# FPGA-Based Smart Parking and Monitoring System Using Iot Integration

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***Abstract*— In recent years, the rapid increase in the number of vehicles has created serious parking problems in urban areas. Drivers often spend a lot of time searching for available parking spaces, which leads to traffic congestion, fuel wastage, and frustration. Traditional parking systems are mostly manual and do not provide real-time information, making them inefficient and difficult to manage for large parking areas.**

**To solve these issues, this paper presents a smart parking system based on FPGA and IoT technology. In this system, IR sensors are used to detect whether a parking spot is occupied or free, and ultrasonic sensors are used to monitor vehicle entry and exit. The FPGA processes all sensor data simultaneously, which helps in achieving faster and more accurate results compared to conventional systems.**

**A servo motor is used to control the parking gate automatically, and an LCD display shows the number of available parking slots. An ESP32 module is used to send real-time data to the cloud, allowing users to check parking availability through a mobile or web application. The system is implemented and tested using a DE10 FPGA board.**

**The results show that the proposed system provides faster response, bet- ter accuracy, and improved efficiency, making it suitable for modern smart parking applications.**

***Index Terms*— FPGA, Smart Parking, IoT, ESP32, Sensors, Cloud Monitoring**

## I. INTRODUCTION

In recent years, the rapid growth in urban population and the increasing number of vehicles have created serious challenges in parking management. Finding a vacant parking slot has become a time-consuming task for drivers, especially in busy cities. This problem leads to traffic congestion, increased fuel consumption, and environmental pollution [20, 30]. As a result, there is a strong need for efficient and automated parking management systems.

Traditional parking systems mainly depend on manual monitoring and lack real-time information sharing. These systems are often inefficient, error- prone, and not suitable for large-scale parking areas. To overcome these lim- itations, several smart parking solutions based on Internet of Things (IoT) and embedded systems have been proposed [16, 18]. These systems use sen- sors and communication technologies to monitor parking slots and provide information to users.

Most of the existing smart parking systems are developed using microcon- trollers such as Arduino or single-board computers like Raspberry Pi [1, 2]. Although these systems are simple and low-cost, they suffer from limited processing capability, especially when handling multiple sensors simultane- ously. This results in slower response time and reduced system performance in large parking environments.

Field Programmable Gate Arrays (FPGAs) offer a powerful alternative due to their ability to perform parallel processing and handle multiple inputs efficiently [10, 13]. Unlike microcontrollers, FPGAs can process data from several sensors at the same time, which significantly improves speed and accuracy. This makes them highly suitable for real-time applications such as smart parking systems.

In addition to processing speed, integrating IoT technology enables re- mote monitoring and control of parking systems. By using wireless modules such as ESP32, parking data can be uploaded to cloud platforms, allowing users to check slot availability through mobile or web applications [5, 27]. This improves user convenience and supports the development of smart city infrastructure.

Based on these observations, this paper proposes an FPGA-based smart parking system integrated with IoT for real-time monitoring and automation. The main contributions of this work are as follows:

- Design and implementation of a real-time smart parking system using FPGA.
- Parallel processing of multiple sensor inputs for faster and accurate slot detection.
- Integration of IoT for cloud-based remote monitoring.
- Automated gate control using servo motor and real-time display using LCD.

The proposed system is implemented on a DE10 FPGA board and vali- dated through hardware testing. The results demonstrate improved perfor- mance compared to conventional microcontroller-based systems.

## II. RELATED WORK

In recent years, several smart parking systems have been developed using IoT and embedded platforms. These systems aim to reduce traffic conges- tion and improve parking efficiency by providing real-time slot availability information.

Pradeep Kumar et al. [1] proposed an Arduino-based smart parking sys- tem using IR sensors and GSM communication. Although the system was cost-effective, it lacked real-time cloud integration and scalability for larger parking areas.

Amit Sharma et al. [2] developed a parking system using Raspberry Pi and ultrasonic sensors. The system provided better processing capability than Arduino-based systems but still faced limitations in handling multiple sensors efficiently in real-time scenarios.

Geng and Cassandras [6] introduced a reservation-based smart parking system that improved resource allocation. However, the system required complex infrastructure and was not suitable for low-cost implementations.

Recent IoT-based solutions [8, 14] have focused on cloud integration and remote monitoring. These systems allow users to check parking availability via mobile applications, but they rely heavily on microcontrollers, which limits their performance in large-scale environments.

Despite these advancements, most existing systems suffer from limited processing speed, reduced scalability, and delayed response time when han- dling multiple sensor inputs simultaneously. This highlights the need for a high-speed and scalable solution, which can be effectively achieved using FPGA-based parallel processing architecture.

Table 1: Comparison of Existing Smart Parking Systems

| System | Platform | Sensors | IoT Sup-port | Performance |
|---|---|---|---|---|
| Kumar et al. | Arduino | IR | GSM | Low |
| Sharma etal. | RaspberryPi | Ultrasonic | Limited | Medium |
| IoT-Based Systems | Microcontrolle | rIsR/Ultrasonic | Yes | Medium |
| Proposed System | FPGA | IR + Ultra-sonic | Yes | High |

### 2.1 Technology Usage Distribution

To better understand the trend in smart parking systems, a pie chart rep- resentation is shown below. It highlights the dominance of microcontroller- based systems compared to FPGA-based approaches.

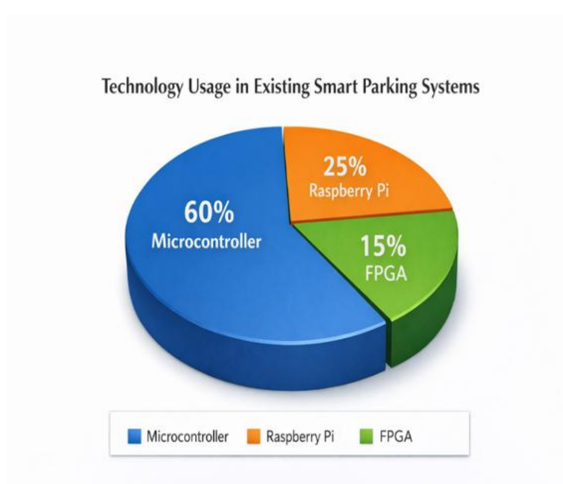


Figure 1: Technology Usage in Existing Smart Parking Systems

## III. PROPOSED SYSTEM

### 3.1 System Overview

The proposed system presents an FPGA-based smart parking architecture designed to provide real-time monitoring and automated control of parking operations. The system integrates multiple hardware components, including IR sensors, ultrasonic sensors, a DE10-Nano FPGA board, a servo motor, an LCD display, and an ESP32 module for IoT connectivity.

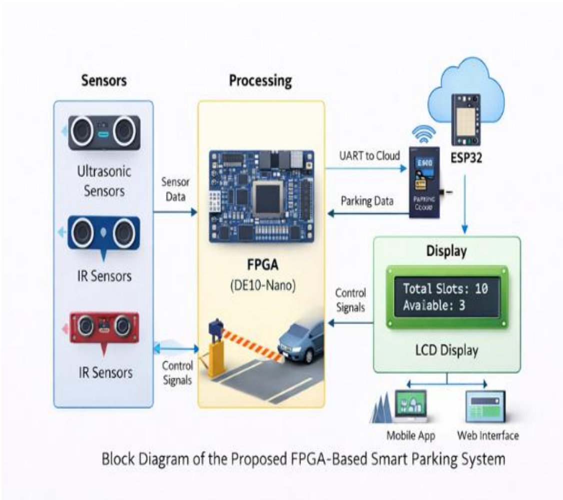


Figure 2: Block Diagram of the Proposed FPGA-Based Smart Parking System

As shown in Fig. 2, the system consists of three major units: sensing, processing, and communication. The sensing unit includes IR sensors for slot detection and ultrasonic sensors for vehicle entry and exit detection. The processing unit is implemented using the FPGA, which performs paral- lel processing of all sensor inputs. The communication unit consists of the ESP32 module, which enables cloud-based data transmission.

### 3.2 Working Mechanism

Entry Detection: When a vehicle arrives at the parking entrance, the system checks the availability of parking slots. If at least one slot is free,the FPGA sends a control signal to the servo motor to open the gate. If no slots are available, the gate remains closed and a "LOT FULL" message is displayed on the LCD.

Slot Monitoring: IR sensors are installed in each parking slot to detect vehicle presence. When a vehicle occupies a slot, the corresponding IR sensor output changes, and the FPGA updates the slot status in real time. Since the FPGA processes all sensor inputs simultaneously, the system achieves high-speed and accurate monitoring.

Gate Control: The servo motor is controlled using PWM signals gen- erated by the FPGA. The gate is automatically opened or closed based on the availability of parking slots and vehicle movement.

Exit Detection: Ultrasonic sensors are used at the exit point to detect vehicles leaving the parking area. Once a vehicle exits, the FPGA updates the corresponding slot status to "Free" and increments the available slot count.

Display System: An LCD display is used to show real-time information such as total slots, available slots, and system messages. This helps drivers quickly identify parking availability.

Cloud Integration: The ESP32 module is used to transmit parking data from the FPGA to a cloud platform using UART communication. This allows users to monitor parking availability remotely through a mobile application or web interface.

### 3.3 Key Advantages of the Proposed System

- Parallel Processing: FPGA processes multiple sensor inputs simul- taneously, reducing latency.
- Real-Time Monitoring: Instant updates of parking slot status.
- Scalability: Can be extended to large parking areas without perfor- mance degradation.
- Automation: Automatic gate control reduces manual intervention.
- IoT Integration: Enables remote monitoring and smart city compat- ibility.

## IV. SOFTWARE REQUIREMENTS

The proposed smart parking system is developed and implemented using a combination of hardware description, embedded programming, and cloud-based tools. The software components used in this work are described as follows:

- Intel Quartus Prime: This software is used for the design, synthesis, and implementation of the FPGA-based system. It provides tools for compiling Verilog code, performing simulation, and generating config- uration files for the DE10-Nano FPGA board.
- Verilog HDL: Verilog Hardware Description Language is used to de- sign the core logic of the

smart parking system. It enables the imple- mentation of parallel processing, sensor interfacing, gate control logic, and communication modules within the FPGA.

- Arduino IDE: The Arduino Integrated Development Environment is used to program the ESP32 module. It provides libraries for Wi-Fi connectivity, serial communication (UART), and cloud data transmis- sion.
- Cloud Platforms (ThingSpeak / Firebase): Cloud platforms are used to store, visualize, and monitor parking data in real time. These platforms allow users to access parking information through web dash- boards or mobile applications.
- UART Communication Protocol: Universal Asynchronous Re- ceiver Transmitter (UART) is used for communication between the FPGA and ESP32 module. It ensures reliable and efficient data trans- fer of parking status and system updates.

## V. RESULTS AND DISCUSSION

The proposed FPGA-based smart parking system was successfully im- plemented and tested using both hardware and software components. The system was validated under different parking scenarios to evaluate its perfor- mance, accuracy, and real-time response capability.

### 5.1 Hardware Implementation

The hardware prototype of the smart parking system is shown in Fig. 3. The setup consists of multiple parking slots equipped with IR sensors for vehicle detection and ultrasonic sensors for entry and exit monitoring. The FPGA (DE10-Nano board) processes all sensor inputs in parallel and controls the servo motor for gate operation. The entire system is interconnected using GPIO interfaces and communication modules.

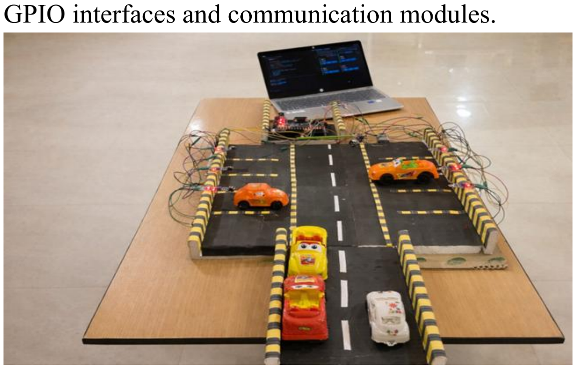

Figure 3: Hardware Prototype of the FPGA-Based Smart Parking System

The hardware results demonstrate that the system accurately detects vehicle presence in each slot and updates the parking status in real time. The use of FPGA ensures fast processing and minimal delay in system response.

### 5.2 Software Interface Results

The software interface for monitoring parking availability is shown in Fig. 4 and Fig. 5. The interface displays the status of each parking slot as either FREE or OCCUPIED.

When all parking slots are free, the system displays availability for all slots. As vehicles occupy the slots, the status is updated dynamically, and the number of available slots is reduced accordingly. This confirms the real- time monitoring capability of the system.

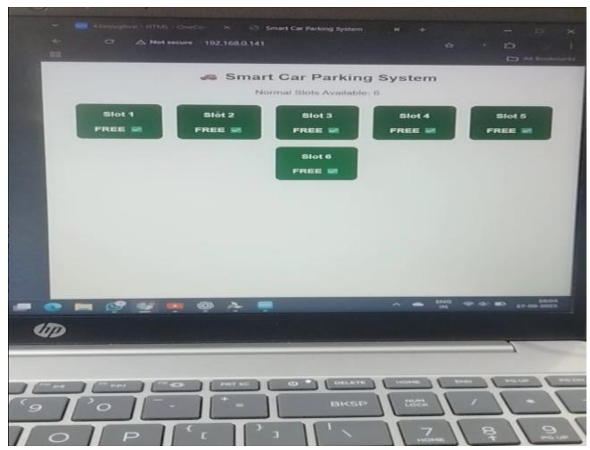


Figure 4: Web Interface Showing All Slots Available

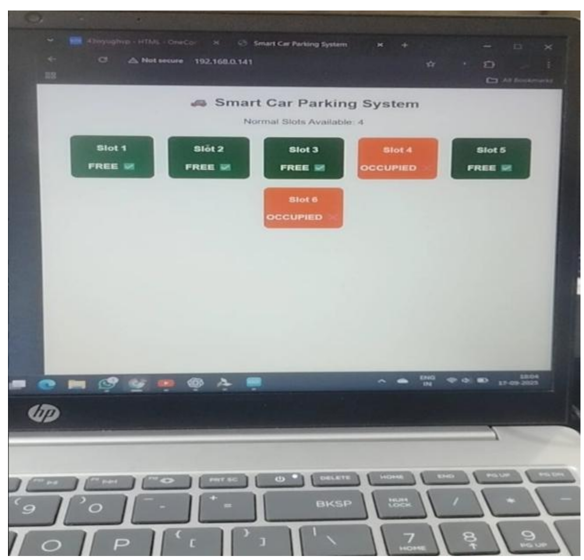


Figure 5: Web Interface Showing Occupied Slots

5.3 Performance Analysis

- The experimental results show that the proposed system provides:
- Fast response time due to FPGA-based parallel processing
- Accurate detection of parking slot occupancy
- Real-time updates through cloud integration
- Reliable operation under different parking conditions
- Compared to traditional microcontroller-based systems, the proposed FPGA- based system demonstrates improved performance in terms of speed, scala- bility, and accuracy.

5.4 Discussion

The integration of FPGA and IoT technologies enables efficient and scal- able parking management. The system reduces manual effort and provides a user-friendly interface for monitoring parking availability. The results con- firm that the proposed system is suitable for real-time smart parking appli- cations in modern urban environments.

## VI. CONCLUSION

In this paper, an FPGA-based smart parking and monitoring system inte- grated with IoT technology has been successfully designed and implemented. The proposed system utilizes IR sensors and ultrasonic sensors for accurate vehicle detection, while the FPGA enables parallel processing of sensor data, resulting in faster response time and improved system efficiency.

The implementation of an automated gate control mechanism using a servo motor and real-time display through an LCD enhances the usability of the system. Furthermore, the integration of the ESP32 module enables cloud connectivity, allowing users to monitor parking availability remotely through web or mobile applications.

The experimental results demonstrate that the proposed system achieves better performance in terms of speed, accuracy, and scalability compared to conventional microcontroller-based parking systems. The system effectively reduces manual effort, minimizes traffic congestion, and improves overall parking management efficiency.

## VII. FUTURE WORK

Although the proposed system provides an efficient solution for smart parking management, several improvements can be considered for future en- hancements:

- Integration of camera-based vehicle detection using computer vision techniques for improved accuracy.
- Implementation of a mobile application with real-time navigation to available parking slots.
- Extension of the system to multi-level parking structures.
- Incorporation of payment systems for automated parking billing.
- Use of machine learning algorithms for predicting parking availability.

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