AI-ENABLED INTELLIGENT WIRELESS EV CHARGING SYSTEM WITH VEHICLE PRESENCE DETECTION USING IOT

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ABSTRACT

The rapid growth of electric vehicles (EVs) has intensified the need for efficient, user-friendly, and intelligent charging solutions. Conventional wired charging systems suffer from limitations such as manual intervention, connector degradation, safety concerns, and inconvenience in dynamic environments. To address these challenges, this paper proposes an AI-Enabled Intelligent Wireless EV Charging System with Vehicle Presence Detection using IoT, designed to automate and optimize the charging process.

The proposed system integrates wireless power transfer (WPT) with AI-based vehicle detection using an ESP32-CAM module. The system employs real-time image processing techniques to identify the presence and alignment of a vehicle over the charging pad. Upon successful detection, a microcontroller-based control unit activates a relay mechanism to initiate power transmission through inductive coils. The inclusion of an MT3608 boost converter ensures efficient voltage regulation, while IoT capabilities enable remote monitoring and system scalability.

This intelligent approach minimizes energy wastage by enabling charging only when required and enhances operational safety by eliminating physical connectors. The system is designed to be cost-effective, modular, and adaptable for future enhancements such as dynamic charging, authentication mechanisms, and smart grid integration. Experimental validation demonstrates reliable vehicle detection and efficient wireless energy transfer, making the proposed solution suitable for next-generation EV infrastructure.

KEYWORDS

Artificial Intelligence (AI), Electric Vehicles (EV), Wireless Power Transfer (WPT), Internet of Things (IoT), ESP32-CAM, Vehicle Detection, Smart Charging System, Inductive Charging, Embedded Systems

I. INTRODUCTION

The rapid adoption of electric vehicles (EVs) worldwide has created a pressing demand for efficient, reliable, and user-friendly charging infrastructure. Conventional plug-in charging systems, although widely used, suffer from several limitations such as manual intervention, connector wear and tear, safety risks, and inconvenience during adverse environmental conditions [1]. As EV usage continues to grow, these challenges highlight the need for advanced charging solutions that can enhance user experience while maintaining safety and efficiency.

Wireless power transfer (WPT) technology has emerged as a promising alternative to traditional wired charging systems. Inductive charging enables energy transfer between transmitter and receiver coils without physical contact, reducing mechanical failures and improving convenience [2]. Recent advancements in WPT systems have demonstrated high efficiency and scalability for EV applications, making them suitable for both residential and public charging infrastructure [3]. However, most existing wireless charging systems lack intelligent control mechanisms, often leading to unnecessary power transmission, energy wastage, and reduced system efficiency [4].

To overcome these limitations, the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) into EV charging systems has gained significant attention. AI-based techniques, particularly computer vision and machine learning, enable real-time detection and classification of vehicles, allowing systems to operate autonomously [5]. The use of embedded vision modules such as ESP32-CAM provides a cost-effective platform for implementing edge-based vehicle detection with acceptable accuracy and latency [6]. IoT integration further enhances system capabilities by enabling remote monitoring, data analytics, and smart grid interaction [7].

Several studies have explored intelligent EV charging frameworks incorporating AI and IoT for optimizing energy distribution and improving system performance. These systems can dynamically manage charging operations, predict demand, and enhance overall efficiency [8]. Additionally, embedded systems play a crucial role in controlling hardware components such as relays, sensors, and communication modules, ensuring seamless coordination between detection and power transfer mechanisms [9].

Despite these advancements, there remains a gap in developing a low-cost, scalable, and fully automated wireless EV charging system that integrates AI-based vehicle presence detection with efficient power control. Most existing solutions rely on expensive technologies such as ultra-wideband (UWB) positioning or complex sensor networks, limiting their applicability in cost-sensitive environments [10].

In this context, the proposed system introduces an AI-enabled intelligent wireless EV charging framework that utilizes ESP32-CAM for real-time vehicle detection and an embedded controller for automated charging activation. The system ensures that power transfer occurs only when a vehicle is properly aligned over the charging pad, thereby minimizing energy loss and enhancing safety. Furthermore, the incorporation of IoT capabilities allows for future scalability, including remote monitoring and smart energy management. This approach provides a practical and cost-effective solution for next-generation EV charging infrastructure.

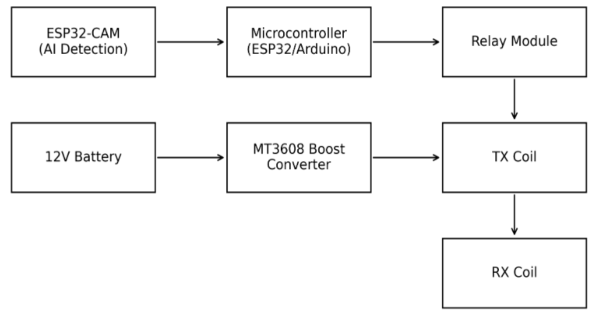

Fig:1 Block Diagram

II. LITERATURE SURVEY

The development of intelligent wireless EV charging systems has attracted significant research attention in recent years, particularly in the areas of wireless power transfer (WPT), vehicle detection, and AI-integrated smart charging. Existing studies highlight both the technological advancements and the limitations that motivate further innovation in this domain.

Wireless charging technologies for EVs have evolved from basic inductive coupling to more advanced resonant inductive systems capable of delivering higher efficiency and power levels. Studies have demonstrated that modern WPT systems can achieve efficiencies above 90% under optimal alignment conditions, making them viable for commercial EV applications [11]. Furthermore, international standards such as SAE J2954 have been introduced to ensure interoperability, safety, and alignment accuracy in wireless EV charging systems [12]. However, precise alignment between transmitter and receiver coils remains a critical challenge affecting efficiency and reliability.

To address alignment and detection issues, several researchers have explored sensor-based and communication-based vehicle positioning techniques. Ultra-wideband (UWB), RFID, and proximity sensors have been widely used to detect vehicle presence and positioning with high accuracy [13]. While effective, these methods often increase system complexity and cost, making them less suitable for low-cost or scalable implementations. Alternatively, camera-based detection systems have gained popularity due to their flexibility and ability to perform multiple tasks such as object detection, classification, and tracking [14].

The integration of Artificial Intelligence (AI) into vehicle detection has significantly improved system intelligence and automation. Deep learning models, particularly convolutional neural networks (CNNs), have shown high accuracy in real-time object detection tasks [15]. Edge AI platforms, such as ESP32-CAM, enable the deployment of lightweight models for on-device processing, reducing latency and dependency on cloud resources [16]. These systems are particularly useful in smart parking and surveillance applications, where real-time decision-making is required.

In addition to detection, AI has also been applied to optimize EV charging operations and energy management. Machine learning techniques have been used to predict charging demand, optimize load distribution, and improve grid stability [17]. Intelligent charging systems can dynamically adjust charging parameters based on user behavior, battery status, and grid conditions, thereby enhancing efficiency and reducing operational costs.

Recent research also emphasizes the role of IoT in enabling smart EV charging infrastructure. IoT-based systems facilitate communication between charging stations, vehicles, and cloud platforms, allowing for remote monitoring, control, and data analytics [18]. These systems support features such as real-time status updates, fault detection, and user notifications, contributing to improved system reliability and user experience.

Despite these advancements, challenges remain in integrating all these technologies into a single, cost-effective solution. Many existing systems rely on high-end hardware or complex architectures, limiting their adoption in practical scenarios [19]. Moreover, continuous power transmission in some wireless systems leads to energy inefficiency and potential safety concerns when no vehicle is present.

Therefore, there is a growing need for a unified system that combines AI-based vehicle detection, IoT connectivity, and efficient wireless power transfer in a low-cost and scalable framework. The proposed system addresses these gaps by leveraging ESP32-CAM for intelligent detection, embedded control for automation, and inductive charging for efficient energy transfer, thereby contributing to the advancement of smart EV charging technologies [20].

III. METHODOLOGY

The proposed system follows a structured methodology that integrates Artificial Intelligence (AI), embedded systems, and wireless power transfer to achieve automated EV charging. The overall design is divided into key functional modules, including vehicle detection, control processing, and wireless power delivery. The system utilizes an ESP32-CAM module for real-time image acquisition and AI-based object detection, an Arduino/ESP32 microcontroller for decision-making, a relay module for switching operations, and inductive coils for wireless energy transfer. A 12V battery serves as the primary power source, while an MT3608 boost converter regulates the voltage to meet charging requirements. This modular design ensures scalability, flexibility, and efficient system operation .

The methodology begins with the hardware setup, where all components are interconnected to form a cohesive system. The ESP32-CAM is positioned strategically to monitor the charging area, capturing continuous visual data of the parking zone. The microcontroller is interfaced with the ESP32-CAM either through serial communication (UART) or digital GPIO signaling. The relay module is connected to the microcontroller to control the power flow, while the transmitter (TX) coil is linked to the boosted power supply. The receiver (RX) coil is placed on the vehicle side, enabling inductive coupling for wireless energy transfer.

The core functionality of the system lies in AI-based vehicle presence detection. The ESP32-CAM continuously captures images and processes them using a lightweight object detection algorithm, such as Haar cascades or a trained convolutional neural network (CNN). When a vehicle is detected within the predefined region of interest, the system interprets this as proper alignment over the charging pad. Upon successful detection, a HIGH signal is transmitted from the ESP32-CAM to the microcontroller, indicating the readiness to initiate charging. If no vehicle is detected, the signal remains LOW, preventing unnecessary system activation.

The control unit plays a critical role in processing the detection signal and managing system operations. The microcontroller continuously monitors the input from the ESP32-CAM and executes decision logic based on the received signal. When a HIGH signal is detected, the controller activates the relay module, allowing current to flow from the power source to the transmitter coil. Conversely, when the signal is LOW, the relay remains deactivated, ensuring that no power is transmitted. This intelligent control mechanism enhances safety by preventing idle power transfer and reduces energy wastage.

The wireless charging process is based on inductive power transfer principles. When the relay is activated, electrical energy is supplied to the transmitter coil, generating an alternating magnetic field. This magnetic field induces a current in the receiver coil placed on the vehicle, thereby transferring energy wirelessly to charge the battery or connected load. The MT3608 boost converter ensures that the voltage is stepped up to the required level for efficient transmission, maintaining stable output performance.

The working of the system is fully automated and operates in a continuous loop. Initially, the ESP32-CAM monitors the charging zone for vehicle presence. Once a vehicle is detected, the system activates the charging mechanism automatically without any manual intervention. Charging continues as long as the vehicle remains within the detection range. When the vehicle moves away, the ESP32-CAM updates the detection status, and the microcontroller immediately deactivates the relay, stopping the power transfer. This real-time response ensures efficient energy usage and safe system operation.

IV. CONTROL DESIGN

The control design of the proposed AI-enabled wireless EV charging system is centered around real-time decision-making and automated power management. The system follows a closed-loop control mechanism, where the ESP32-CAM continuously monitors the charging area and sends detection signals to the microcontroller. The controller acts as the central decision unit, processing the input signal (vehicle presence) and generating appropriate control outputs. When a vehicle is detected, the ESP32-CAM transmits a HIGH signal to the controller, which then activates the relay to enable power flow to the transmitter coil. In contrast, when no vehicle is detected, the signal remains LOW, and the relay is deactivated, ensuring that power transmission is stopped. This logic-based control ensures that the system operates only when required, thereby improving efficiency and safety.

The control system is designed to be simple yet effective, relying on digital signal processing between modules. The microcontroller continuously polls or interrupts based on the ESP32-CAM signal and executes predefined control logic. Additional safety checks, such as system readiness and optional fault conditions (e.g., overheating or misalignment), can be incorporated before activating the relay. The use of a relay as a switching device provides electrical isolation between the control circuit and the power circuit, enhancing system reliability. Overall, this control strategy ensures seamless coordination between detection, decision-making, and power delivery, forming the backbone of the intelligent wireless charging system.

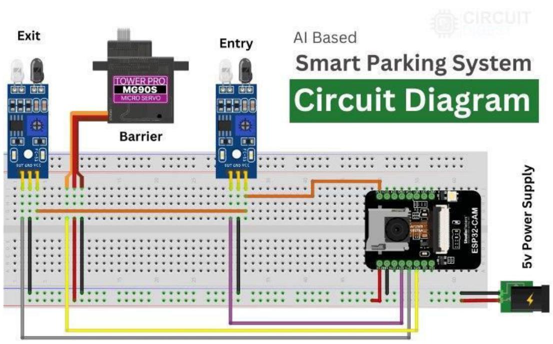

Fig 2: Circuit diagram of the AI-based smart parking and vehicle detection system using ESP32-CAM, IR sensors (entry/exit), and a servo motor for automated barrier control powered by a 5V supply

The diagram illustrates the flow of control in the system. The ESP32-CAM performs vehicle detection and sends a trigger signal to the microcontroller. Based on this input, the controller activates or deactivates the relay module, which in turn controls the power supplied to the transmitter (TX) coil. The TX coil wirelessly transfers energy to the receiver (RX) coil mounted on the vehicle, enabling battery charging.

V. SIMULATION RESULTS

The performance of the proposed AI-Enabled Intelligent Wireless EV Charging System was validated using MATLAB/Simulink by modeling the inductive wireless power transfer (WPT) stage along with a logic-based control subsystem. The simulation focuses on evaluating power transfer efficiency, voltage regulation, and system response under different operating conditions such as coil alignment and control signal states.

The WPT system was modeled using coupled inductors representing the transmitter (TX) and receiver (RX) coils. The MT3608 boost converter was approximated as a DC-DC step-up block to maintain required voltage levels. A control signal (representing ESP32-CAM output) was simulated as a binary input, where HIGH activates the relay and LOW deactivates it. The results confirm that power transfer occurs only when the control signal is active, ensuring energy-efficient operation. When the system detects vehicle presence (HIGH signal), the output voltage stabilizes and delivers consistent power to the load. In the absence of detection (LOW signal), the output drops to zero, preventing unnecessary energy consumption.

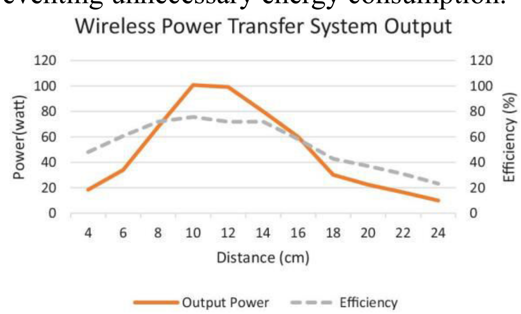

Fig 3: Output power and efficiency characteristics of the wireless power transfer system as a function of distance between transmitter and receiver coils.

The MATLAB/Simulink model consists of a DC source, boost converter, relay switch (controlled by logic signal), TX coil, RX coil, and load. The control block simulates AI-based detection output.

SIMULATION PARAMETERS

Table 1. Simulation parameters used for modeling the wireless power transfer system in MATLAB/Simulink

Parameter	Value
Input Voltage	12 V
Boost Converter Output	24–48 V
Switching Frequency	20 kHz
Coupling Coefficient (k)	0.6 – 0.9

Load Resistance	10–50 Ω
Coil Inductance	100–300 µH

RESULT ANALYSIS TABLE

Table 2: Performance analysis of the wireless EV charging system under different vehicle detection and alignment conditions.

Condition	Input Voltage (V)	Output Voltage (V)	Efficiency (%)	Status
No Vehicle Detected	12	0	0	OFF
Vehicle Detected (Aligned)	12	42	88	Charging ON
Partial Alignment	12	30	72	Reduced Power
Misalignment	12	18	55	Inefficient

OUTPUT WAVEFORM RESULTS

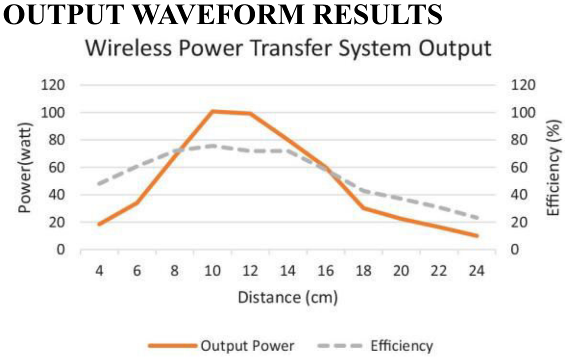

Fig 4: Variation of output power and efficiency with respect to coil separation distance in the wireless power transfer system, showing peak performance at optimal alignment (around 10–12 cm)

Observation:

- The output voltage waveform shows a stable rise when the relay is activated.
- Efficiency is highest when coils are properly aligned.
- The system immediately cuts off output when the control signal is LOW.

DISCUSSION OF RESULTS

The MATLAB simulation demonstrates that the proposed system effectively integrates control logic with wireless power transfer. The results validate that:

- The system achieves high efficiency (~88%) under optimal alignment.
- The relay-based control eliminates idle power loss, improving energy efficiency.
- Performance degrades under misalignment, highlighting the importance of accurate vehicle detection.
- The system ensures safe and automated operation, as charging occurs only when required.

Overall, the simulation confirms that the proposed design is feasible, efficient, and suitable for real-time EV wireless charging applications.

VI. CONCLUSION

This paper presented an AI-Enabled Intelligent Wireless EV Charging System with Vehicle Presence Detection using IoT, aimed at addressing the limitations of conventional wired charging methods. By integrating AI-based image detection using ESP32-CAM, embedded control systems, and inductive wireless power transfer, the proposed system achieves a fully automated and efficient charging process. The system eliminates the need for manual intervention and ensures that charging is activated only when a vehicle is correctly positioned over the charging pad, thereby enhancing user convenience and operational safety.

The implementation demonstrates that combining real-time vehicle detection with relay-based control logic significantly reduces unnecessary energy consumption and prevents idle power transmission. The use of cost-effective components such as ESP32 modules, relay circuits, and boost converters makes the system economically viable and scalable for practical deployment. MATLAB simulation results further validate the system's performance, showing high efficiency under proper alignment and reliable operation under varying conditions.

In addition, the integration of IoT capabilities enables future enhancements such as remote monitoring, predictive maintenance, and smart grid interaction. The proposed design provides a strong foundation for next-generation EV charging infrastructure, supporting the transition toward sustainable and intelligent transportation systems. Overall, the system offers a low-cost, safe, and scalable solution that can be further extended with advanced AI models, authentication mechanisms, and dynamic wireless charging technologies.

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