IoT- based Smart Parking System for Industry 4.0 with QR code access and real- time navigation

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Abstract. This paper presents an Internet of Things (IoT)-based smart parking system that incorporates the features the concepts of Industry 4.0 through. The system employs sensors for vehicle occupancy detection, wireless communication for data transmission and cloud-based processing for parking management. QR codes make vehicle access safe and the mobile application provides the users real-time parking availability and routing to vacant parking slots. This approach improves system scalability, cuts down search time, and minimizes vehicle emissions by reducing congestion and demonstrates a strong digital automation framework for effective urban transportation in Smart City infrastructures.

1. Introduction

Growing technological, economic and environmental changes have brought about an increased interest in the concept of Smart Cities. The objective of its concept is to boost productivity, optimize city management and minimize operational expenses [1]. It encompasses healthcare, education, energy consumption, public security, systematic monitoring and management of infrastructure, building and intelligent transportation system [2]. Smart Parking System is a key part of the smart city's transport system. In densely populated areas, finding a parking spot requires a considerable amount of time, patience and attention. About 30 to 50 percent of drivers in these areas spend between 3 and 14 minutes looking for a free parking spot. This results in increased traffic congestion, air pollution, and driver frustration. Globally over 7 million premature deaths were akin to air pollution according to the United Nations Environment Program. By 2030, the expense of health care in the US due to traffic jams is expected to reach $17 billion [3]. Besides, drivers with access to parking availability information are 45% more likely than those who do not to park successfully when they arrive at their location. Limitations in traditional parking systems due to population growth and traffic demands are driving the ongoing expansion of intelligent parking solutions. The smart parking system market is expected to grow at the rate of 18.47% annually from 2022 and reach a market value of USD 21 billion by 2030[4].

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2. Literature Review

In the 1930s to regulate parking spaces, facilitate time-based parking, and fee collection, parking meters and mechanical ticketing systems were introduced. With the arrival of the electronic parking meters in the 1980s automated charge collecting and enhanced enforcement capabilities were made possible. Development of sensor-based parking systems in the late 20th century was able to provide real-time data on parking space availability [5]. The integration of Smart parking systems can help cut down on congestion, which will in turn lower air pollution and the health problems that come with it [6].

A smart parking system (SPS) is made up of several interrelated components that include a data management system for processing and analyzing data, a user application that offers real-time updates, a communication network for smooth data transmission, and occupancy sensors placed in parking spots to identify the presence of vehicles which work together to improve the user experience and parking management [7]. It can be divided into various categories based on the sensors, communication networks, prediction models, and user interfaces employed. The different types of sensors that are generally used to implement SPS are Infrared (IR), Ultrasonic, Camera, Inductive Loop detector, Magnetometer, Light Detection and Ranging (LIDAR), Radio Frequency Identification (RFID), and Microwave Radio Detection and Ranging (RADAR).

The Light Emitting Diode (LED) in the IR sensor emits infrared radiation and the receiver in it detects the radiation reflected from any object that is in its proximity. This property allows them to detect vehicles. They are sensitive to rain and snow and hence more suitable for indoor parking facilities [8]. Ultrasonic sensors are generally mounted on the ceiling of indoor parking facilities to detect vehicles. They use acoustic waves in the range of 25 kHz - 50kHz to detect any nearby objects that reflect the acoustic wave. Careful implementation is necessary so that the sensor can segregate between a vehicle and a passer-by. A network of cameras is used in SPS for vehicle detection, surveillance, detect license plates of vehicles for billing, reservation, and authentication. This eliminates the need of multiple sensor usage in SPS. However, they are quite expensive and high maintenance. Another issue is availability of good lighting at all times and places for efficient working of a camera based smart parking system [9].

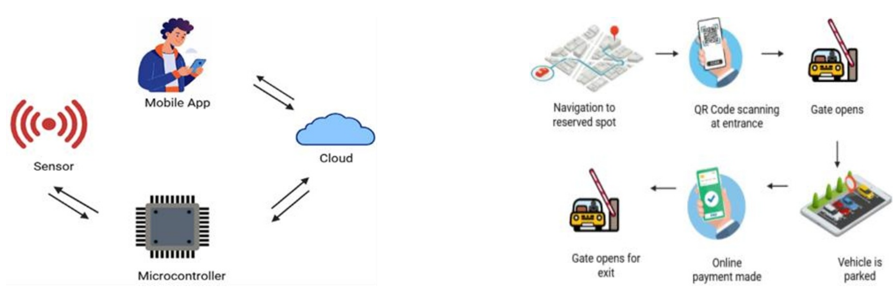
Inductive loop detectors and Magnetometer are both installed under roads to detect vehicles above it using electromagnetic induction and electromagnetic field respectively. They can be used in both open and closed parking lots. Inductive loop detectors are even capable of classifying different kinds of vehicles using some computational techniques. But they are expensive and have a high installation cost [10]. LIDAR is primarily used for vehicle detection. It uses LASER light to calculate the distance by illuminating the object of interest and measuring the reflected light with the sensor [11]. RFID technology is commonly used in SPS for vehicle and user identification. When the RFID tag is scanned by the RFID receiver, it transmits digital data stored inside it and the receiver receives the data for object identification [12]. Doppler Microwave RADAR can be used to determine both moving and stationary objects. IR Sensor and Inductive Loop Detector are the most popular in SPSs due to their low implementation and maintenance cost [6].

Depending on network communication, SPS can be classified into Wireless Sensor Network (WSN)-based, Image Processing-based, Vehicular Ad Hoc Network (VANET)-based, Wired Network-based, and Internet of Things (IoT)- based. In WSN based parking management systems, wireless sensors are strategically placed in parking facilities to detect and monitor parking space lot occupancy. The data is collected from the sensors and regularly transmitted to a database. This enabled real-time occupancy rate, security and generation of statistical reports. A network of cameras is generally used in Image Processing-based SPSs to detect parking lot occupancy. However, in some cases, ultrasonic sensors are utilized for lot detection while cameras are primarily employed for license plate recognition, facilitating billing processes and enhancing vehicle security. VANET based parking systems is consists of three main components: Parking Side Unit (PSU), Road Side Unit (RSU), and On-Board Unit (OBU). The PSU sends the parking availability information from the OBU to neighbouring RSUs. While the system is effective, it may give errors when a vehicle without a PSU enters the parking facility. Loop detectors or other wired sensors used in Wired Network-based SPSs detect vehicle presence and communicate real-time vehicle occupancy rates on a monitor. IoT based systems all the computational, mechanical and digital devices are connected through the internet and do not require human intervention for data transfer. They use sensors, cloud platforms, and smartphone apps. To provide customers services like real-time parking availability, navigation, reservations, and online payments, SPSs utilise a variety of user interfaces, such as web applications, smartphone apps, and Vehicle Information and Communication Systems (VICS). VICS based SPS smartphone applications are the least and most popular respectively [13].

3. Methodology

3.1 System Architecture

The proposed Smart Parking System utilizes a modular architecture consisting of four primary components: a sensor layer, a microcontroller layer, a cloud backend, and a user interface. Infra-red Sensors (IR) installed in the parking slots are used for real-time occupancy detection. They send analog signals to the microcontroller, which in turn sends this data to the cloud storage. The microcontroller layer of the SPS consists primarily of the ESP32-CAM for gate automation, QR Code scanning, and camera functions. The camera in the module scans the QR Code the customers present and extracts the booking ID, slot number, and timestamp. The scanned data is authenticated by querying in the cloud, by changing the status from pending to confirmed, cancelled, completed, expired or active. The electronic signals are sent to the cloud using the HTTP protocol. Supabase is used here for real-time cloud storage of booking data, account information, slot availability, bookings, etc. It uses PostgreSQL for managing the database. The user interface in this case is a flutter-based mobile application to view slot availability, navigate to specific slots, reserve, and pay.



(a) (b)

Fig 1. (a) System architecture of the SPS and (b) Work flow

3.2 Work Flow

This system requires the users to install the mobile application on their devices. The users have to register on the application using their email id and provide basic information such as name, vehicle number and type of vehicle. The user is also required to provide a valid ID such as an Aadhar Card for verifying their identity. A unique dynamic QR code is generated upon successful registration and verification for the user and saved to their profile. Users can find a parking spot that is closest to their location by using the 'Find Parking Spot' option on the application. Real-time slot monitoring of each parking slot is achieved by continuous tracking, further this data is transmitted to the cloud which can be visualized on the user's mobile device. The real-time parking slot monitoring system utilizes IR sensors connected to an ESP32-CAM to detect the presence of vehicles in each slot. When a vehicle is detected, the sensor output changes state, and this data is read by the microcontroller at regular intervals. The collected data is then transmitted via UART to the microcontroller, which acts as a communication bridge. The microcontroller processes this information and updates the real-time database on the Supabase cloud platform. The mobile application fetches this data and displays available and occupied slots dynamically.

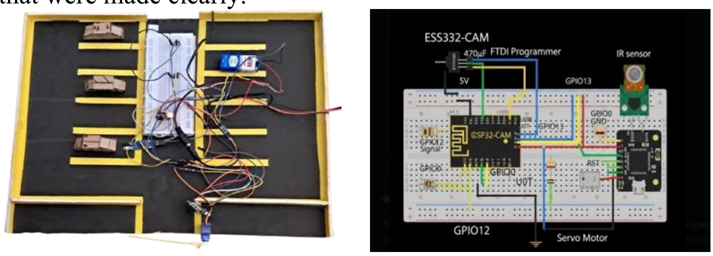
Users can view the status of the slots and reserve a vacant slot through the application interface by paying a small, non-refundable reservation fee in advance. This is done to discourage last minute cancellations. Furthermore, if a vehicle does not appear within the first 15 minutes of the reservation period, then the booking will be automatically cancelled which enables the admin to make the parking slot available to other users. Navigation to the selected slot is guided through Google Maps integration using coordinates of the slot. At the entrance of the parking, the user scans their app-generated QR code using the ESP32-CAM.The QR code is verified against backend records. If a reservation exists, the servo-motor controlled gate opens. Each reserved slot is then mapped to the user. If the user parks in a wrong slot, the system identifies mismatch using sensor data and triggers an alert in the form of a notification. At the time of exit, the QR code is scanned once again for verification. If the payment is completed or verified, the gate opens and reservation ends. If not, the user is redirected to the payment page. The slot status is updated to "vacant" again.

3.3 Dynamic QR Code Generation

A dynamic QR code is generated on the screen depending on the current booking information, the parking lot information, and the assigned parking space. The application creates a data object when the screen is created with details such as the slot number, the parking lot ID where the reservation was made, the unique booking ID, and a verification code for authentication. The jsonEncode() function converts this data into a JSON string that is compact and portable, that can be encode into a QR code. The QR Code is graphically represented on the screen using the QrImageView widget from the qr_flutter package. This widget uses the JSON text as input and creates a QR code image dynamically at runtime. To ensure that the QR code generated can be still be scanned under normal lighting, it is shown inside a stylized container. In case the QR scanning doesn't work, a verification code shown as plain text below the QR image is used as a backup. Based on the current booking state, the screen title and instructions are altered. This context-aware rendering logic improves the user experience. For instance, the title and message remind the user to present the QR code at the entry gate if they have not yet entered the parking lot (entry time is null). A new message appears if they are leaving. This guarantees a smooth interface between the user and the gate validation hardware by customising the dynamic QR code for each stage of the parking journey such as entry, stay, and leave.

4. Results

To validate the functionality of the proposed smart parking system, a working prototype was developed as shown in Fig 2(a). The prototype mimics a real-world parking layout, comprising multiple parking slots, entry/exit pathways, and embedded electronic components. An ESP32-CAM microcontroller module was deployed at the entrance to handle real-time QR code verification and gate control using a servo-motor. In order to detect the presence of vehicles, IR sensors were placed at individual slots, this enables the system to update occupancy status accordingly. As the ESP32-CAM module contains integrated Wi-Fi and onboard camera, it handles tasks like QR code recognition, communication with the database, and controlling the servo motor. A 5Volts, 1.5A external supply powers the microprocessor, sensors, and the servo motor. A 470µF electrolytic capacitor was connected across 5V and GND pins to reduce the chance of brownouts and ensure smoother operation of the ESP32-CAM.A common ground rail was created on a breadboard to ensure a shared reference voltage and reduce noise. Proper decoupling with capacitors minimized the power drops during motor movement as well as camera startup. An FTDI module was used to program the ESP32-CAM via serial communication. Fig 2(b) given below shows all the connections that were made clearly.



(a) (b)

Fig 2. (a) Prototype of SPS and (b) Circuit diagram

In order to facilitate real-time user interaction with the system, a Flutter-based mobile application was created as part of the proposed SPS. The application interface has a user-friendly layout and intuitive navigation as shown in Fig 3(a), (b) and (c). New users can create their accounts on the registration page by providing essential personal details such as full name, email id, phone number, password and a copy of their Aadhar card. Users can also sign-in via the Google sign-in integration. Once registered, additional information such as the type of vehicle (car/bike) and vehicle number are ought to be provided, after which the users are redirected to the homepage dashboard. On the homepage dashboard, users can view options such as find parking, scan QR, booking history and their profile.

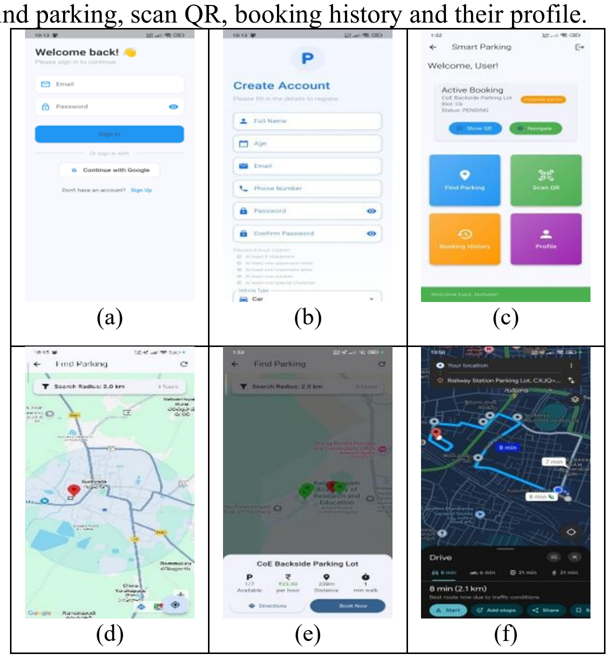


Fig 3. (a) Login Screen of the mobile application, (b) Registration Page, (c) Home screen, (d) map showing nearby parking lots with the radius filter enabled, (e)details of the parking areas/zones and (f) navigation to the parking slot

Using the find parking option, users can discover the parking areas or zones that are near their current location. They can also use the radius filter which enables them to set the radius as 500m, 1km, 2km, etc which displays all the parking areas or zones within that distance from their location as shown in Fig 3(d). If the location pin is red then there are no vacant parking slots whereas if the pin is green then parking slots are available for booking in that particular parking area/zone which can be seen in Fig 4(e). The details of the available parking slots, their average cost, location from the user and time to reach it by walk are also shown when clicked on a parking area/zone. The application also provides the navigation to the locations using Google Maps.

The application allows users to save the details of multiple vehicles they own under a single username as seen in Fig 4(a). When choosing the parking area or zone, the user can select the type of vehicle they want to park. Once the parking area or zone is selected, all the slots within it will be visible Fig 4(b). The user can reserve any slot they want and enter the duration for which they want to park. A minimum amount of money is required to be paid upfront when making a booking. This can be achieved by online payment methods such as UPI, net banking, etc. Besides, the SPS has a digital wallet which enables users to add money to it.

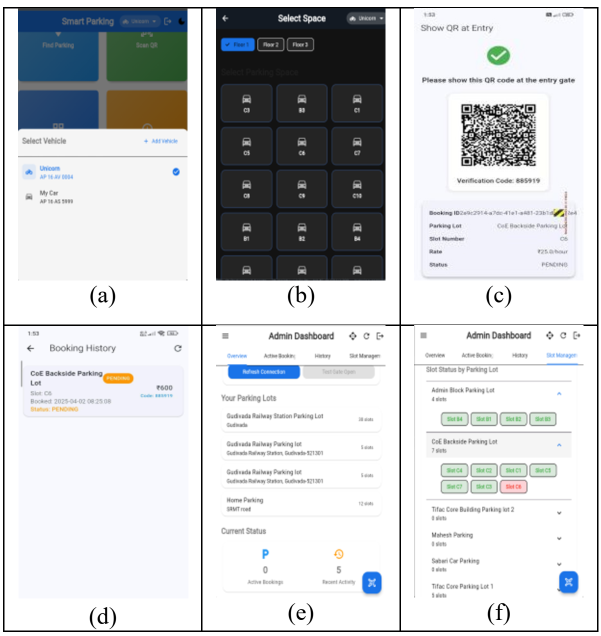


Fig 4. (a) Multiple vehicles registered under a single user name and (b) All the slots available within a parking area or zone (c) booking confirmation (d) booking history (e) admin dashboard shows all the parking areas or zones and (f) slot management

A QR code is generated after the booking is made (Fig 4(c)). The home page dashboard displays the active booking details, including the selected parking lot, slot number, and booking status. The screen also provides options to see the QR code for gate access and to navigate to the parking location via Google Maps. At the entrance of the parking area, the user has to scan the QR Code and park their vehicle in the reserved spot. Users receive a notification if they park in the wrong slot. A reservation can be extended if necessary. A 10-minutes window is provided for users after the reserved time within which they can extend the parking duration. Only if an extension is not availed, will the particular slot become available for booking for another vehicle. When exiting the facility, the user has to scan their

QR code again. After the system verifies the received payment, the gate opens. All the previous bookings can be viewed under the booking history option (Fig.5(d)) on the homepage. The Admin Dashboard gives details about all the parking area which falls under the admin's control (Fig.4(e)). By using the slot management option, admin can have a detailed idea about the occupancy rates of the different parking areas. All the vacant slots appear in green colour whereas all the occupied slots appear in red colour as can be seen in Fig.4(f).

5. Conclusion and Future Scope

Usage of QR codes in Smart Parking Systems will provide a seamless option for booking as well as the payment for a parking reservation. The online QR code generation will guarantee convenience and effectiveness both for the user and the administrator. They will remain an essential technology as the urban transportation advances. Further improvements can be made to the proposed system by employing number plate detection which can be used to crosscheck the details of a vehicle when it enters a parking facility. This ensures only a registered vehicle enters the parking facility. If a mismatch is detected in the vehicle details, then the admin could be alerted and access to the facility can be denied. This method will provide an added layer of security. Additionally, integrating the existing database with that of the law enforcement could help to check for stolen or blacklisted vehicles. Another enhancement could be an automatic parking slot recommendation to users based on the type of vehicle that they drive by creating a database of the vehicles present on road in our country.

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