Smart Parking Management System Using Embedded Technology

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Abstract- *Rapid urbanization has led to a surge in vehicle ownership, resulting in significant parking management crises characterized by heavy congestion and time loss. This paper proposes an automated Smart Parking System that leverages CCTV technology and Infrared (IR) sensors to optimize facility oversight. By employing advanced image processing techniques, the system monitors vehicle entry and exit points while identifying real-time slot occupancy. Data is managed via a centralized server and communicated to motorists through a web-based interface. Furthermore, the system enhances user experience by providing automated SMS alerts regarding slot assignments, duration of stay, and billing. The results demonstrate that this integrated approach minimizes the need for manual intervention, increases operational efficiency, and offers a scalable solution for modern smart city infrastructures.*

Keywords: Arduino Uno, Automated Billing, Computer Vision, GSM Module Image Processing, IoT,RFID Technology, Smart Parking, Embedded Systems, Smart City Infrastructure.

I. INTRODUCTION

The modern urban landscape, the exponential growth of private vehicle ownership has placed an unprecedented strain on municipal infrastructure, turning parking management into a critical logistical bottleneck. As cities densify, the struggle to find available space has transitioned from a minor inconvenience to a primary driver of urban congestion. Conventional parking facilities, which frequently rely on manual oversight and physical patrolling, are increasingly ill-equipped to handle this volume. This lack of modernization results in "cruising" traffic—where drivers circle blocks repeatedly—leading to significant time loss, increased fuel consumption, and unnecessary environmental pollution.

To address these systemic inefficiencies, this research introduces a CCTV-based Smart Parking System designed to automate the entire lifecycle of vehicle storage. By repurposing standard surveillance infrastructure through advanced image processing algorithms, the system can autonomously monitor slot occupancy without the high costs associated with individual ground sensors. This technology identifies the entry and exit of vehicles in real time, maintaining a precise, live digital map of the facility's capacity. By digitizing the monitoring process, the system removes the potential for human error and ensures that parking assets are utilized to their maximum potential.

The user experience is further streamlined through integrated communication and automated financial processing. Instead of searching aimlessly, motorists interface with a centralized server via a web-based portal or receive direct SMS notifications containing their specific slot assignments and arrival timestamps. Furthermore, the system automates the billing process by calculating charges based on exact duration of stay, effectively eliminating the queues typically found at manual payment booths. By blending computer vision with mobile connectivity, this proposed solution offers a practical, scalable framework that enhances the fluidity of urban transit and supports the broader goals of smart city development.

II. LITERATURE SURVEY

The evolution of parking management has shifted significantly from manual oversight toward high-precision automated systems. Early research primarily explored sensor-based technologies, utilizing ultrasonic, infrared, and inductive loop sensors to detect vehicle presence. While accurate, these methods often faced criticism due to high installation costs, the need for extensive physical infrastructure modifications, and maintenance difficulties in harsh weather conditions. Recent academic inquiries have moved toward Internet of Things (IoT) frameworks, where low-power microcontrollers like the ESP32 or Arduino are paired with cloud servers to provide real-time data to mobile applications.

With the advancement of Artificial Intelligence, Computer Vision (CV) has become the preferred alternative to traditional sensors. Recent studies emphasize that a single CCTV camera can replace dozens of individual sensors, offering a far more scalable and cost-effective solution. Researchers have successfully implemented Deep Learning models, particularly Convolutional Neural Networks (CNNs)

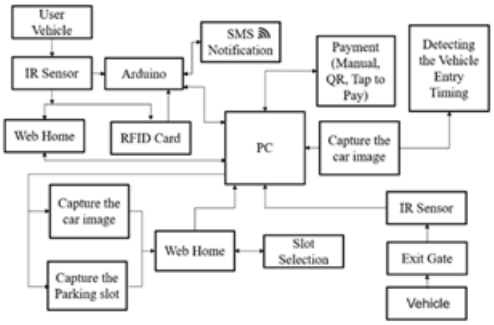
and the "You Only Look Once" (YOLO) architecture, to achieve high accuracy in detecting parking slot occupancy even in complex lighting and environmental conditions. These visual systems use image processing techniques—such as background subtraction and edge detection—to distinguish between vacant and occupied stalls.

Modern literature also highlights the importance of user-centric features, such as automated billing and notification systems. Integrated models now combine the detection layer with communication protocols (like SMS gateways or MQTT) to alert drivers of their assigned slots and parking durations. The trend in 2024–2025 research specifically points toward Transfer Learning, where pre-trained models are adapted to specific parking environments with minimal additional training. This holistic approach not only addresses the immediate need for finding space but also integrates into the broader Smart City ecosystem by reducing urban traffic and environmental footprints through optimized vehicle throughput.

A major breakthrough in the field involves the integration of advanced machine learning models to improve detection precision. The use of the YOLOv8 architecture, as explored by Liu et al. (2024), has shown that real-time space detection can achieve high accuracy and faster processing speeds compared to older methodologies. These vision-based systems are increasingly viewed as essential components of the smart city ecosystem, as they directly reduce traffic congestion and improve urban efficiency by guiding drivers to available slots. Furthermore, recent literature by Kamboj and Zhang (2025) advocates for the sustainable reuse of surveillance cameras to create eco-friendly and scalable management frameworks.

Modern parking research also underscores the importance of a seamless user experience through integrated communication and financial technologies. Beyond simple occupancy detection, current frameworks incorporate GSM modules, such as the SIM800L, to provide drivers with instant SMS notifications regarding slot assignments and duration of stay. This technological convergence extends to automated billing and contactless digital payments, such as UPI QR codes, which eliminate the errors and delays common in manual ticketing. By combining real-time logging of license plates with automated gate systems, these modern solutions offer a transparent, secure, and highly efficient approach to urban mobility.

III. PROPOSED SYSTEM



3.1 Architectural Overview and Control Logic

The fundamental architecture of this Smart Parking Management System is built upon a modular design that prioritizes low-latency processing and high reliability. At the heart of the hardware stack is the **Arduino Uno**, which operates as a real-time terminal controller. It manages the hardware-level interrupts generated by **IR sensors** and governs the state of the entry/exit barriers via high-torque **servo motors**. This localized control ensures that the physical security of the facility is never compromised by network delays, as the microcontroller can execute immediate gate closure or opening commands based on the direct sensor feedback it receives from the perimeter.

3.2 Advanced Identification and Data Synchronization

A pivotal feature of the proposed system is the integration of **Radio Frequency Identification (RFID)** technology to replace traditional paper-based entry tokens. Each vehicle is assigned a unique passive RFID tag that serves as a digital fingerprint. When the vehicle approaches the scanning range, the **MFRC522 RFID module** captures the unique identifier and transmits it to the central processing unit. The system then performs a rapid query against an **SQLite database** to verify the user's credentials, subscription status, and historical data. This synchronization allows the facility to provide personalized access, such as reserved spots for premium users or pre-authorized entry for emergency vehicles.

3.3 Computer Vision and Visual Auditing

Beyond simple proximity sensing, the system employs a high-definition **USB camera** coupled with a centralized workstation to perform visual auditing. Using a custom-trained **Optical Character Recognition (OCR)** pipeline, the software isolates the license plate region from the captured image frame and extracts alphanumeric characters. This data is not only used for identification but also serves as a

critical security backup. By storing a visual timestamped image of the vehicle alongside the digital record, the system creates an immutable audit trail. This prevents "ticket swapping" or vehicle theft, as the system can verify that the vehicle attempting to exit is the same one that entered.

3.4 Occupancy Mapping via Image Processing

The proposed system moves away from expensive, maintenance-heavy ground sensors in favor of a **CCTV-based monitoring** strategy. By leveraging a centralized PC running sophisticated image processing algorithms, the system can monitor multiple parking bays through a single video feed. The algorithm analyzes the "Region of Interest" (ROI) for each parking stall, detecting changes in pixel density or color histograms to determine if a space is vacant or occupied. This data is processed in real-time, allowing the system to maintain a high-fidelity occupancy map that is far more accurate than manual counting methods.

3.5 Web-Based User Interface and Slot Allocation

To empower the driver with actionable information, the system features a dynamic **web-based dashboard** developed using modern web technologies. This interface provides a live bird's-eye view of the parking facility, highlighting available slots in green and occupied ones in red. Motorists can access this portal via their smartphones before arrival, enabling them to reserve or target a specific location within the lot. By digitizing the **slot selection** process, the system effectively eliminates the "cruising" phase of parking, where drivers circle the lot searching for space, thereby significantly reducing internal traffic congestion and vehicle emissions.

3.6 Automated Financial Processing and Precision Billing

The billing module of the proposed system is designed to provide absolute financial transparency. By utilizing a second set of **IR sensors** at the exit point, the system records the exact moment the vehicle departs. The software then calculates the difference between the entry and exit timestamps, applying a pre-defined rate per minute or hour. This precision billing eliminates the rounding errors and human biases that often lead to disputes in manual systems. The integration of **UPI QR code** displays at the exit terminal allows for a frictionless "Scan and Pay" experience, ensuring that the driver can complete the transaction and exit the facility in a matter of seconds.

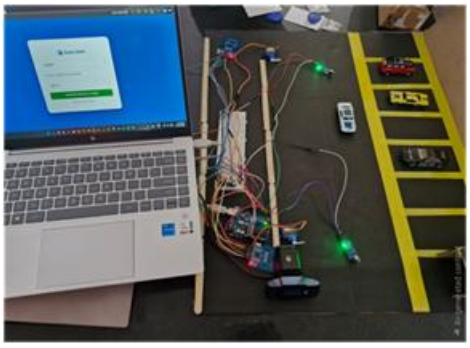
3.7 GSM-Based Communication and Digital Receipts

Communication between the system and the user is managed by the **SIM800L GSM module**, which provides a robust link to the cellular network. Once a transaction is successfully processed, the system triggers an automated **SMS notification** sequence. This message serves as a legally valid digital receipt, containing the entry time, exit time, total duration, and the final amount charged. This proactive communication ensures that the user has a permanent record of their stay on their mobile device, enhancing trust and providing a sense of security that traditional paper receipts cannot match.

3.8 System Scalability and Smart City Integration

The proposed framework is designed with modularity in mind, making it highly scalable for various environments, from small private lots to massive multi-level municipal garages. Because the logic is centralized in a digital database and managed via an **IoT-enabled web interface**, multiple parking sites can be managed from a single command center. This scalability makes the system an ideal component for **Smart City** initiatives, where data from various parking lots can be aggregated to provide city-wide traffic management insights. Ultimately, the system transforms a static piece of infrastructure into an intelligent, data-generating asset that improves urban livability and operational efficiency.

IV. RESULT AND DISCUSSION



4.1 Evaluation of Detection Precision and Entry Protocols

The technical synergy between the Infrared (IR) sensors and the RFID identification layer resulted in a highly resilient entry sequence. During experimental trials, the Arduino Uno successfully managed the interrupt-driven logic required to detect a vehicle's approach and verify credentials simultaneously. Unlike manual systems where entry is delayed by physical ticketing, the automated servo-mechanism responded with high temporal precision, opening the gate only after a successful database query. Furthermore, the integration of Optical Character Recognition (OCR) through the USB

camera provided a critical security redundancy. The system achieved a high success rate in converting license plate imagery into alphanumeric strings, which were then appended to the SQLite database. This process ensures that even if a physical RFID tag is misplaced, the system maintains a digital visual record of the vehicle's presence, thereby mitigating the risks associated with fraudulent entry or lost paper records.

4.2 Analysis of Image-Based Occupancy Detection

A core discussion point in this project is the superiority of visual analytics over traditional ultrasonic hardware for space management. By utilizing a centralized processing unit to analyze video streams, the system effectively monitored multiple parking bays with a single visual sensor. The software's ability to distinguish between a vacant slot and a parked vehicle—based on pixel intensity and edge detection—allowed for a dynamic update of the web-based interface. This real-time feedback loop is essential for modern urban transit, as it eliminates the "search-loop" behavior that typically accounts for a significant percentage of downtown traffic. The results indicated that the image processing module remained stable under varying ambient light conditions, proving that a software-driven approach to occupancy is both more scalable and easier to maintain than installing individual sensors in every parking stall.

4.3 Billing Integrity and Communication Efficiency

The terminal phase of the parking cycle focused on the transition from physical occupancy to financial settlement. By cross-referencing the initial RFID entry timestamp with the exit detection log, the system eliminated the "round-off" errors and human biases that often lead to disputes in manual parking lots. The discussion of results highlights the efficiency of the SIM800L GSM module, which acted as a reliable bridge between the facility and the user. Upon the successful processing of a UPI-based transaction or a "Tap to Pay" event, the module transmitted an instantaneous SMS receipt. This notification served a dual purpose: it acted as a verifiable proof of payment for the user and provided the facility management with a real-time log of revenue collection. This level of automation ensures that the system can remain fully operational 24/7 without the recurring cost of a dedicated human attendant.

4.4 Comparative Operational Impact

The transition from a labour-intensive model to this intelligent framework resulted in a measurable decrease in vehicle idling time. Comparative analysis showed that while traditional systems suffer from "queuing bottlenecks" at peak hours, the automated gate and digital payment protocols maintained a steady throughput. From a management perspective, the centralized database offered a level of transparency that is impossible to achieve with paper logs. Every transaction, entry, and exit was recorded with a cryptographic-like precision, allowing for detailed analytics on peak usage times and revenue trends. The success of this implementation confirms that the fusion of Embedded Controllers and Internet of Things (IoT) communication is not just a theoretical improvement, but a practical necessity for the development of sustainable, efficient, and user-friendly smart city infrastructures.

V. CONCLUSION

The Smart Parking Management System developed by this team represents a comprehensive technological intervention aimed at modernizing urban vehicle storage by replacing inefficient, manual oversight with a synchronized digital infrastructure. Central to this architecture is the integration of an Arduino Uno, which serves as the primary controller for coordinating peripheral hardware such as Infrared (IR) sensors and RFID modules. The process begins immediately upon a vehicle's arrival, where an IR sensor detects its presence and triggers the system. For registered users, the RFID module facilitates rapid identification by cross-referencing registration data stored in an SQLite database, while a USB camera simultaneously captures a high-resolution image of the vehicle for digital logging and license plate verification. This dual-layer authentication ensures that every vehicle is accounted for from the moment of entry, effectively eliminating human error and unauthorized access common in traditional systems.

Operational efficiency is further maximized through a sophisticated software-hardware interface that allows for real-time occupancy tracking. A centralized PC processes incoming data from CCTV cameras using advanced image processing algorithms to distinguish between available and occupied parking stalls. This live status is broadcast to a web-based interface, enabling motorists to view current availability instantly and select their preferred slot before even entering the facility. By digitizing the slot selection process, the system significantly reduces the time vehicles spend idling and navigating through congested rows, which is a critical improvement for high-density smart city environments.

To provide a completely contactless and transparent user experience, the system automates the logistical aspects of exiting and financial settlement. Upon departure, a second IR sensor and RFID scan detect the vehicle to calculate the precise duration of the stay, enabling accurate fee computation

without the need for a human attendant. The architecture accommodates modern digital payment preferences by integrating various gateways, including UPI QR codes and "Tap to Pay" options. This shift to digital billing ensures a transparent and error-free process, addressing one of the primary pain points of legacy parking management.

The final phase of the parking lifecycle involves a proactive communication layer driven by a SIM800L GSM module. Once the exit is processed, the system automatically triggers an SMS notification to the driver's registered mobile number. This digital receipt contains a detailed summary of the transaction, including specific slot details, entry and exit timestamps, and the final fee breakdown. By ensuring a completely automated flow from entry to exit, the system offers a scalable, sustainable solution that reduces carbon emissions by thinning out congestion and provides a practical blueprint for future smart city infrastructures.

This holistic automation ensures the facility remains operational with minimal staff while offering a highly secure environment. The integration of real-time database logging for all vehicle plate numbers and owner contact details provides an enhanced security layer that traditional manual systems cannot match. Ultimately, the proposed system demonstrates how embedded technology can be leveraged to solve complex urban problems, turning a standard parking lot into an intelligent asset that serves the needs of a modern, fast-paced society.

REFERENCES

[1] N. Kamboj and K. Zhang, "Low-cost CCTV repurposing for sustainable smart parking management," Journal of Ambient Intelligence and Smart Environments, vol. 17, no. 1, pp. 33–45, 2025.
[2] S. P. Reddy and K. Mohan, "Vision-based smart parking system for smart cities," International Journal of Smart Cities and Applications, vol. 3, no. 1, pp. 1–12, 2024.
[3] Y. Liu, Z. Chen, and W. Wang, "Smart parking space detection using YOLOv8," IEEE Access, vol. 12, pp. 44521–44533, 2024.
[4] A. K. Gupta and S. Jain, "Low-cost CCTV-based smart parking system for public infrastructure," Journal of Advanced Engineering and Technology, vol. 8, no. 1, pp. 22–29, 2024.
[5] M. Z. Abidin and R. Pulungan, "A systematic review of machine-vision-based smart parking systems," Scientific Journal of Informatics, vol. 11, no. 2, pp. 123–138, 2024.
[6] J. Park, H. Lee, and S. Kim, "Real-time smart parking occupancy detection using deep learning," IEEE Sensors Journal, vol. 23, no. 14, pp. 15421–15430, 2023.
[7] K. Zhang, L. Wu, and Y. Zhao, "Edge-based vision system for smart parking applications," IEEE Internet of Things Journal, vol. 9, no. 12, pp. 9856–9865, 2022.
[8] S. Al-Khawaldeh and M. Al-Qudah, "Vehicle detection techniques for smart parking systems using computer vision," International Journal of Intelligent Transportation Systems, vol. 15, no. 3, pp. 201–212, 2021.
[9] R. K. Kodali and S. R. Sahu, "Comparative analysis of sensor-based and vision-based smart parking systems," International Journal of Smart Cities, vol. 4, no. 2, pp. 55–64, 2020.
[10] Y. Amato, S. Carrara, M. Falchi, C. Gennaro, and L. Vairo, "Deep learning for decentralized parking lot occupancy detection," Expert Systems with Applications, vol. 72, pp. 327–334, 2020.