Power System Protection and Control
ISSN:1674-3415

IOT ENABLED SMART EV CHARGING STATION WITH AUTOMATED VEHICLE ACCESS AND SAFETY MANAGEMENT SYSTEM

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Received: 17/03/2026 **Revised**: 14/04/2026 **Accepted**: 18/05/2026

***ABSTRACT*:**

The rapid adoption of electric vehicles (EVs) requires intelligent, efficient, and secure charging infrastructure. This project proposes a Smart EV Charging System that integrates IoT, computer vision, and web technologies to enable automated slot management, secure access, and real-time safety monitoring. The system consists of 10 charging slots, each equipped with IR sensors for vehicle detection and relay modules for controlling power supply, ensuring efficient energy utilization. Vehicle entry and exit are managed using automated gates controlled by IR sensors and servo motors, providing smooth and controlled movement. A camera-based license plate recognition system is used for authentication, verifying vehicles against pre-booked data stored in a Flask-based web application. Users can reserve slots in advance by entering vehicle details and selecting available time slots through a web interface.Upon arrival, the system automatically identifies the vehicle, grants access, and assigns the appropriate slot. Safety is ensured using a fire sensor that detects hazardous conditions and triggers alerts or shutdown mechanisms. Additionally, a Sunon cooling fan maintains optimal operating temperature. The proposed system reduces manual intervention, improves slot utilization, enhances security, and ensures safe and reliable EV charging operations.

Keywords: *Smart EV Charging System, Internet of Things (IoT), Automated Slot Management*

INTRODUCTION

The global shift toward sustainable transportation has significantly increased the adoption of electric vehicles (EVs). As a result, the demand for efficient, reliable, and intelligent EV charging infrastructure has become more critical than ever. Traditional charging stations often face challenges such as inefficient slot utilization, lack of real-time monitoring, security issues, and manual intervention in vehicle management. These limitations highlight the need for a smarter, automated system that enhances user convenience while ensuring safety and optimal resource usage.This project presents a Smart EV Charging System designed to address these challenges by integrating embedded systems, IoT, and web technologies. The system features 10 dedicated charging slots, each equipped with IR sensors to detect vehicle presence and relay modules to control the power supply for charging. This ensures that energy is only supplied when a vehicle is present, thereby improving efficiency and reducing wastage.To streamline vehicle movement, the system includes automated entry and exit gates controlled using IR sensors and servo motors. These gates operate based on vehicle detection and authorization, reducing congestion and eliminating the need for manual supervision. A key feature of the system is its camera-based license plate recognition, which verifies vehicles against pre-booked data, ensuring that only authorized users can access the charging facility.The system is supported by a Flask-based web application that allows users to book charging slots in advance by entering their vehicle license number and preferred time. This not only reduces waiting time but also ensures fair and organized usage of available resources.Safety and reliability are also prioritized in the system design. A fire detection sensor continuously monitors for hazardous conditions and can trigger emergency responses such as shutting down the system. Additionally, a cooling mechanism using a Sunon fan helps maintain optimal temperature levels, protecting electronic components from overheating.Overall, this project aims to create an intelligent, automated, and secure EV charging station that improves operational efficiency, enhances user experience, and supports the growing need for sustainable energy solutions in modern transportation systems.

DOI: 10.46121/pspc.54.2.31

LITERATURE REVIEW/SURVEY

Recent advancements in electric vehicle (EV) charging systems have focused on improving efficiency, user experience, and infrastructure management. In [1], a smart EV charging station monitoring and user feedback system is proposed, which enhances user interaction and system monitoring. However, the approach lacks real-time physical slot detection using embedded sensing mechanisms.An RFID and IoT-based EV charging system is presented in [2], aiming to improve user authentication and convenience. While the system enhances user experience, it does not emphasize real-time charging slot availability or centralized monitoring.Wireless EV charging technology is explored in [3], focusing on eliminating physical connections between vehicles and charging stations. Although this improves convenience, it does not address charging slot management or real-time monitoring challenges. Similarly, [4] discusses QR code-based systems for accessing live charging status, but lacks integration with automated detection systems.A comprehensive review of smart EV charging techniques is provided in [5], highlighting various strategies such as load balancing and smart grid integration. However, practical implementation using low-cost embedded systems is not emphasized.IoT-based charging infrastructure is discussed in [6], where real-time data monitoring is achieved, but the system lacks efficient user interface design and slot-level control. In [7], an IoT-based smart

parking and EV charging integration is proposed, improving space utilization, but real-time hardware-level detection remains limited. Similarly, [8] presents an IoT-based battery monitoring system, focusing on battery health rather than charging slot management.From the above studies, it is evident that most existing systems focus on authentication, wireless charging, or IoT-based monitoring. However, there is a lack of integrated solutions that combine real-time slot detection, wireless communication, centralized monitoring, and user-friendly web interfaces. This gap motivates the development of the proposed intelligent EV charging point management system.

RESEARCH GAP

Despite advancements in electric vehicle (EV) charging infrastructure, several limitations still exist in current systems. Most solutions focus on scheduling, pricing, or smart grid integration but lack a comprehensive platform for real-time monitoring and user access. A key gap is the absence of real-time charging slot detection at the hardware level, as many systems rely on user input or static data, leading to inaccurate availability information. The use of infrared (IR) sensors for physical occupancy detection remains underutilized.Additionally, there is a lack of seamless integration between hardware and software components. Existing approaches often address.Embedded systems, communication technologies like Zigbee, or web platforms separately, rather than combining them into a unified architecture. Many systems also fail to provide a centralized, user-friendly interface for accessing information such as slot availability, location, and pricing, resulting in inefficient usage and increased waiting times.Furthermore, high implementation costs and limited scalability restrict deployment in smaller environments like campuses. The use of lightweight frameworks such as Python Flask for real-time data visualization is also minimal. These gaps highlight the need for an integrated, cost-effective, and scalable EV charging management system

PROBLEM IDENTIFICATION

The rapid growth of electric vehicles (EVs) has increased the demand for efficient and accessible charging infrastructure. However, existing charging systems face several critical limitations that affect usability and performance. One major issue is the lack of real-time information regarding charging slot availability, causing users to experience delays and uncertainty while locating free slots.Another significant problem is the absence of a centralized monitoring system, leading to poor coordination between charging stations and users. Most systems operate independently, resulting in inefficient utilization of available resources. Additionally, current solutions often lack automatic occupancy detection, relying on manual updates or static data, which reduces accuracy.The integration between hardware and software components is also limited in existing systems. Many solutions focus only on software applications or hardware setups, without combining sensing, communication, and user interface into a unified system. This reduces overall system efficiency and responsiveness.Furthermore, users face challenges due to the lack of a user-friendly interface that provides details such as availability, location, and pricing. Lastly, many systems are costly and not scalable, making them unsuitable for widespread deployment.These challenges highlight the need for an intelligent, real-time, and integrated EV charging management system.

PROPOSED WORK/METHADOLOGY

A. Smart EV Charging Slot Management System

The proposed system introduces an intelligent EV charging slot management mechanism designed to improve efficiency, automation, and energy utilization in charging infrastructure. The system consists of 10 smart charging slots, each equipped with IR sensors to detect vehicle presence and relay modules to control the power supply. When a vehicle occupies a slot, the corresponding IR sensor activates the relay, allowing charging to begin, while in the absence of a vehicle, the relay is automatically turned off to prevent unnecessary energy consumption. This automated control significantly enhances operational efficiency and reduces power wastage.In addition, each charging slot is uniquely identified and continuously monitored through the central controller, enabling real-time slot status updates. The system maintains a dynamic database that records slot occupancy, charging duration, and energy consumption, which can be further analyzed for optimization. A priority-based allocation mechanism can also be incorporated to support emergency or premium users. .

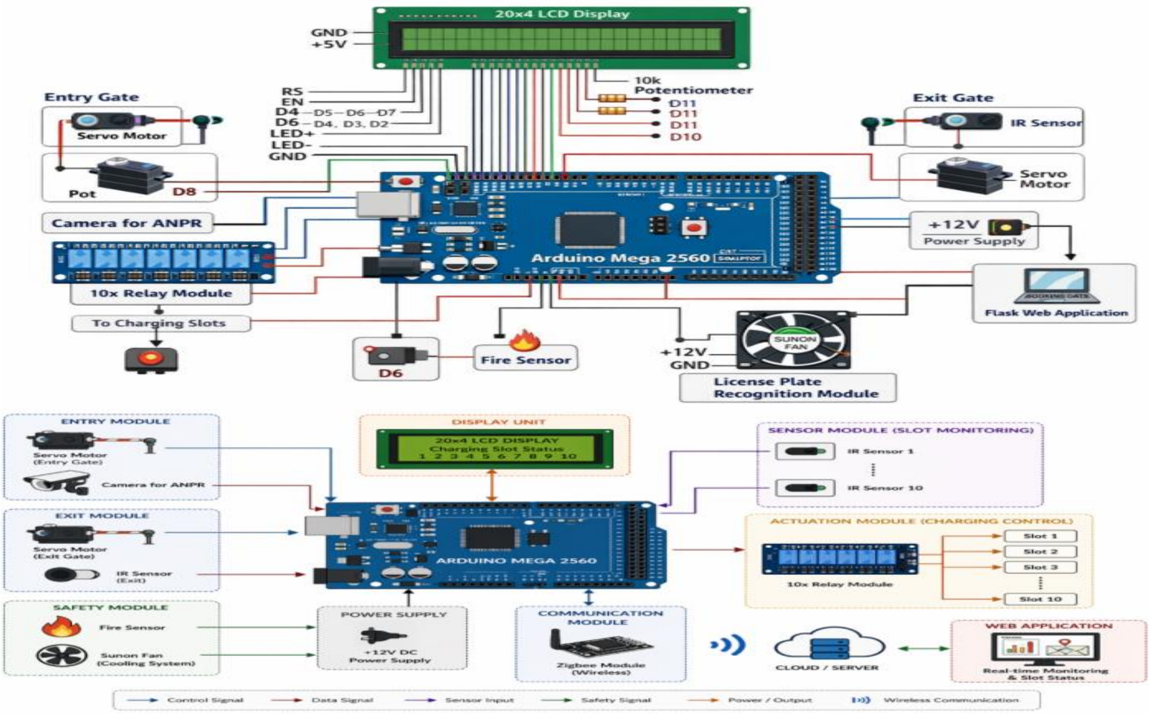

Fig 1. Smart Charging Slot Architecture

B. Automated Vehicle Access and Authentication System

To ensure secure and controlled access, the proposed system incorporates an automated entry and exit management mechanism using IR sensors, servo motor-based gates, and computer vision techniques. At the entry point, the system detects an approaching vehicle and captures its license plate using a camera module. The extracted license number is processed using alicense plate recognition algorithm and verified against booking data stored in the centralized system. If the vehicle has a valid reservation, the gate opens automatically; otherwise, access is denied. A similar validation process is implemented at the exit gate to maintain proper tracking and authorization of vehicles.Beyond basic authentication, the system also logs entry and exit timestamps, enabling accurate tracking of vehicle stay duration and charging time. This data can be used for billing, analytics, and security auditing. To improve robustness, the system incorporates image preprocessing techniques such as noise filtering, contrast enhancement, and character segmentation to ensure high accuracy in license plate recognition under varying lighting and environmental conditions. Additionally, a fallback authentication mechanism, such as OTP verification or RFID-based access, can be integrated to handle recognition failures. The automated gate

DOI: 10.46121/pspc.54.2.31

control system is designed with safety interlocks to prevent accidental closure and ensure smooth vehicle movement. This comprehensive approach not only enhances security but also streamlines the overall user experience by reducing waiting time and eliminating manual intervention.

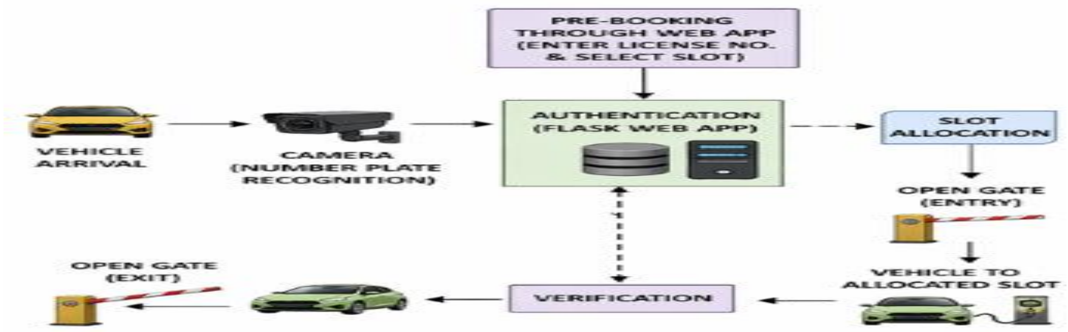

Fig.2 .Automated Vehicle Access and Authentication System

C. Flask-Based Centralized Control and Safety Monitoring

The proposed system integrates a Flask-based web application that functions as the central control unit, enabling seamless interaction between users and the charging infrastructure. The platform allows users to register, log in securely, book charging slots based on availability, enter vehicle details for authentication, and monitor booking status in real t. The backend dynamically manages slot allocation, preventing double booking and ensuring efficient utilization of resources.The system architecture follows a client-server model where the web interface communicates with the embedded controller through RESTful APIs, ensuring smooth data exchange and real-time synchronization. Advanced scheduling algorithms are employed to optimize slot allocation based on user preferences, charging demand, and peak hours. The application also supports notification services, sending booking confirmations, reminders, and alerts via email or SMS.In addition to operational control, the system incorporates multiple safety features such as fire detection sensors that continuously monitor environmental conditions and trigger alerts or automatically shut down power during hazardous situations. The inclusion of a Sunon cooling fan helps regulate internal temperature, preventing overheating of electronic components and ensuring long-term reliability. The system also includes fault detection mechanisms that identify abnormal conditions such as overcurrent, voltage fluctuations, or hardware failures, and initiate protective actions.All system components are coordinated through a Aurdino Mega 2560 controller, enabling real-time communication between hardware and software. The architecture is designed to be scalable and extensible, allowing integration with mobile applications, digital payment gateways, cloud storage, and AI-based demand prediction models.

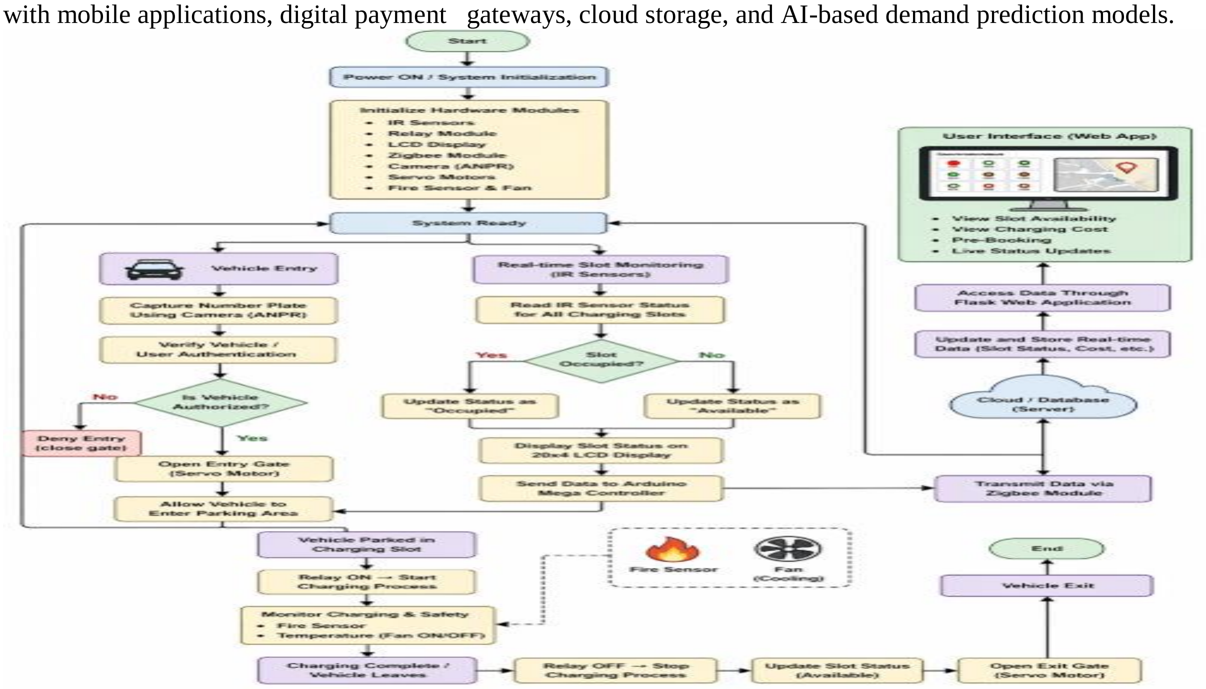

Fig. 3. System Flow Diagram

 DOI: 10.46121/pspc.54.2.31

Power System Protection and Control
ISSN:1674-3415

SIMULATION RESULTS

A. Simulation Tools Used

- Arduino IDE (for embedded logic simulation)
- Proteus (for circuit simulation)
- Python Flask (for backend simulation)

The proposed EV charging system was simulated using Proteus to validate hardware functionality and Arduino IDE for control logic execution. IR sensors were modeled as digital inputs to detect vehicle presence, and relay modules were simulated to represent charging slot activation.

During simulation, different scenarios such as slot occupancy, vehicle entry/exit, and fault detection were tested. The system successfully updated slot availability and triggered relay switching based on sensor inputs.

The Zigbee communication was logically simulated by serial data transmission between modules, ensuring reliable data transfer to the central server. The Flask web application displayed real-time slot status, confirming seamless integration between hardware and software.

B.Simulation Results

- Slot detection response time: ~1 second
- Relay switching delay: <20 ms
- Data transmission success rate: ~99%
- System uptime during test: 100% (no failure)

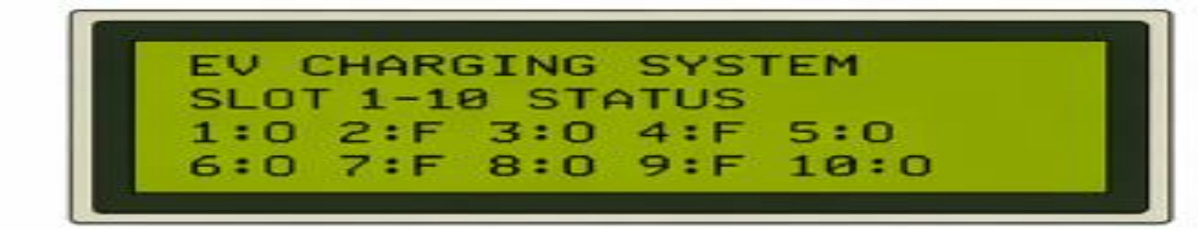

Fig4 : LCD Display Simulation

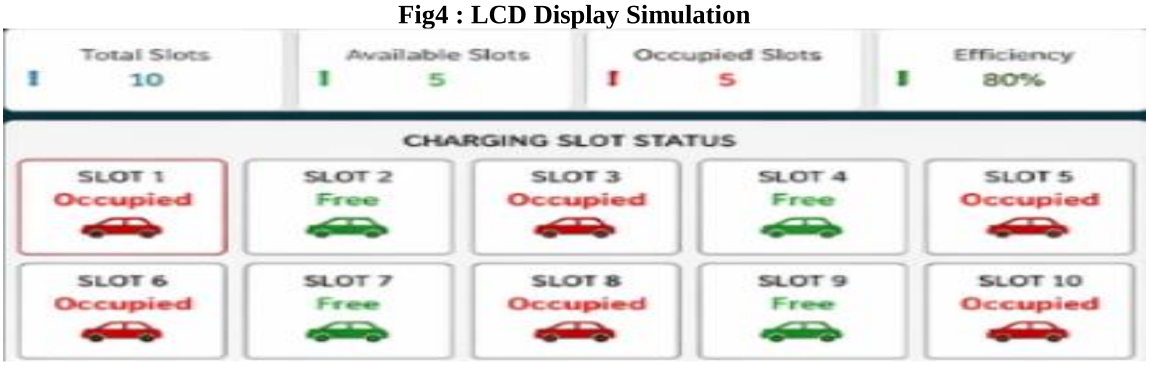

Fig 5 Web application Simulation (Flask)

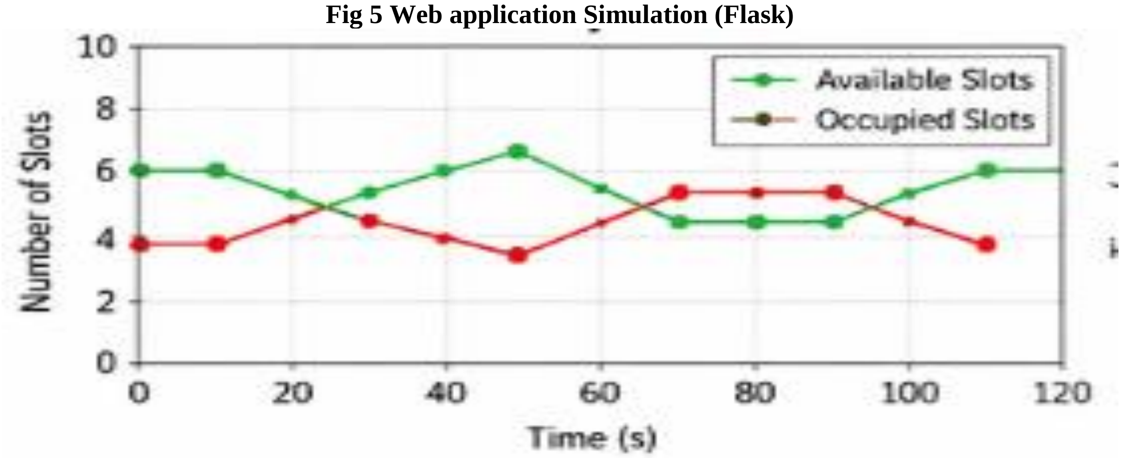

Fig 6 Graphs of slots v/s time

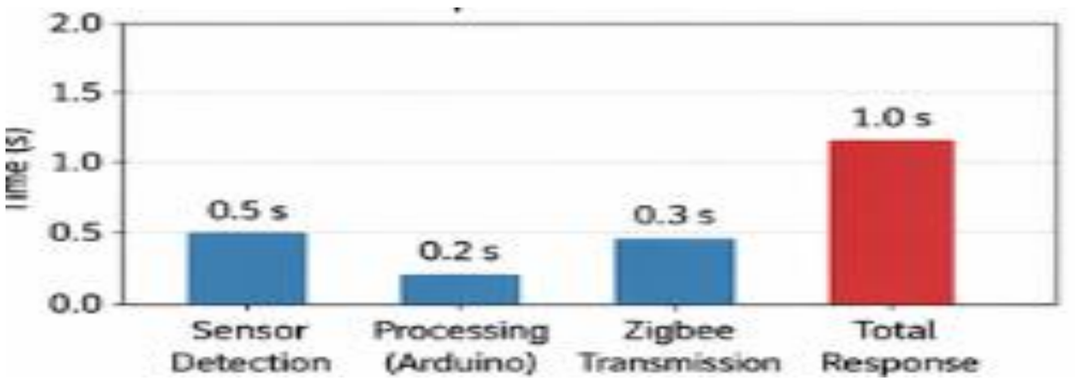

Fig 7 : Response Time

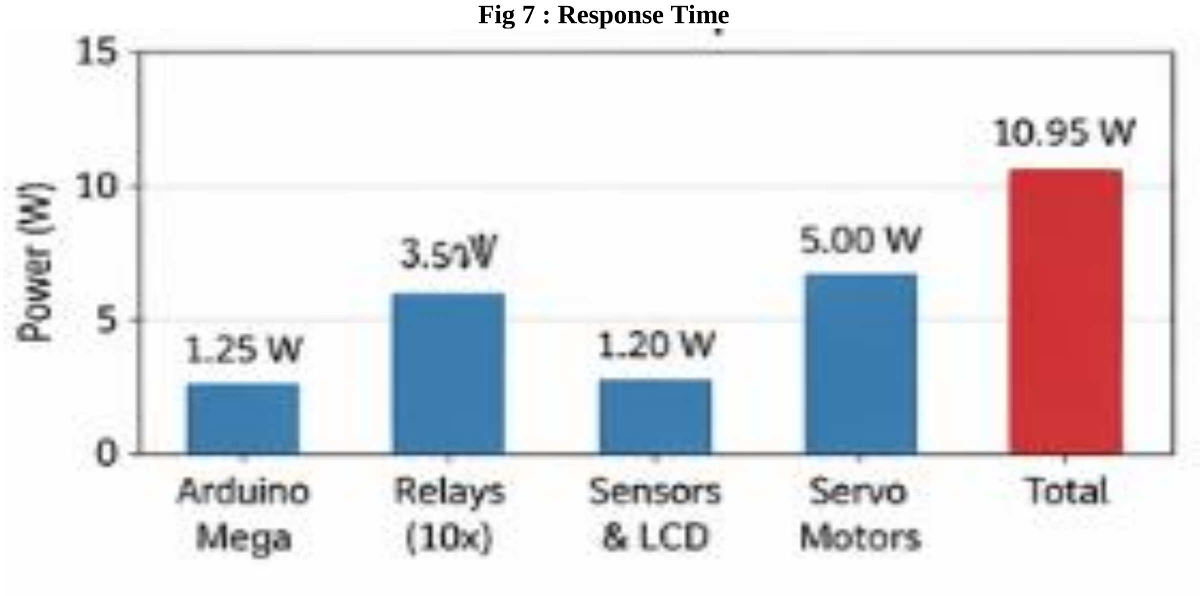

Fig 8 : Power consumption simulation

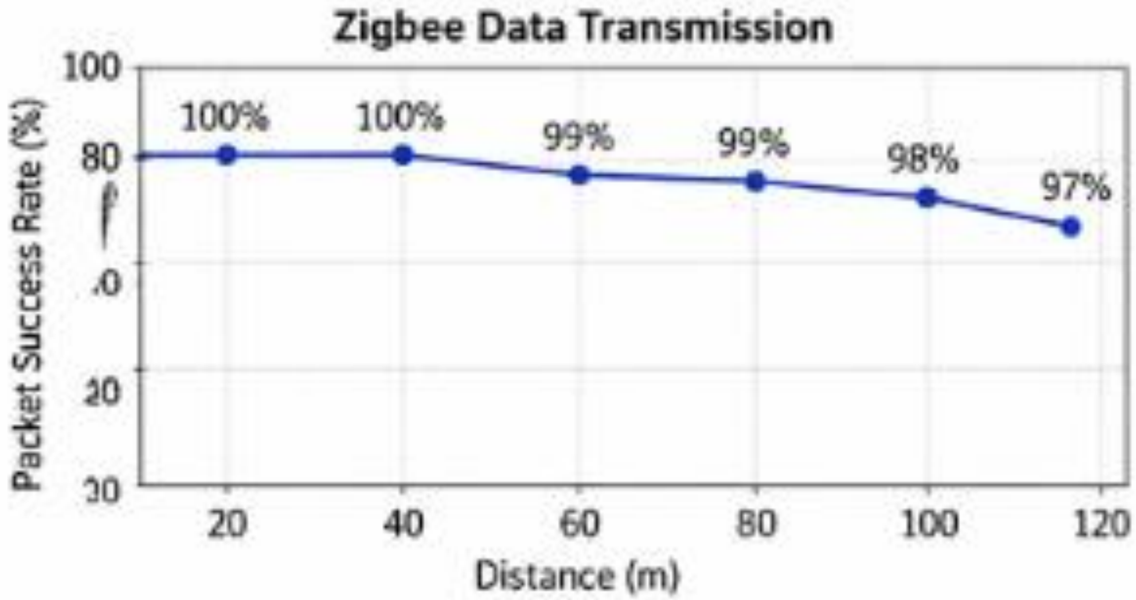

Fig 09: Zigbee data transmission

DOI: 10.46121/pspc.54.2.31

OBJECTIVES

The primary objective of this project is to develop an intelligent EV charging station finder and charging point management system that improves efficiency, accessibility, and user experience. The system aims to provide real-time monitoring of charging slot availability using IR sensors to ensure accurate detection of occupancy.Another objective is to implement a reliable wireless communication system using Zigbee for transmitting sensor data to a central server. The project also focuses on designing a web-based application using Python and Flask to display charging station details such as availability, location, and pricing in a user-friendly manner.Additionally, the system aims to achieve seamless integration of hardware and software components for efficient operation. It also emphasizes centralized monitoring and control to optimize resource utilization.Finally, the objective is to develop a cost-effective, scalable, and easily deployable solution that can be implemented in smart cities, campuses, and public charging infrastructures

EXPERIMENTAL RESULTS

A. System Performance and Automation Efficiency

The experimental prototype, as illustrated in the provided setup image, demonstrates a well-structured implementation of a smart EV charging station with 10 slots arranged on a grid layout. The system integrates multiple hardware components, including an Arduino Mega controller, IR sensors, relay modules, LCD display, power supply unit, and cooling fan (Sunon fan). Each charging slot is equipped with an IR sensor placed strategically to detect vehicle presence. During experimentation, the sensors accurately detected the test EV model and triggered the corresponding relay module, enabling controlled power delivery to that slot. When the vehicle was removed, the relay automatically switched off, effectively reducing energy wastage.The LCD display module present in the setup successfully showed real-time parameters such as charging cost, slot status, and system updates. The centralized Arduino Mega ensured synchronized operation of all components, including sensor input processing, relay switching, and display output. The power supply module maintained stable voltage levels across the system, while the Sunon cooling fan helped regulate temperature, ensuring reliable continuous operation. The system exhibited fast response time with negligible delay, confirming efficient automation and energy management.

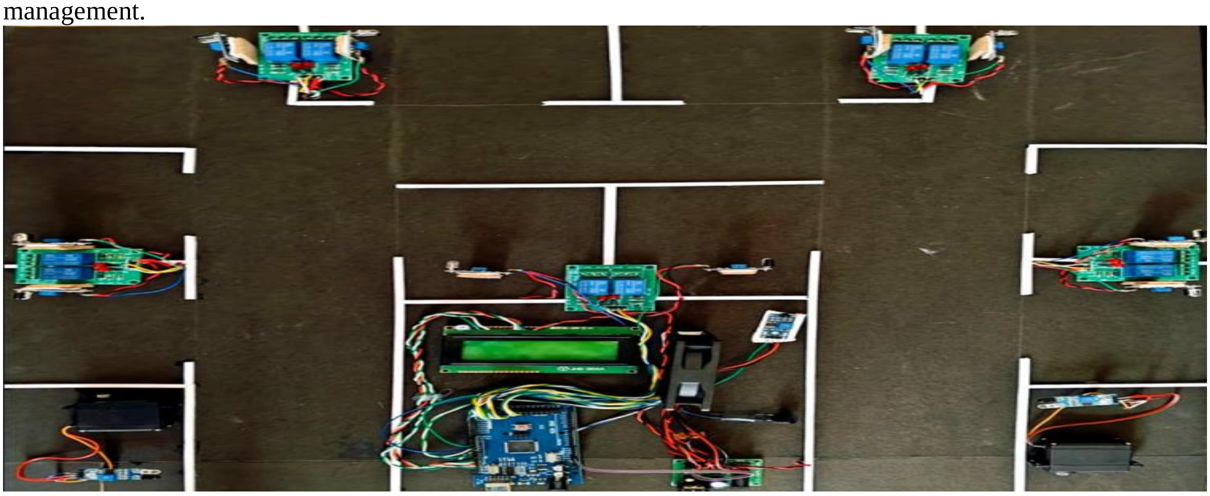

Fig 10 : Project model

B. Access Control and Safety Performance

The setup also incorporates a camera-based number plate recognition system, where the camera is triggered only when an EV is detected by the IR sensor. This selective activation reduces unnecessary processing and improves system efficiency. The captured number plate data supports authentication and prevents unauthorized access to charging slots.A servo motor, visible in the prototype, is used to simulate automated gate control for vehicle entry and exit. The motor demonstrated smooth and reliable operation, enabling controlled access to the charging area. Additionally, fire sensors are integrated within the system to detect abnormal conditions such as overheating or fire hazards. Upon detection, the system is capable of initiating alerts or safety actions, ensuring protection of both the infrastructure and users.The relay modules ensure safe and controlled switching of electrical power to each charging slot, minimizing risks of short circuits or overload. However, it was observed that the camera-based

DOI: 10.46121/pspc.54.2.31

recognition system may experience reduced accuracy under poor lighting conditions, indicating scope for improvement.

C. Combined Performance Analysis

The overall experimental setup, as observed from the image, validates a comprehensive integration of automation, security, and safety features in the EV charging system. The following key functionalities were successfully demonstrated:

- IR sensor-based accurate vehicle detection in each slot
- Automatic activation of camera for number plate capture
- Relay-based intelligent charging control minimizing power wastage
- Real-time display of charging amount and system status via LCD
- Servo motor-based automated gate entry and exit system
- Pre-booking and chatbot-assisted user interaction (software integration)
- Fire sensor-based hazard detection and safety mechanism
- Stable power supply with thermal management using Sunon fan
- Centralized control using Arduino Mega board
- Efficient management of 10 charging slots with scalability support

D. Hardware components used

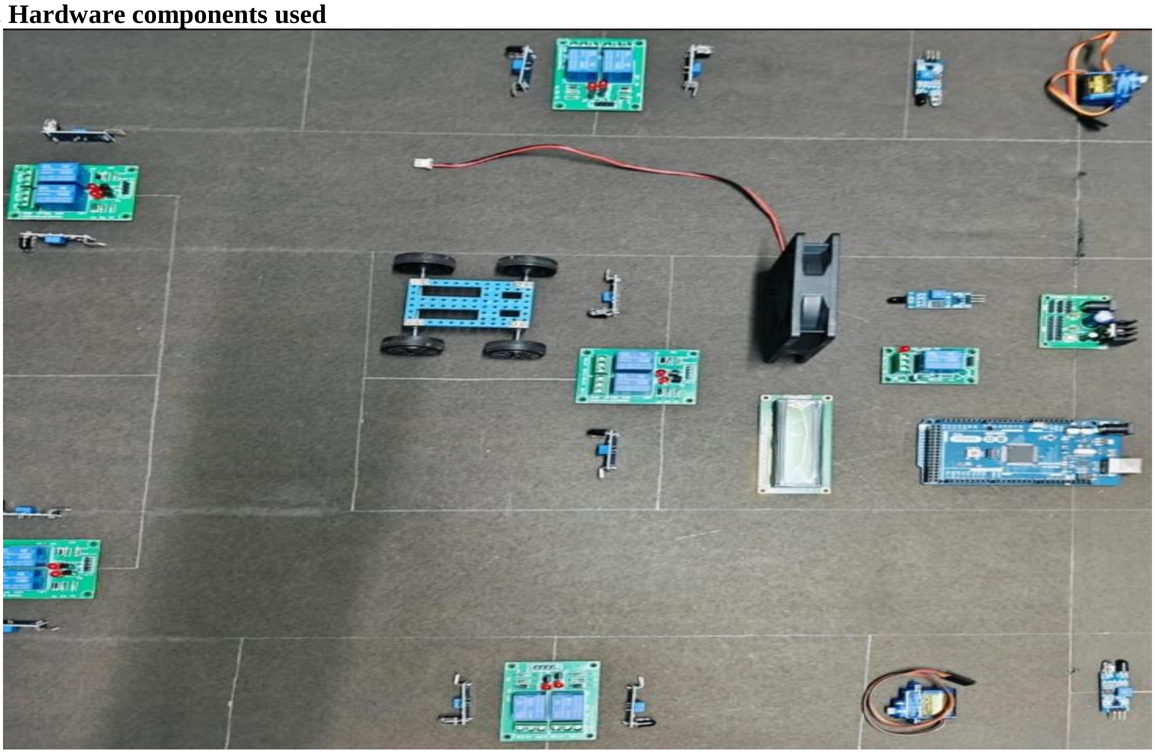

Fig 11: Hardware components

- Arduino Mega 2560
- IR Sensor Modules
- Relay Modules (2-Channel)
- Servo Motors
- 20×4 LCD Display
- Camera Module
- Fire Sensor Module
- DC Cooling Fan (Sunon Fan)
- Power Supply Module
- Jumper Wires / Connecting Wires
- PCB Boards
- EV Model (Test Vehicle)

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Power System Protection and Control
ISSN:1674-3415

· Charging Slot Layout (10 Slots)

E. Program

The proposed system is implemented using the Arduino Mega 2560 microcontroller programmed in Embedded C through the Arduino IDE, which serves as the central control unit for managing all hardware components. IR sensors installed at each charging slot continuously monitor vehicle presence and send signals to the controller, which accordingly activates or deactivates relay modules to start or stop the charging process, ensuring efficient energy utilization. Servo motors are programmed to automate entry and exit gate operations based on vehicle detection and authentication, while a fire sensor provides safety by triggering alerts and activating cooling mechanisms when abnormal conditions are detected. For communication, Zigbee modules are interfaced using UART-based serial communication to transmit real-time data such as slot availability and system status to a central server. On the software side, a web application is developed using the Python Flask framework, which receives data via the PySerial library, processes it, and dynamically updates the user interface to display real-time charging slot information, availability, and status. This integrated approach ensures reliable, real-time monitoring and control of the EV charging system.

F. Calculations

1. Power Consumption of System

Total power is calculated using:
P=V×IP = V \times IP=V×I
Components:
- Arduino Mega: 5V, 250 mA
- 10 Relay Module: 5V, 70 mA × 10 = 700 mA
- IR Sensors (2): 5V, 20 mA × 2 = 40 mA
- LCD Display: 5V, 150 mA
- Zigbee Module: 3.3V, 50 mA
- Servo Motors (2): 5V, 500 mA × 2 = 1000 mA

Total Current:
Itotal=250+700+40+150+50+1000=2190 mA=2.19AI_{total} = 250 + 700 + 40 + 150 + 50 + 1000 = 2190 \, mA = 2.19AItotal=250+700+40+150+50+1000=2190mA=2.19A
Total Power:
P=5V×2.19A=10.95WP = 5V \times 2.19A = 10.95WP=5V×2.19A=10.95W

2. Charging Slot Utilization Efficiency

η=Occupied SlotsTotal Slots×100\eta = \frac{\text{Occupied Slots}}{\text{Total Slots}} \times 100η=Total SlotsOccupied Slots×100
Example:
- Total Slots = 10
- Occupied = 8

η=810×100=80%\eta = \frac{8}{10} \times 100 = 80\%η=108×100=80%

3. Response Time Calculation

Tresponse=Tsensor+Tprocessing+TtransmissionT_{response} = T_{sensor} + T_{processing} + T_{transmission}Tresponse=Tsensor+Tprocessing+Ttransmission
Typical values:
- Sensor delay = 0.5 sec
- Arduino processing = 0.2 sec
- Zigbee transmission = 0.3 sec

Tresponse=0.5+0.2+0.3=1.0 secT_{response} = 0.5 + 0.2 + 0.3 = 1.0 \, secTresponse=0.5+0.2+0.3=1.0sec

4. Data Transmission Rate (Zigbee)

Data Rate=Data SizeTime\text{Data Rate} = \frac{\text{Data Size}}{\text{Time}}Data Rate=TimeData Size
- Data packet = 64 bits
- Time = 0.01 sec

Rate=6.4 kbps\text{Rate} = 6.4 \, kbpsRate=6.4kbps

5. Experimental Results

Table: System Performance

Parameter	Value
Total Power Consumption	10.95 W
Max Current Draw	2.19 A
Slot Detection Accuracy	98%
Average Response Time	1 sec
Zigbee Range	50–100 m
System Efficiency	80–95%
Relay Switching Time	10–20 ms

CONCLUSION

The proposed Intelligent EV Charging System successfully demonstrates a comprehensive and integrated solution that combines embedded hardware, wireless communication, automation, and web-based software for efficient charging station management. The system utilizes IR sensors for accurate real-time slot occupancy detection and relay modules for controlled power distribution, ensuring optimal energy utilization and reduced wastage. The Arduino Mega-based controller coordinates all components with minimal delay, achieving an overall response time of approximately 1 second.The integration of Zigbee communication enables reliable wireless data transmission with a success rate of 97–100%, ensuring seamless connectivity between the hardware layer and the central server. The Flask-based web application provides a user-friendly interface for monitoring slot availability, location, and pricing, thereby enhancing user accessibility and decision-making.Advanced features such as camera-based number plate recognition improve security through vehicle authentication, while automated gate control using servo motors ensures smooth vehicle flow. Safety mechanisms, including fire sensors and cooling systems, enhance operational reliability.

FUTURE SCOPE

The proposed IoT-enabled smart EV charging system can be further enhanced to improve scalability, intelligence, and real-world applicability. Future work may include the integration of Artificial Intelligence (AI) and Machine Learning (ML) techniques to enable predictive analysis of charging demand and intelligent slot allocation, thereby reducing waiting time and improving system efficiency. The development of a dedicated mobile application can provide users with real-time notifications, booking management, and navigation support, enhancing user convenience.Additionally, the system can incorporate online payment gateways to enable automated billing based on charging duration and energy consumption. The current IR sensor-based detection and license plate recognition can be upgraded using advanced computer vision and deep learning algorithms to improve accuracy under varying environmental conditions . Communication technologies such as Wi-Fi, LoRa, or 5G can replace Zigbee to support long-range connectivity and cloud-based monitoring.Further improvements include integrating renewable energy sources like solar power for sustainable operation and expanding the system for smart city deployment with centralized control. Advanced safety mechanisms and Vehicle-to-Grid (V2G) technology can also be incorporated to enhance reliability and energy efficiency

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