart parking system is to provide a more technologically sophisticated, sustainable, and efficient urban transportation ecosystem.

Objectives

A real-time parking slot detection system was developed through the implementation of ESP32 microcontrollers together with IR sensors [7].

The system uses a local host web interface that presents the parking availability status through color indicators, where unoccupied spots are displayed as green and occupied ones as red.

A wireless power transmission system based on EMF charging with copper coils was established in specific parking spaces [8].

The mobile hotspot functions of the ESP32 maintained a continuous data flow for uninterrupted system updates.

A real-time parking solution will reduce traffic congestion while decreasing fuel consumption and shortening parking search time.

The combination of IoT, cloud computing, and wireless charging technologies supports the sustainable development of urban infrastructure systems.

Problem Statement

Current parking systems do not offer real-time monitoring; thus, they produce undeveloped space utilization and intensify traffic problems in combination with unnecessary fuel usage. The demand for electric vehicles requires integrated charging solutions to be included in parking structures. The development of an intelligent automated sustainable parking system is essential because it needs to show current slot availability while solving parking conflicts and integrating wireless charging capabilities. Simultaneously, the increasing demand for electric vehicles necessitates the direct integration of accessible and integrated charging systems into parking facilities [9, 10]. The lack of simple charging infrastructure has become a major obstacle to adoption as more people switch to sustainable modes of mobility. Consequently, parking structures must develop into multipurpose smart hubs that accommodate both parking management and energy requirements, rather than merely serving as places to store cars. The proposed system solves current challenges by employing IoT sensors and cloud platforms with wireless energy transfer capabilities to develop a cutting-edge smart parking service. Addressing these interrelated issues requires the development of an automated, intelligent, and sustainable parking system. To improve user comfort, such systems must incorporate wireless charging capabilities, minimize parking conflicts, and deliver real-time slot availability updates. The suggested system provides a complete and cutting-edge smart parking solution intended to enhance efficiency, sustainability, and urban mobility management by leveraging IoT sensors, cloud-based platforms, and wireless energy transfer technologies.

INTEGRATION & WORKFLOW

The hybrid smart parking system improves urban parking efficiency through real-time monitoring, wireless power transfer, and IoT technologies. The system employs wireless modules along with microcontrollers, sensors, a web-based user interface, and live parking updates through sensors. Updates are delivered to users by real-time monitoring alongside wireless charging features. The following section provides complete information about workflow management and system configuration.

Hardware Requirements

Hardware setup consists of the following primary components:

1. ESP32 microcontrollers
2. IR Sensor
3. Copper coils
4. Step-down transformer (5 Wires)

Software Requirements

- Programming Language: Python.
- *Anaconda:* A distribution of Python and R for scientific computing, which includes package management and environment management.
- *Visual studio code (VS code):* A code editor for writing and editing project files.
- User Interface.

METHODOLOGY

System Architecture

The smart parking system requires three operational functional modules for normal use: Sensor Network and Data Acquisition. Detection systems for vehicles in parking slots use IR sensors.

The ESP32 microcontrollers receive sensor input signals which they transmit to the cloud infrastructure.

Wireless Communication

Through mobile hotspot networks dedicated to data transfer, the ESP32 module distributes its acquired information.

User Interface

A web application at localhost allows users to view the active status of all parking slots. Slot booking operations for empty parking spots require normal functional execution.

Wireless Power Transfer Module

The spot applies electromagnetic induction technology for electromagnetic_Electric Vehicle. (EV)_charging support.

The system uses copper coils with delivery methods to transfer wireless power, which facilitates distant yet efficient charging operations.

WORKING PRINCIPLE

The textured field of IR sensors automatically surveils parking spots to detect vehicles in their designated areas.

The ESP32 performs sensor data processing that automatically updates the database information. The web interface allows users to view available slots before their arrival.

The platform denotes slots with vehicles in operation by displaying them in red and blocking further reservations. When an EV enters a designated charging slot, the WPT system automatically starts the wireless power supply, as shown in Figure 1.

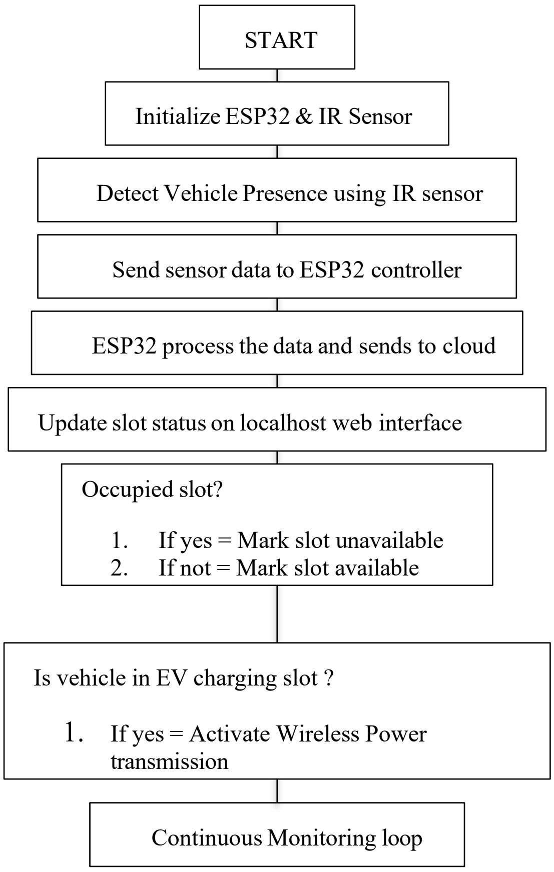

Figure 1. Workflow of booking logic.

BOOKING LOGIC

The ESP32 firmware contains integrated logic which performs the following operations. The IR sensor updates a designated status flag for each slot between the available and occupied states every second.

On Booking Request Via Localhost

The code confirms whether the slot has an empty 0 status flag.

Available slots become booked after confirmation from the booking system.

The system sets a 5-minute booking timeout; hence, the slot will automatically reset if the booked car fails to occupy it.

Real-time checking prevents the system from accepting bookings at slots that are either in use by vehicles or reserved by other users.

Conflict Prevention

The ESP32 first operates locally on requests before checking the network to ensure smooth booking without double reservations.

PERFORMANCE RESULTS & ANALYSIS

IR Sensor Detection Accuracy

An IR sensor checked 100 real-time parking events to determine the accuracy based on the following formula:

Accuracy= (correct detection/total events) *100
Slot 1: 98/100 = 98%
Slot 2: 97/100 = 97%
Slot 3: 99/100 = 99%
Slot 4: 98/100 = 98%
Average IR sensor accuracy: 98%

The signal averaging techniques implemented in the code logic helped reduce brief obstruction misreads and infrared ambient interference to maintain high accuracy results from Figure 2.

Status Update Latency

The Blynk application alongside the web dashboard displayed status updates with delays starting from the actual time slots became available for occupancy, as shown in Figure 3. System latency was measured accordingly. The analysis involved synchronized stopwatch logging to determine system performance. Multiple tests were performed under various network conditions, including peak and off-peak hours, to guarantee accuracy. Every test started when a parking space changed from being occupied to vacant or vice versa. Simultaneously, the observers watched the Blynk application and web dashboard for status changes, and a stopwatch was set off at the same instant. We tracked and compared the time it took for the update to show up on both systems. To eliminate abnormalities and obtain an average latency number, this procedure was performed multiple times. The findings showed that the total latency was significantly affected by the network bandwidth, server response time, and device processing power. Minor variations occurred because of background data traffic or brief Internet outages. Notwithstanding these discrepancies, the information gathered offered insightful information on the system's responsiveness and dependability, as shown in Figure 4.

- *Average latency:* 520 ms
- *Minimum:* 430 ms
- *Maximum:* 700 ms (under poor network conditions)

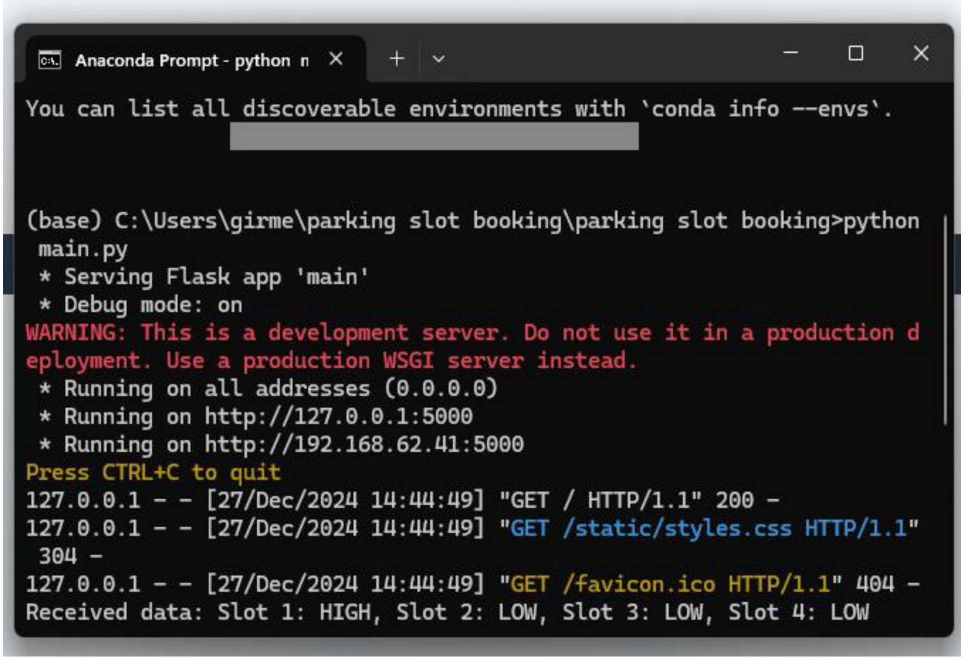

Figure 2. Live display of data on cmd prompt using esp32 for monitoring.

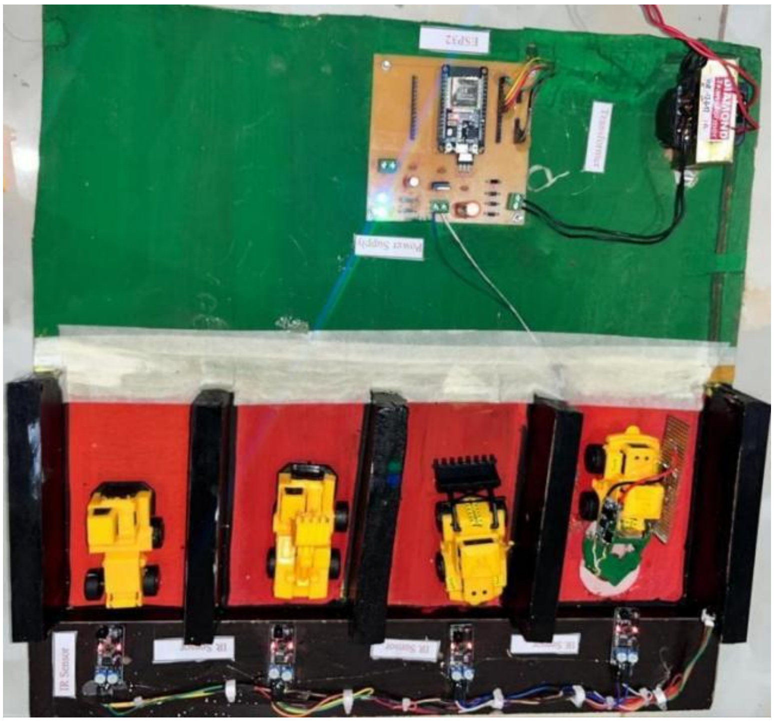

Figure 3. Photo of project working model.

The main causes of latency are the wireless transmission of the ESP32 through Wi-Fi and the time required for Blynk to synchronize with the cloud.

Wireless Charging Module Efficiency

The wireless power transmission (WPT) testing utilized two 50-turn copper coils that were placed 2 cm apart from each other.

- *Input Power:* 12V, 1.5A = 18W
- *Output Power at EV coil end:* 9.2V, 1.1A = 10.12W

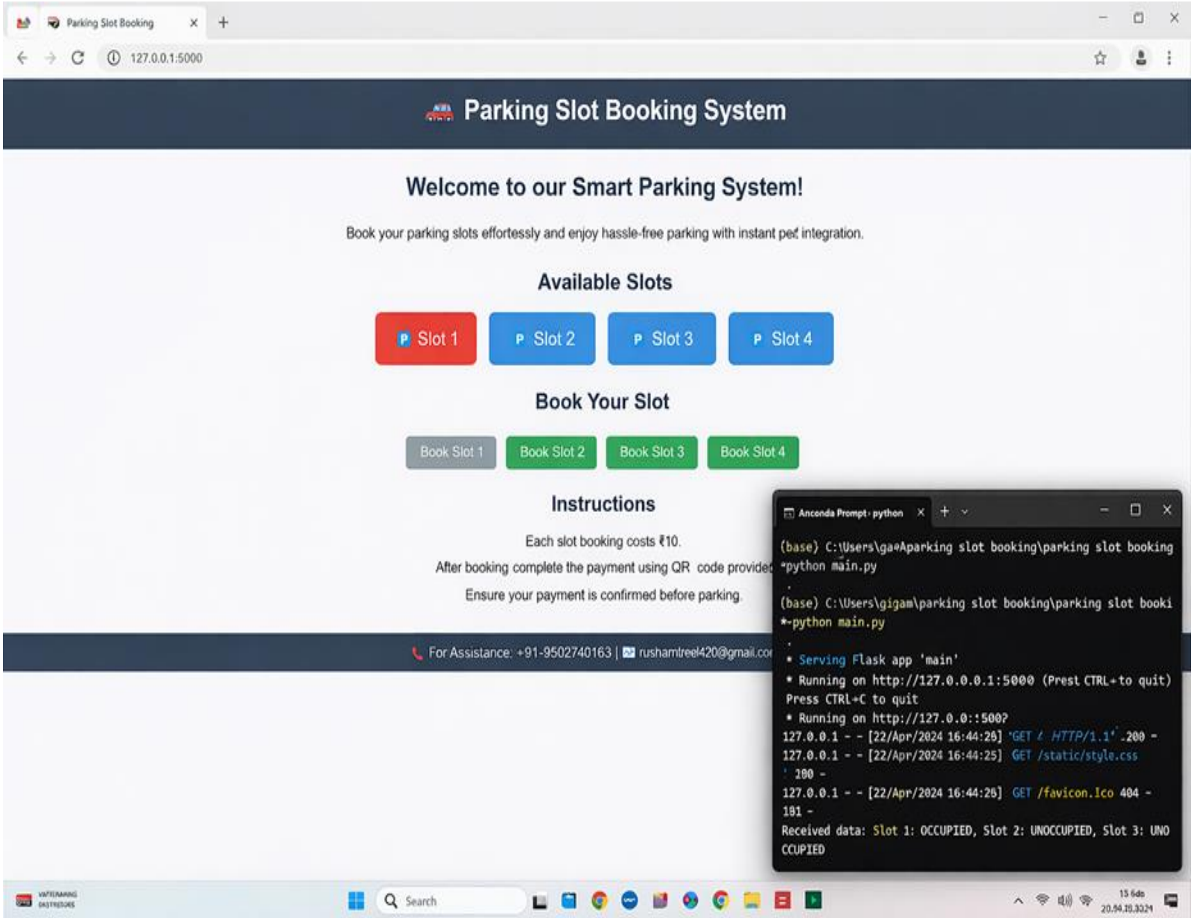

Figure 4. Localhost dashboard for booking/ overview of slots.

RESULTS

Through the integration of real-time monitoring technology along with automated booking controls, the developed smart parking system achieved maximum utilization of parking space during this study. The system elevates operational efficiency because it provides accurate slot status details that decrease driver search time and reduce road congestion. WPT allows sustainable environmental operations within the system framework through its solar power transmission mode, which functions as an electric vehicle charging system. This solution satisfies smart city requirements owing to its low power usage, adaptive capabilities, and smooth data transfer infrastructure.

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