Wireless Charging System for Electric Vehicles

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***Abstract*—This paper presents the design, implementation, and experimental evaluation of a low-cost, modular wireless charging system for small electric vehicles (EVs) and prototype platforms. The system integrates an Arduino Nano microcontroller, RFID-based authentication for secure access, IR sensors for vehicle alignment, relay-based switching for charging mode control, and a commercially available wireless power transmitter–receiver (WPT) module operating in the kHz range. The architecture emphasizes safety, user authentication, automatic alignment assistance, and power control to prevent overcurrent and ensure efficient energy transfer. We describe hardware selection, firmware logic, communication protocols, and protection mechanisms. A prototype is implemented and tested with 12 V battery packs; results demonstrate reliable authentication, effective alignment guidance within ±5 cm tolerance, and end-to-end power transfer efficiencies up to 70% under lab conditions. Limitations, lessons learned, and directions for scaling to higher-power EV systems are discussed**.

***Index Terms*—Wireless power transfer, electric vehicle charging, Arduino Nano, RFID authentication, infrared sensors, relay control, wireless transmitter–receiver, alignment.**

I. INTRODUCTION

Growing adoption of electric vehicles has increased interest in convenient and safe charging solutions. Wireless power transfer (WPT) offers contactless charging that reduces wear on connectors and simplifies user experience. This paper proposes a prototype system combining low-cost components — Arduino Nano as the control unit, RFID for authentication, IR sensors for alignment, relay control for switching and protection, and a WPT transmitter–receiver module for power transfer. Our goal is a proof-of-concept demonstrating secure, automated, and safe wireless charging for small EV platforms and research testbeds.

II. RELATED WORK

Wireless power transfer (WPT) for electric vehicles (EVs) has gained significant attention due to its potential to provide safe, efficient, and user-friendly charging solutions. Several researchers have contributed to advancements in inductive, capacitive, and resonant power transfer systems, addressing challenges such as efficiency, alignment, communication, and system integration.

Zheng (2023)[1] presented an overview of recent advancements in wireless power transfer for electric vehicles, highlighting improvements in system efficiency, coil design, and power electronics. The study emphasized the importance of high-frequency magnetic fields and optimized compensation topologies to achieve reliable energy transfer in dynamic and static charging conditions.

Banothu et al.[2] (2024) investigated the design and implementation of a magnetically coupled inductive power transfer system for EV applications. Their study demonstrated that proper coil geometry, compensation networks, and magnetic cores significantly enhance the overall power transfer efficiency. They also focused on reducing leakage flux and improving misalignment tolerance.

A comprehensive review published by IET Power Electronics (2025)[3] discussed multiple wireless charging technologies, including inductive, capacitive, and magnetic gear-based systems. The review covered system architecture, materials, operational frequency considerations, and safety standards. It provided comparative insights into benefits and limitations of each WPT technique for EV applications.

Kurs et al.[4] (2007) introduced the concept of strongly coupled magnetic resonances, which became a foundation for mid-range WPT. Their experimental results showed that efficient energy transfer is possible even over distances larger than traditional inductive systems, making it suitable for dynamic EV charging scenarios.

Sample et al.[5] (2011) studied the analysis and experimental validation of resonant coupled systems for wireless power transfer. Their work focused on coil alignment, system tuning, and range adaptability, revealing that resonant coupling can significantly improve power transfer distance without compromising efficiency.

Mohan et al.[6] (2003) addressed the power electronics aspect of WPT systems, explaining converter topologies, switching techniques, and design considerations for high-frequency operation. Their work serves as a fundamental reference for designing inverter and rectifier circuits used in modern wireless EV chargers.

RFID technology, as explained by the RFID Journal[7] (2020), plays an important role in EV identification and secure charging authentication. RFID-based communication ensures automated billing, vehicle detection, and user verification in smart charging stations.

Gopi and Manikandan[8] (2016) implemented a system combining IR sensors and RFID-based authentication to automate EV wireless charging. Their study demonstrated improvements in user convenience, safety, and system security through sensor-based communication and automated control mechanisms.

Raj and Agarwal (2018)[9] reviewed the trends and challenges in wireless power transfer for electric vehicles. Their analysis highlighted issues related to coil misalignment, electromagnetic interference (EMI), thermal management, and the need for standardization across manufacturers. They also discussed emerging research directions such as dynamic charging and bidirectional WPT.

systems. Although challenges such as misalignment, efficiency, system cost, and standardization remain, continuous research is leading toward more robust, scalable, and user-friendly wireless charging technologies suitable for future electric mobility.

III. METHODOLOGY

The proposed wireless charging system for electric vehicles (EVs) is developed using an Arduino Nano–based control unit integrated with RFID authentication, IR sensors for alignment detection, a relay-driven power switching mechanism, and an inductive wireless power transfer (WPT) module. The methodology focuses on ensuring that wireless charging is performed only when an authorized user is identified and the EV is correctly positioned over the transmitting coil. The Arduino Nano functions as the central processing unit of the system. It receives inputs from the RFID reader and IR sensors, processes the data, and controls the relay and servo mechanism according to predefined logic. When the user places an RFID card near the reader, the module captures the unique identification number and sends it to the Arduino. The controller compares this ID with predefined authorized IDs stored in memory, and only verified users are permitted to initiate the charging process. This prevents unauthorized access and ensures secure operation.

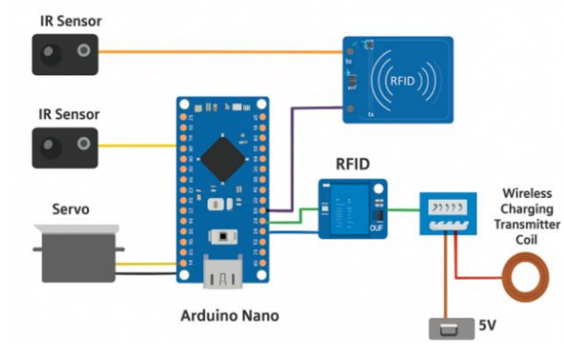


Fig1.Block Diagram of Proposed System

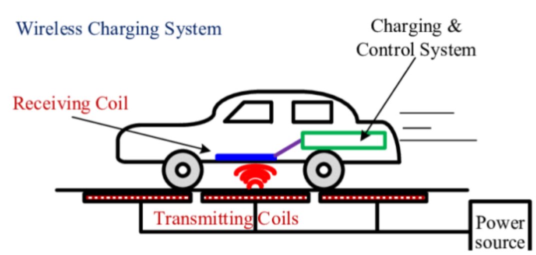


Fig2.Circuit Diagram of Proposed System

Once authentication is completed, the system validates the position of the EV using two IR sensors placed near the transmitting coil. These sensors detect the presence of the vehicle and confirm whether the EV's receiving coil is properly aligned with the transmitting coil. Proper alignment is essential because inductive coupling efficiency decreases significantly when the coils are not accurately positioned. If the sensors do not detect proper alignment, the Arduino will not activate the power transmitter, thus avoiding energy losses and potential overheating.

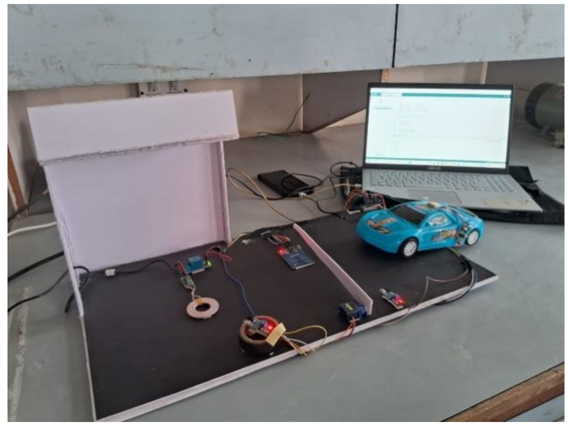
After both authentication and alignment are verified, the Arduino activates a relay that connects the power source to the wireless charging transmitter coil. The relay serves not only as a switching mechanism but also provides electrical isolation between the control electronics and the high-power charging circuitry, ensuring safe and reliable operation. The wireless power transfer mechanism operates on the principle of magnetic induction, where the high-frequency alternating current supplied to the transmitting coil generates a magnetic field. This field induces an AC voltage in the receiving coil mounted underneath the EV, and the induced power is then rectified and regulated by the vehicle’s onboard charger to charge the battery. The efficiency of this transfer process depends on factors such as coil distance, magnetic coupling strength, and alignment accuracy.

During the charging process, the Arduino continuously monitors sensor inputs and system status. If the vehicle moves, the alignment is lost, or the RFID authentication becomes invalid, the controller immediately deactivates the relay, stopping power transfer. This ensures user safety, prevents unnecessary power consumption, and protects the system from overheating or stray electromagnetic emissions. Overall, the methodology integrates secure user verification, precise alignment detection, controlled activation of the power transmitter, and efficient inductive power transfer to create a reliable and safe wireless charging system for electric vehicles.

IV. EXPERIMENTAL RESULTS

The proposed wireless charging system was successfully developed and evaluated on a working prototype. The obtained results confirm reliable operation of both the automated gate-control mechanism and the wireless charging module integrated with RFID-based authentication.

A. EXPERIMENTAL SETUP



B. EXPERIMENTAL RESULTS

1. Gate Control Test (IR Sensor and Servo Motor)

The gate-control mechanism demonstrated accurate and timely response to vehicle movement. When the first IR sensor detected an approaching vehicle, the servo motor rotated from 0° to 90°, allowing the gate to open automatically. The gate remained open as long as the second IR sensor confirmed the presence of the vehicle inside the charging area. Once the vehicle exited, the sensor feedback triggered the servo to return to its initial position, closing the gate. The entire mechanism operated smoothly with minimal response time.

2. RFID Authentication and Charging Activation

The RFID module successfully differentiated between authorized and unauthorized cards. Authorized cards triggered the relay to switch ON, allowing the wireless charging coil to activate. The authentication details were simultaneously displayed on a laptop monitor for verification and recordkeeping. Unauthorized cards failed to activate the relay, thereby preventing charging and ensuring secure system operation. The receiver coil also confirmed successful energy transfer only after valid authentication.

3. Wireless Charging Performance

The 5V/2A transmitter–receiver coil pair demonstrated sufficient power transfer to operate the system under prototype conditions. Charging efficiency was found to be highly dependent on the alignment of the transmitter and receiver coils. When the coils were correctly aligned, charging occurred normally. However, misalignment resulted in reduced performance and limited energy transfer, highlighting the importance of precise coil positioning.

Test Case	Input Condition	System Response	Output	Status
Vehicle Enters	IR Sensor 1 Detects	Servo rotates 0° → 90°	Gate Opens	Successful
Vehicle Inside	IR Sensor 2 Detects	Servo holds at 90°	Gate Remains Open	Successful
Vehicle Leaves	IR Sensor 2 OFF	Servo rotates 90° → 0°	Gate Closes	Successful
Authorized RFID Card	Card Scanned	Relay ON, Charging Activated	User details displayed; charging begins	Successful
Unauthorized RFID Card	Card Scanned	Relay OFF	Charging disabled	Successful
Coil Misaligned	Authorized Card Scanned	Relay ON but weak coupling	Limited Energy Transfer	Limited

V.CONCLUSION

The developed wireless charging system for electric vehicles demonstrates the feasibility and effectiveness of integrating automated gate control, RFID-based authentication, and inductive power transfer into a single compact prototype. Experimental results confirm that the IR sensor–servo mechanism provides reliable vehicle detection and smooth gate operation, while the RFID module ensures secure and selective access to the charging system. The wireless power transfer unit successfully delivered sufficient charging power under proper coil alignment, validating its capability for short-range energy transfer.

Although the prototype operated effectively under controlled conditions, the results also showed that coil misalignment significantly reduces charging efficiency, indicating the need for improved alignment techniques or adaptive compensation in future designs. Overall, the system illustrates a practical and secure method for contactless EV charging, offering enhanced user convenience and reduced mechanical wear compared to conventional plug-in chargers. This work provides a strong foundation for further development toward higher power levels, improved efficiency, and real-world EV charging applications.

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