Implementation of Parking System Using ESP32 Integrated with Rapid SCADA via MQTT

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Abstract

This research presents the implementation of an Internet of Things-based parking system. The system uses ESP32 microcontrollers integrated with a SCADA system via the MQTT protocol. The proposed system utilized ultrasonic sensors to detect vehicle presence in parking slots. It capture a real-time distance and parking status to the SCADA system for monitoring and administration. We also created a user interface to exhibit parking status. The interface accommodates both PC and smartphone platforms, facilitating versatile deployment across diverse contexts. A prototype apparatus was utilized in an experiment. The design simulated vehicle heights ranging from 0 cm to 200 cm in 10 cm increments. The results show high detection accuracy. Measured values from sensor showed minimal deviation from the actual distances, resulting in an average error of only 0.57%. Communication performance evaluation indicates low end-to-end latency. Data was transmitted from the ESP32 to the SCADA and HMI interfaces, often within one second. These results confirm the system's capability for near real-time operation. The results validate the efficacy of the proposed system work effectively for smart parking management. The system is particularly suitable for urban environments where efficient space utilization and swift response are critical. This research constitutes a prototype implementation. Future development will prioritize system dependability and the implementation of improved security measures to safeguard data privacy. These initiatives will encompass enhancements in scalability to facilitate extensive deployments and refinements in the user interface to augment usability. The integration of advanced analytics with city-wide traffic control solutions will be investigated. This will enhance urban mobility efficiency and advance environmental sustainability goals.

Keywords: MQTT, SCADA, IoT-based, Parking System

1. Introduction

In Thailand and around the world, the number of cars has increased dramatically in recent years [1], especially in Bangkok and other major cities. Thailand and other countries are facing the same problems as a result of rapid urbanization, growing populations, and changing economies. Many problems arise from the imbalance of vehicles and parking. These problems include increased vehicle emissions, higher pollution and fuel consumption, as well as traffic congestion [2]. As a result, drivers spend inordinate amounts of time looking for parking, which is inefficient and frustrating, ultimately affecting a person's daily productivity [3].

Parking systems have come to alleviate drivers' parking difficulties by providing real-time information on available parking spaces [3]. The systems use various technologies to detect vehicles and share this information with drivers or disseminate it to a centralized monitoring platform. Parking systems also help reduce traffic congestion, save fuel, and save time by guiding drivers to available parking. They also improve land use efficiency and environmental sustainability [2]. The parking systems are more integral to urban planning and intelligent transportation frameworks to enhance efficiency.

The parking systems can be implemented using a variety of technologies for vehicle detection and data transmission, including wired networks, wireless senssor networks (WSNs), image processing systems, VANETs, and IoT platforms [5-6]. Each type of the technology has different advantages and limitations. The wired networks offer high reliability and security for data transmission. However, it comes at the high installation costs and limited flexibility. Following by WSNs which commonly employ infrared or ultrasonic sensors. It provides users with real-time monitoring and data management. However, it limited range and susceptible to interference. Subsequently, investigate image processing systems. It provides detailed inspection and autonomous vehicle recognition using cameras and AI algorithms. However, the performance get effect from light conditions. Next, study VANETs. It supports real-time, dynamic vehicle-to-infrastructure communication but is complex and expensive to implement. Finally, the IoT solutions are exceptionally adaptable, scalable, and user-friendly. IoT platforms integrate several IoT sensors and cloud technologies to provide real-time data transmission and centralized management. However, it may elicit privacy issues and necessitates substantial data capacity. The selection of an appropriate parking system depends on project requirements, environmental considerations, and budgetary constraints [5-6].

The objective of this project is to design and implement a parking system employing Internet of Things (IoT) technologies. These technologies are selected for this project, as they can be the integration of several sensors, offer real-time data transmission, and accommodate scalable implementations [5]. The proposed system utilizes ESP32 microcontrollers and SCADA platform. Data is transmitted to the SCADA

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system via MQTT for monitoring and control. The ESP32 was selected to be edge device because of its robust design, ultra-low power consumption, and high level of integration. It has Wi-Fi and Bluetooth in a single chip. operates reliably in conditions, and supports multiple power-saving modes. That making it highly efficient for IoT applications. So, The ESP32 is a perfect choice for implementing a parking system based on IoT [7]. This properties solution is suitable for different situations. This versatile and reliable approach is applicable in various situations. This significantly aids users in identifying parking issues and improving efficiency in urban traffic management.

2. Literature Review

Parking systems help drivers to reduce the time spent finding an available space to park. Parking systems improve traffic flow and fuel efficiency. In addition, their contribution to environmental sustainability is clear. As a component of smart city projects, these solutions integrate various technologies to enhance urban traffic. Commonly used sensors include ultrasonic, infrared, magnetic, and radar sensors for vehicle detection; camera-based systems combined with computer vision and artificial intelligence; and wireless communication methods such as Wi-Fi, Zigbee, LoRa, and NB-IoT for data transmission. User-friendly visualization is typically implemented through mobile applications [4–6].

Parking system solutions can be categlorized into five primary groups according to sensing and communication technologies: wired network, wireless sensor network, image processing, vehicular ad-hoc network, and internet of things. Wired network systems facilitate precise information delivery. They are costly to establish and lack flexibility. WSNs comprising ultrasonic and infrared devices, enable real-time monitoring. They are not strong to interference and range limitations. The Image processing systems use camera and artificial intelligence for find vehicle recognition; nevertheless, their precision depends on lighting and weather conditions. VANET-based systems employ vehicle-to-infrastructure communication techniques for real-time updates but still, they are complex and expensive. IoT-based systems integrate IoT sensors into a centralized platform, enabling scalability, continuous data transfer, and a user-friendly interface. These characteristics render IoT-based methodologies optimal for dynamic urban parking administration [5].

Among these technologies, IoT has emerged as the foundation driving modern parking systems. Pham et al. [8] demonstrated a cloud-connected IoT architecture where parking lots act as interconnected IoT networks, enabling real-time slot updates and optimized allocation while reducing cost and latency. Pham et al. [9] have shown how IoT architectures can scale to large deployments while maintaining efficient communication. Alam et al. [10] presented a survey showing that IoT-driven designs consistently outperform manual and semi-automatic systems. This enables automation, remote monitoring, and reliable data analytics. In addition, Lin et al. [11] They highlighted the IoT as the essential connection between decentralized sensors and centralized management systems. That IoT architecture support real-time surveillance and integration with urban transportation services.

Subsequent research illustrates the adaptability of IoT across several domains. Ke et al. [12] developed a parking surveillance system utilizing IoT sensors for real-time vehicle detection, achieving over 95% accuracy in field trials and alleviating network congestion. Lou et al. [13] They study on multisensor IoT detection methodology. That result of accuracy approximate about 98.81% with low power usage. They demonstrated the efficacy of IoT for dependable detection using interconnected sensors. Saleem et al. [14] presented an IoT-based system that provides dependable, real-time parking recommendations, demonstrating its effectiveness in real-world urban environments.

This extensive research elucidates the rationale for the utilization of IoT-based technologies for effective and scalable parking management. IoT establishes a framework that integrates sensors, devices, and management platforms into a unified network, enabling real-time monitoring of parking availability and vehicles. Communication protocols and architectures enable IoT systems to accurate data acquisition, reliable information dissemination, and adaptable services such as automated reservations and display available spaces.

An IoT-based architecture with easy integration, real-time agility, and scalability has shown ideal support for the goal of this research. This research presents an IoT-based parking system as a foundation for the suggested implementation, establishing IoT as an essential innovation to constructing scalable efficient urban transportation solutions.

3. Research Methodology

This study explain design process, implementation strategy, and validation of the parking system test. Beginning with a overview of this system. Subsequently providing discussion of physical and logical designs. Last, design a testing and validation of system performance.

3.1 System Overview

This part explain comprehensive overview of the system. We will outline the primary components and their interactions to provide a complete parking management methodology. That is hardware and software elements into an IoT-based architecture, enabling seamless data acquisition, processing, and visualization.

From Fig. 1 , an ESP32 installed in each parking place within the sensing layer to detect vehicles. We use an AJ-SR04M ultrasonic sensor that measure distance from a vertical orientation. The AJ-SR04M ultrasonic sensor was used in this system. It works with 3–5.5 V. It consumes very low power. In standby, it uses about 2 mA.

In sleep modes, it uses 20–40 µA. It measures distances from 20 cm to 8 m. The resolution is about 2 mm. It works with a 40 kHz signal. The beam angle is about 75°, giving a wide detection area. It can operate in temperatures from –20 °C to +75 °C. These features make it suitable for IoT-based parking system [15]. The ESP32 locally processes the raw distance data and produces two data packets. Package of the parking status, was encoded as a binary value where “0” represent a vacant slot and “1” signifies an occupied position. The second package comprises the quantified distance in centimeters for monitoring and validation purposes. The ESP32 transmits both data packages to an MQTT broker over the MQTT protocol via the network router. The broker serves as the core communication between devices and applications. Within the monitoring and control layer, a SCADA subscribes topics of Parking State and Distance then records it in database for historical preservation and further analyze. A custom-designed HMI web interface functions as an autonomous component distinct from the SCADA platform. The HMI establishes a direct connection to the MQTT broker over WebSocket communication and subscribes to the parking state topic on the broker. The web interface tracks the occupancy status of each parking space, showing whether it is available or occupied. The data is delivered via a web server to access the HMI, enabling drivers and operators to monitor real-time parking information.

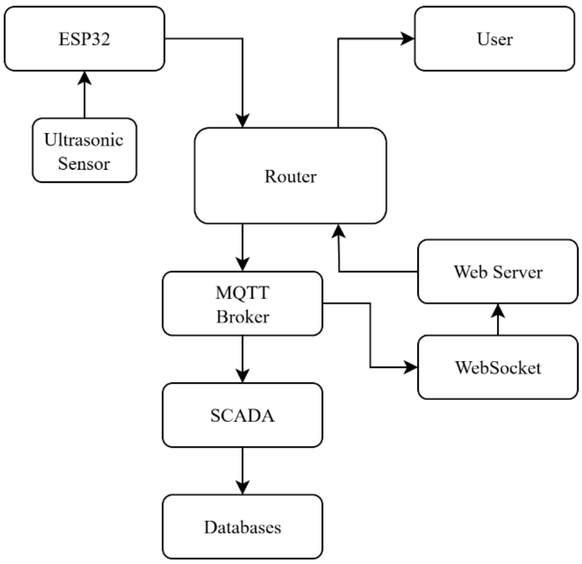

Fig. 1: Conceptual workflow of the system overview

This architecture establishes an end-to-end workflow. When a vehicle detection and data processing is processed the ESP32. Then the result will send through MQTT protocol. And finally, the result has been recorded in database through SCADA-based data management. We use websocket to subscribe the MQTT message and show status on HMI.

3.1.1 Physical Design

This subsection will define the physical architecture of the proposed system. Emphasize the hardware components, their interconnections, and the deployment topology employed for the implementation of this parking detection and communication network.

Each parking node have ultrasonic sensor on the top of parking area to detect the distance between the sensor and the vehicle or ground. Wired a sensor to ESP32, which controls data collection and preprocessing. A router was installed in parking area to able wireless communication and support a Wi-Fi connection. ESP32 will connected to this router. Data transmission from the sensing nodes to the network like Fig. 2 at left side.

The central node, an internal router, is positioned closest to the host PC operating the SCADA platform, MQTT broker, web server, and database services. Wired LAN connect between host PC and internal router to low latency connection and provide communication between the central system and the network like Fig. 2 at right side.

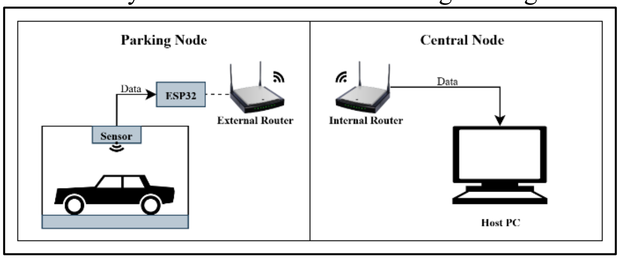

Fig. 2: Conceptual diagram of the physical installation

This network topology make sensing nodes be able to communicate with the external router at the parking area, while the internal router maintains a stable wired link to the central server. Together, these components form the foundation for accurate vehicle detection and transfer a data exchange across the system.

3.1.2 System Architecture

The system architecture and software workflow was explain in this part, emphasizing the processing, transmission, and integration of sensor data with the SCADA platform via the MQTT protocol.

Fig. 3 show process of microcontroller. Which incessantly acquires distance readings from the ultrasonic sensor positioned above the parking space to ascertain the presence of a car. The choice is predicated on a dynamic threshold derived from the physical dimensions of the parking space. The threshold is determined by deducting a constant value of 1.1 meters from the highest slot height recorded from the sensor point to the ground. The value of the 1.1-meter measurement denotes the estimated clearance of the lowest commercially available car, specifically referencing the Lotus Evija, which has a height of 1.122 meters [16]. A distance of 1.1 meters provides an adequate buffer to ensure the recognition of all standard vehicles despite sensor interference and environmental variations. In a typical example, when the sensor is situated 2.5 meters above the ground, the determined threshold is 1.4 meters, derived from 2.5 meters minus 1.1 meters. Thus, any recorded distance under 1.4 meters is classified as occupied, while lengths equal to or greater than this threshold are considered vacant. Following classification, the ESP32 produces two data sets: the unprocessed distance measurement and the derived parking state, with 0 indicating an empty spot and 1 signifying an occupied slot.

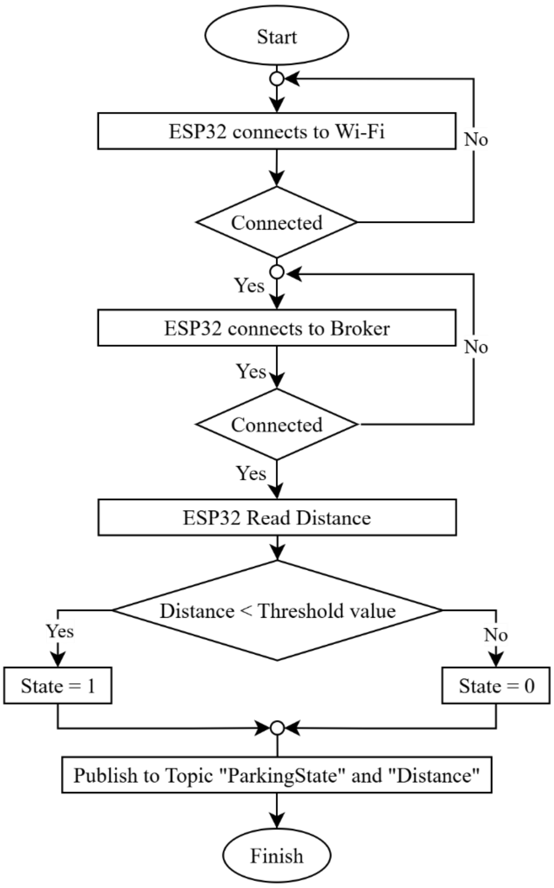

Fig. 3: Process of the ESP32 microcontroller

The data are communicated to the MQTT broker via the MQTT protocol, traversing the external router adjacent to the parking node and directed to the internal network at the central server. The SCADA system at the central node subscribes to both topics, records data to the database, and facilitates centralized monitoring and historical analysis. A completely designed custom web-based HMI subscribes to the parking state topic via a WebSocket connection to the broker, separate from the SCADA platform.

Fig. 4: Human-Machine Interface (HMI) display

From Fig. 4 , HMI focuses on monitoring the status information in real-time through a web interface from the web server. Access derver can check the current status of each slot from anywhere in the world if have internet connection. This design shows operational flow from sensor measurement to the control server and monitor server, ensuring accurate detection, reliable communication, and seamless integration to hardware and software components.

3.2 Testing and Validation of the Design

This section separate the experiment of performance system to verify its functional standards and its reliable operation in conditions at real-world. This testing procedure on two main elements. The accuracy of the ultrasonic sensors detection and latency of communication network in transmitting data from the sensing nodes to the monitoring platforms and SCADA system.

Before describe test design, authors want to explain about detail of parking lot. It consists of 4 parking slots, as shown in Fig. 5. Each slot is monitored by one ultrasonic sensor. Due to the limited cable length of the sensors, one ESP32 microcontroller is used to control two sensors. This setup allows accurate distance measurement for each parking slot while keeping the wiring simple and manageable.

Fig. 5: Real-world installation of the parking system

Experiment was undertaken to verify the accuracy of the ultrasonic sensors by simulating different vehicle heights. Objects were increment distances corresponding to vehicle heights, increasing of 10 centimeters from 0 cm to 200 cm. This range was selected based on automotive reference data. The tallest car recorded was the Hyundai Staria, measuring 1.99 meters in height [16]. This test was repeat ten times at each height level to assure measurement is smooth and correct. This technique allowed accurate verification of the sensor's capability to detect vehicles effectively within the expected operational range, which in real-world scenarios extends from ground level to around 2 meters.

Responsiveness of communication architecture was evaluated to confirm it real-time performance. ESP32 was use to send data packets that have timestamped to MQTT broker at a rate of one message per second. Under standard network conditions. The notifications were subscribe by both SCADA platform and the customized HMI interface. The communication latency was determined from comparisons of timestamps that ESP32 send and timstamp of reception by the SCADA system and HMI. This testing approach confirmed that the system could provide data expeditiously and sustain synchronized changes among the sensing nodes, the central database, and the user interface.

4. Results and Discussion

This part defines the test results of the proposed smart parking system and offers an analysis of the results. The results can be split into two sections: the precision of the ultrasonic sensors and the latency of the communication network. Graphical visualizations of the information collected are provided to show performance and confirm the system's efficacy under simulated operational situations.

4.1 Accuracy of the Ultrasonic sensors

The accuracy measurement was performed with objects inserted at increments ranging from 0 cm to 200 cm in 10 cm intervals to represent different vehicle roof heights. Fig. 6 displays the compare between the actual heights and the measurements obtained through the ultrasonic sensor.

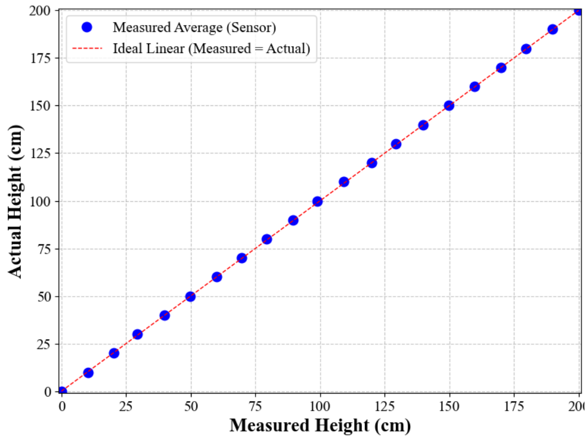

Fig. 6: Comparison of measured and actual heights

Results show sensor value is closely to the reference line that represent perfect value. In other words, it show minimum error measured range. A quantitative study indicates an average error of roughly 0.57%. This precision indicates that the sensor can detect vehicle heights up to about 2 meters. The error of about 0.57% comes from normal limits of ultrasonic sensors. The speed of sound in air can change with temperature and humidity, which affects the measurement. Also, if the vehicle surface is not flat or not straight to the sensor, the echo signal may be weaker. The sensor itself also has a small accuracy limit and a short blind zone. Even though filtering was used, these natural conditions still cause of error.

4.2 Response Time

Figure 7 summarizes the results. This shows the distribution of response times of SCADA system data received from ESP32. Graph explain the time taken for data use to transfer from ESP32 to SCADA system when the data is successfully received.

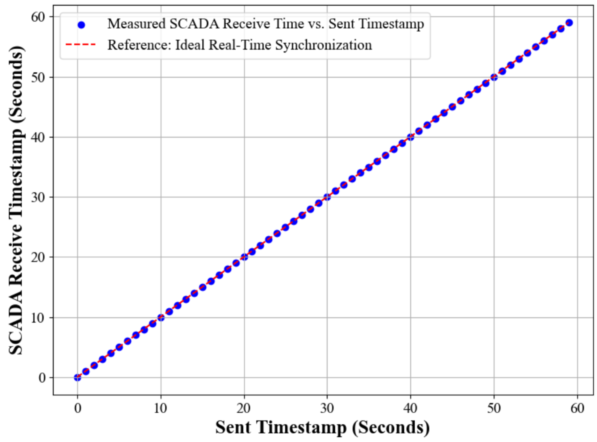

Fig. 7: SCADA data transmission response time distribution

From the graph, the response times is still less than one second, demonstrating SCADA system processing data in near real-time. In industrial and automation environments. Performance on this level must be perfect for effective monitoring and control to ensure timely and accurate system feedback.

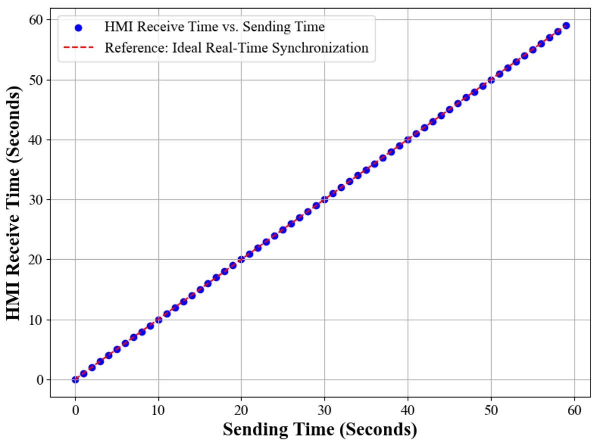

Fig. 8: HMI data transmission response time distribution

Fig. 8 demonstrates the distribution of responses for data collection from the ESP32 through HMI interface. Response time explain duration between the timestamp transmitted from the ESP32 and its subsequent reception and processing by the HMI system. The data suggests that HMI can provide near real-time transmission, as most reaction times are under one second.

5. Discussion

During the analysis of reaction times of SCADA and HMI, data transmission latency most stayed under one second. That alone is important. ESP32 and monitoring system operate easily together and can handle real-world situations without complications. In a smart parking system, low latency is important.

Following the comparison of the sensor readings with the actual distances, all of them corresponded closely with the likely values. Several values differed marginally, although nothing unexpected occurred, and the overall curve remained mainly linear. This develops confidence; the sensor and data processing appear to be accurate to detect vehicles and assess their distance in this configuration.

The study porpose a prototype of the car parking system. Several facets require improvement before usage. There are many areas for improvement. Such as system security, fault management, and assuring scalability. Developing data processing and implementing a method for reporting abnormal values could increase the system's long-term stability. The demonstrations prove that this IoT-based parking system is not solely a construct of theory. It functions successfully, and with additional improvements, it might transform into a viable solution. With additional improvements, it is on an effective path of becoming a fully formed solution.

A cloud-based smart parking system combined IoT with cloud servers. It helped drivers find empty parking slot and reduced waiting time. It was tested in a university and worked well. But it needed careful parameter tuning. It also did not fully solve security and large-scale deployment [8].

A fog-computing smart parking system was also proposed. It reduced delay and supported booking and automatic payment. It offered indoor navigation using BLE. It improved user experience. But it required complex BLE installation and had higher cost. It was still under development [9].

The authors propose a better parking system. It uses ESP32, Ultrasonic sensor, MQTT protocal, and RapidSCADA. It provides real-time monitoring and database logging. It does not require cloud or fog servers. It is simple and easy to deploy. It does not include indoor navigation. But it is practical and affordable for small and medium parking areas.

6. Conclusion

This project implemented an IoT-based parking system with ESP32 devices connected to a SCADA platform via the MQTT protocol. Information on parking space occupancy was identified and transmitted nearly at once, minimizing delays. The trials demonstrated that the ultrasonic sensors showed an error margin of approximately 0.57%, and data was transmitted with a delay of under 1 second, therefore supporting the theory that this technology is well-suited for smart parking applications.

The system is primarily a prototype at this stage. Additional efforts are required to go towards implementation. Enhancements are required for system security, network issue management, and scalability for larger parking areas. Additionally, sensor accuracy must improve, additional information processing methods should be developed, and the user interface should be reduced. These measures will be essential to address actual requirements and guarantee satisfaction for users.

7. References

[1] CEIC Data, "Thailand Number of Registered Vehicles," CEIC, 2025. [Online]. Available: https://www.ceicdata.com/en/indicator/thailand/number-of-registered-vehicles. [Accessed: Jul. 26, 2025].

[2] Faheem, F., et al., *A Survey of Intelligent Car Parking System.* Journal of Applied Research and Technology, 2013. **11**(5).

[3] Javaheri, A., et al., *Evaluating the Impact of Smart Parking Systems on Parking Violations.* IEEE Access, 2024. **12**: p. 175585-175596.

[4] Biyik, C., et al. *Smart Parking Systems: Reviewing the Literature, Architecture and Ways Forward*. Smart Cities, 2021. **4**, 623-642 DOI: 10.3390/smartcities4020032.

[5] Channamallu, S.S., et al., *Smart Parking Systems: A Comprehensive Review of Digitalization of Parking Services.* Green Energy and Intelligent Transportation, 2024.

[6] M S, V., S. V, and D. Gnaneswar, Finding the Spot: IoT enabled Smart Parking Technologies for Occupancy Monitoring – A Comprehensive Review. Journal of ISMAC, 2023. **5**: p. 369-384.

[7] Espressif Systems, “ESP32 Wi-Fi & Bluetooth SoC | Espressif Systems,” Espressif Systems. [Online]. Available: https://www.espressif.com/en/products/socs/esp32. [Accessed: 7-Sep-2025].

[8] Pham, T.N., et al., A Cloud-Based Smart-Parking System Based on Internet-of-Things Technologies. IEEE Access, 2015. **3**: p. 1581-1591.

[9] Pham, T.N., D.T. Mai, and X.K. Pham, Smart Parking Services: An Overall Solution Based on Internet of Things and Fog Computing. IEEE Access, 2023. **11**: p. 112929-112939.

[10] Alam, M.R., et al., A Survey on IoT Driven Smart Parking Management System: Approaches, Limitations and Future Research Agenda. IEEE Access, 2023. **11**: p. 119523-119543.

[11] Lin, T., H. Rivano, and F.L. Mouël, *A Survey of Smart Parking Solutions.* IEEE Transactions on Intelligent Transportation Systems, 2017. **18**(12): p. 3229-3253.

[12] Ke, R., et al., A Smart, Efficient, and Reliable Parking Surveillance System With Edge Artificial Intelligence on IoT Devices. IEEE Transactions on

Intelligent Transportation Systems, 2021. **22**(8): p. 4962-4974.
[13] Lou, L., et al., An IoT-Driven Vehicle Detection Method Based on Multisource Data Fusion Technology for Smart Parking Management System. IEEE Internet of Things Journal, 2020. **7**(11): p. 11020-11029.
[14] Saleem, Y., et al., *IoTRec: The IoT Recommender for Smart Parking System.* IEEE Transactions on Emerging Topics in Computing, 2022. **10**(1): p. 280-296.
[15] "Arduino Distance Measuring Transducer Sensor Model: AJ-SR04M," Fabian. [Online]. Available: https://www.fabian.com.mt/viewer/42586/pdf.pdf. [Accessed: 7-Sep-2025].
[16] Automobiledimension.com, "Car search engine," [Online]. Available: https://www.automobiledimension.com/car-search-engine.php. [Accessed: Aug. 2, 2025].

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