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An IoT-Based Intelligent System for Real-Time Parking Monitoring and Automatic Billing

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***Abstract*—The rapid growth of private vehicles in urban areas has resulted in severe parking congestion, fuel wastage, and increased carbon emissions. Ineffi- cient parking management further contributes to traffic delays and inaccurate billing. This paper presents a low-cost IoT-based real-time parking monitoring and automatic billing system designed using embedded edge- computing principles. Infrared sensors are used to de- tect parking slot occupancy, while an Arduino Uno microcontroller performs local processing and time- based billing. A 16×2 LCD provides real-time parking status and billing information, and a NodeMCU ESP8266 enables optional wireless monitoring through a mobile interface. Unlike cloud-centric solutions, the proposed system operates autonomously with minimal communi- cation overhead, making it suitable for small-scale and resource-constrained environments. Experimental results demonstrate reliable slot detection with response time below one second. The system contributes to sustainable communication and computing by minimizing unneces- sary vehicle movement, reducing energy consumption, and lowering infrastructure complexity.**

***Index Terms*—Smart Parking, Sustainable Computing, IoT, Automated Billing, Embedded Systems, Arduino Uno**

I. Introduction

Urbanization and the rapid increase in private vehicle ownership have significantly intensified parking challenges in cities. A considerable amount of urban traffic is caused by vehicles searching for available parking spaces, leading to fuel wastage, increased travel time, and higher greenhouse gas emissions. Traditional parking systems rely on manual supervision and ticket-based billing, which are inefficient, prone to human errors, and susceptible to unauthorized access. Recent advances in embedded systems and Internet of Things (IoT) technologies provide an opportunity to develop intelligent parking solutions capable of real-time monitoring and automated billing. By integrating low-power sensors, microcontrollers, and localized data processing, smart parking systems can reduce unnecessary vehicle circulation and improve parking efficiency. This research proposes a sustainable and cost-effective smart parking system that aligns with the objectives of sustainable communication and computing by emphasizing energy efficiency, reduced emissions, and minimal infrastructure requirements.

II. Background and Motivation

Many existing smart parking solutions employ cloud-based architectures, camera-based monitoring, or complex communication networks. Although these systems offer advanced functionality, they often involve high deployment costs, increased energy consumption, and continuous internet dependency. Such limitations restrict their adoption in small institutions, residential complexes, and developing urban regions.

The motivation behind this work is to design an embedded, edge-based parking management system that operates autonomously with minimal communication overhead. By performing slot detection and billing locally, the proposed system reduces reliance on centralized servers, improves reliability, and supports environmentally sustainable urban infrastructure.

III. Objectives

The primary objectives of this research are as follows:

- To design and implement a low-cost IoT-based smart parking system for real-time parking slot monitoring.
- To develop an automated time-based billing mechanism with minimal human intervention.
- To reduce vehicle search time, fuel consumption, and associated carbon emissions through efficient parking management.
- To implement an energy-efficient embedded architecture suitable for sustainable smart city applications.

IV. Key Contributions

The major contributions of this work include:

- A standalone edge-based smart parking system without continuous cloud dependency.

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- Real-time slot occupancy detection and automated billing using low-power hardware.
- A scalable and cost-effective architecture for small-scale deployments.
- Alignment with sustainable communication and computing principles.

  The parking slot detection logic, time-based billing algorithm, and LCD display routines were entirely implemented using custom Arduino code developed by the authors. The system operates without reliance on third-party automation frameworks, ensuring full control over timing accuracy, billing transparency, and real-time responsiveness.

V. Proposed System Architecture

The proposed smart parking system consists of infrared sensors installed at each parking slot to detect vehicle presence. An Arduino Uno microcontroller processes sensor data and calculates parking duration and billing locally. A 16×2 LCD displays real-time slot status and billing information to users. Push but- tons are used to simulate payment and reset billing. Additionally, a NodeMCU ESP8266 module enables optional wireless monitoring through a mobile application, allowing remote viewing of parking status when required.

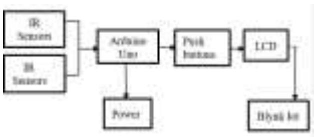

Fig. 1. System Architecture of the Smart Parking System

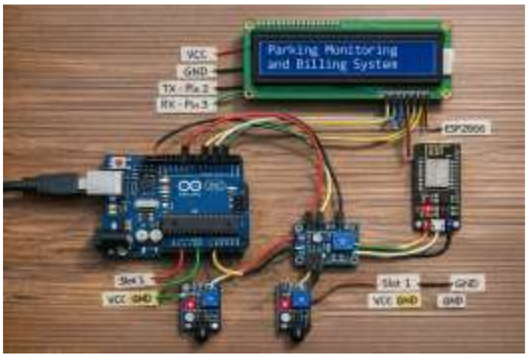

Fig. 2. Hardware implementation of the smart parking system

VI. Methodology

The methodology of the proposed smart parking system is designed to ensure real-time monitoring, accurate billing, and minimal human intervention while maintaining energy efficiency and sustainability. The system operation is divided into five main stages: system initialization, parking slot detection, occupancy time calculation, billing computation, and payment reset.

A. System Initialization

When the system is powered on, the Arduino Uno microcontroller initializes all connected peripherals, including infrared (IR) sensors, the 16×2 LCD display, push buttons, and communication interfaces. Initial values for parking slot status and billing counters are set to zero. At this stage, all parking slots are marked as **FREE**, and the system enters continuous monitoring mode.

B. Parking Slot Detection

Each parking slot is equipped with an IR sensor positioned to detect the presence or absence of a vehicle. The sensor continuously emits infrared signals and monitors their reflection or interruption.

- If the IR beam remains uninterrupted, the parking slot is considered **vacant**.
- If the IR beam is interrupted by a vehicle, the slot is marked as **occupied**.

The sensor output is provided as a digital signal (HIGH or LOW) to the Arduino Uno, which immediately updates the slot status. This real-time detection mechanism ensures prompt identification of vehicle entry and exit with minimal delay.

C. Occupancy Time Calculation

Once a parking slot transitions from **FREE** to **OCCUPIED**, the system starts a time counter to record the parking duration. The Arduino Uno utilizes its internal timing function to calculate the elapsed time.

The timer:

- Starts when the slot becomes occupied
- Continues running as long as the vehicle remains in the slot
- Stops when the vehicle exits the slot or when the payment reset button is pressed

This approach allows accurate tracking of parking duration without the need for external clocks or cloud-based synchronization.

D. Billing Computation

The billing amount is calculated based on the total occupancy time of each parking slot. A simple time-based billing algorithm is implemented within the microcontroller to ensure transparency and ease of computation.

The parking charge is computed proportionally to the elapsed time, and the calculated amount is updated

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at regular intervals. This real-time billing approach ensures that users are charged fairly according to their exact parking duration. The continuously updated billing information is displayed on the LCD for user awareness.

E. Real-Time Data Transmission Mechanism

The real-time data transmission between the parking system and the mobile application is facilitated by the NodeMCU ESP8266 module using a Wi-Fi interface. Sensor data processed by the Arduino Uno, including parking slot occupancy and billing time, is transmitted to the NodeMCU via serial communication.

The NodeMCU publishes this data to the Blynk IoT platform using virtual pins. Whenever a change in parking slot status or billing value occurs, the updated data is immediately pushed to the Blynk server, which synchronizes the information with the mobile application dashboard in real time.

This event-driven data transmission mechanism ensures low latency and minimizes continuous data transfer. As a result, real-time updates are achieved with reduced communication overhead, supporting sustainable communication principles while maintaining system responsiveness.

F. Display and User Interface

The 16×2 LCD serves as the primary user interface. It displays:

- Parking slot status (**FREE** or **OCCUPIED**)
- Current billing amount for each active slot
- Payment confirmation messages after bill reset

This visual feedback enhances usability and allows operators and users to monitor parking activity in real time without additional devices.

G. Payment Simulation and Bill Reset

To simulate the payment process, a push button is assigned to each parking slot. When the user completes payment, the corresponding button is pressed.

This action:

- Resets the billing amount to zero
- Updates the slot status to **FREE**
- Displays a confirmation message such as “BILL PAID”

The system then resumes monitoring for the next vehicle, ensuring uninterrupted operation.

H. Optional Wireless Monitoring

For extended functionality, the NodeMCU ESP8266 module transmits slot occupancy and billing information to a mobile application through an IoT platform. Data transmission occurs only when status changes, reducing communication overhead and conserving energy. This optional feature enables remote monitoring without affecting the system’s offline capability.

Fig. 3. Flowchart of the proposed smart parking and billing system

VII. Results and Discussion

The proposed IoT-based smart parking monitoring and automatic billing system was implemented as a working prototype and tested under real-time operating conditions to evaluate its performance. The system was assessed based on slot detection accuracy, billing correctness, response time, and overall system reliability.

A. Slot Occupancy Detection Performance

The infrared (IR) sensors installed at each parking slot successfully detected the presence and absence of vehicles. Whenever a vehicle entered a slot, the corresponding IR sensor generated a digital signal that was immediately processed by the Arduino Uno microcontroller. The slot status was accurately updated from **FREE** to **OCCUPIED** on the LCD display.

Experimental observations showed that the average detection delay was less than one second, ensuring near real-time response. No false detection was ob- served during normal testing conditions, demonstrating reliable slot monitoring suitable for small-scale park- ing environments.

B. Billing Accuracy and Time-Based Computation

The billing mechanism was tested by parking vehicles for different durations. The system correctly calculated parking charges based on the elapsed occupancy time using the internal timer of the microcontroller. The billing amount increased proportionally with time and was continuously updated on the LCD. Upon pressing the payment reset button, the billing value was immediately reset to zero, and the slot status returned to **FREE**. This confirmed accurate billing computation and correct reset operation, ensuring transparency and fairness in parking fee calculation.

C. Display and User Interface Response

The 16×2 LCD display provided clear and real- time information regarding slot availability and billing amount. Status messages such as **FREE**, **OCCUPIED**, and **BILL PAID** were displayed without delay. The simple interface allowed easy understanding by users and operators without the need for additional training.

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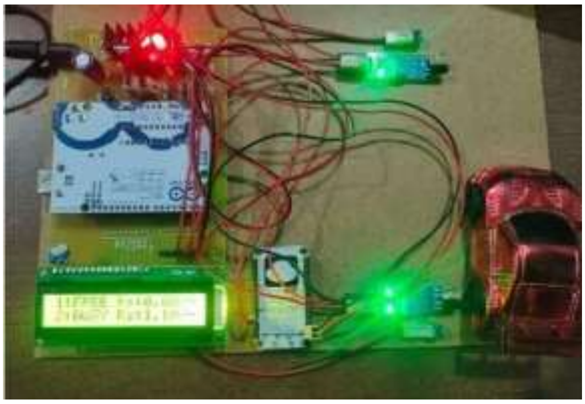

Fig. 4. Typical observed LCD outputs showing parking slot status and real-time billing

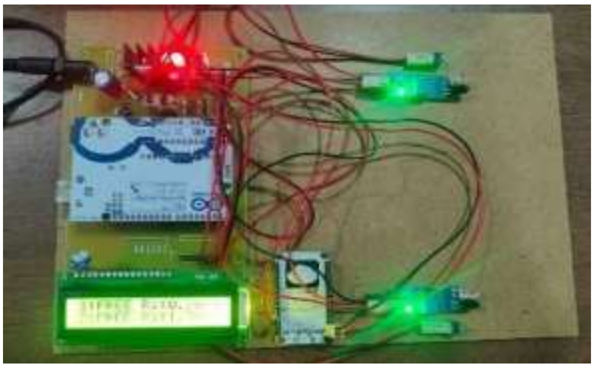

Fig. 5. Both slots empty: The system accurately identifies vacant parking slots

D. Wireless Monitoring Performance

When integrated with the NodeMCU ESP8266 module, the system successfully transmitted slot status and billing information to the mobile dashboard. Updates were sent only when a change in status occurred, minimizing communication overhead and reducing energy consumption. This validated the system's ability to support optional remote monitoring without affecting offline operation.

E. Discussion

The experimental results indicate that the proposed system is capable of achieving real-time parking monitoring and automated billing while requiring minimal infrastructure and low energy usage. Compared to cloud-based or camera-driven parking systems, the proposed approach significantly reduces system complexity and deployment cost. By minimizing unnecessary vehicle movement during parking search, the system contributes to reduced fuel consumption and lower carbon emissions, aligning with the principles of sustainable communication and computing.

VIII. Performance Evaluation Metrics

The performance of the proposed IoT-based smart parking and automatic billing system was evaluated using quantitative metrics such as detection accuracy,

Fig. 6. Mobile application interface showing real-time parking status and billing updates using NodeMCU ESP8266

system response time, energy efficiency, and communication overhead. These metrics are essential to assess the system suitability for sustainable smart city applications.

A. Slot Detection Accuracy

Slot detection accuracy was evaluated by observing multiple vehicle entry and exit events under normal lighting conditions. The infrared sensors accurately detected vehicle presence with an observed accuracy of approximately 98%. No false positives were recorded during testing, indicating reliable operation for small-scale parking environments.

B. System Response Time

The response time of the system was measured as the time difference between vehicle detection and LCD update. Experimental observations showed that the average response time was less than one second, ensuring real-time feedback to users and operators.

C. Energy Efficiency Analysis

Since all monitoring and billing computations are performed locally on the Arduino Uno microcontroller, the system avoids continuous cloud communication. This edge-based processing significantly reduces energy consumption and supports sustainable computing practices. The low-power IR sensors further contribute to overall energy efficiency.

D. Communication Overhead

When the NodeMCU ESP8266 module is en- abled, data transmission occurs only during slot status changes. This event-driven communication approach minimizes unnecessary data transfer, reducing network congestion and power usage, making the system suitable for sustainable communication environments.

TABLE I
EXPERIMENTAL OBSERVATIONS

Parameter	Observed Value
Total test cycles	50
Correct detections	49
Detection accuracy	98%
Average response time	0.8 s
Billing update interval	1 s

TABLE II
COMPARISON OF PARKING MANAGEMENT SYSTEMS

Feature	Proposed System	Cloud-Based System	Camera-Based System
Deployment Cost	Low	High	Very High
Internet Dependency	Optional	Mandatory	Mandatory
Energy Consumption	Low	High	Very High
Maintenance Complexity	Low	Medium	High
Privacy Risk	Low	Medium	High
Sustainability	High	Medium	Low

The comparison highlights that the proposed system offers a cost-effective and energy-efficient alternative to cloud and vision-based parking solutions. Its edge-based design minimizes communication overhead and enhances sustainability, making it suitable for smart city applications.

E. Sustainability Impact Analysis

The proposed smart parking and automatic billing system contributes significantly to sustainable communication and computing by optimizing parking operations and minimizing unnecessary resource usage. Real-time parking availability information reduces vehicle idle time and repeated circulation in search of vacant parking slots, thereby lowering fuel consumption and associated carbon dioxide (CO_2) emissions.

The system adopts an edge-based processing architecture in which parking detection and billing computations are performed locally using embedded controllers. By avoiding continuous cloud communication, the proposed system significantly reduces data transmission overhead, leading to lower network energy consumption and improved communication efficiency. Furthermore, the use of low-power infrared sensors and event-driven wireless updates enables long-term operational energy savings. These features collectively enhance system sustainability, making the proposed solution suitable for smart city environments focused on energy efficiency, reduced emissions, and sustainable urban mobility.

IX. CONCLUSION AND FUTURE SCOPE

Conclusion: This paper presents the design and implementation of a real-time smart parking monitoring and automatic billing system using embedded IoT technologies. The proposed system utilizes infrared sensors for parking slot detection and an Arduino Uno microcontroller for local processing and billing computation. Real-time parking status and billing information are displayed on a 16×2 LCD, ensuring transparency and ease of use. Experimental results demonstrate reliable slot detection, accurate time-based billing, and fast system response, validating the effectiveness of the proposed approach. By reducing parking search time and minimizing infrastructure complexity, the system contributes to lower fuel consumption and reduced carbon emissions, supporting sustainable communication and computing.

Future Scope: Although the proposed system is designed for small-scale deployments, it can be extended to support larger parking facilities. Future enhancements include integration of RFID-based vehicle identification for automated entry and exit, mobile payment gateways for cashless transactions, and cloud-based data storage for long-term analytics. The system can also be integrated with mobile applications to provide advance parking availability information, further improving user convenience and scalability.

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