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AI Based Self Aligning Wireless EV Charging System

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Abstract : Wireless electric vehicle (EV) charging offers significant advantages in convenience and autonomous-vehicle readiness, but suffers from efficiency degradation due to lateral coil misalignment during parking. This paper presents an automatic alignment system that integrates ultrasonic sensing, Bluetooth coordination, and motorized actuation to achieve precise coil positioning before power transfer. The system employs a distributed control architecture: a vehicle-side module measures lateral misalignment using an ultrasonic sensor and sends correction commands via Bluetooth to a ground-side pad with a motorized X-Y platform. An Arduino based closed-loop algorithm detects misalignment, computes corrections using proportional control, and coordinates repositioning through wireless communication. A relay interlock ensures safe energization only after alignment converges within tolerance. The modular, low-cost architecture provides a practical pathway for residential, public, and autonomous-vehicle charging deployment.

***IndexTerms* - Wireless power transfer, electric vehicle charging, automatic alignment, misalignment compensation, inductive coupling, distributed control, ultrasonic sensing, Bluetooth communication**

I. INTRODUCTION

Electric vehicle adoption is accelerating globally as governments and industries pursue decarbonization targets and sustainable transportation solutions. While conventional plug-in charging remains the dominant method, it presents several usability challenges including physical connector wear, safety hazards in wet conditions, and inconvenience for users with mobility limitations. Wireless power transfer technology offers a compelling alternative by enabling contactless energy delivery through magnetic induction, eliminating the need for physical plug-in operations and enabling autonomous charging capabilities essential for future self-driving vehicles.

However, wireless EV charging systems face a critical technical challenge: lateral misalignment between the transmitter coil embedded in the ground and the receiver coil mounted on the vehicle undercarriage. Even moderate misalignments of 50-100 mm, commonly occurring during typical parking maneuvers, can cause power transfer efficiency to drop by 20-40%. This efficiency degradation results in increased charging time, higher energy losses, excessive heat generation, and reduced system reliability. Consequently, precise coil alignment is essential for practical wireless charging deployment.

Various alignment solutions have been proposed, including vision-based systems, auxiliary detection coils, and sensor switching approaches. While these methods demonstrate technical feasibility, most require complex hardware, sophisticated algorithms, or specialized infrastructure that significantly increases system cost and complexity. This creates a barrier for mass-market adoption, especially in residential settings where cost-effectiveness and simplicity are critical requirements.

This paper presents the design and implementation of a low-cost automatic alignment system for wireless EV charging that addresses these limitations. The proposed system employs a distributed control architecture with a vehicle-side ultrasonic sensor for misalignment detection and a ground-side charging pad mounted on a motorized XY positioning platform. An Arduino Uno microcontroller processes real-time sensor data and transmits correction commands wirelessly via Bluetooth to the pad's motor driver circuit. The control algorithm implements proportional feedback to iteratively reduce lateral offset until alignment converges within acceptable tolerance. A relay-based safety interlock prevents coil energization during platform movement, ensuring operator protection.

II. LITERATURE REVIEW

Wireless electric vehicle charging systems have been extensively studied in the literature as a promising solution for contactless power transfer [6][7][9]. The technology eliminates the need for physical plug-in connections and enables autonomous charging operation, making it particularly suitable for future transportation systems [2][6]. However, lateral misalignment between the transmitter and receiver coils remains a significant challenge that degrades power transfer efficiency and increases system losses [1][3][5]. According to [5], power transfer efficiency can drop significantly with lateral offsets in the range of 50-100 mm, which commonly occurs during vehicle parking. This efficiency degradation necessitates the development of automatic alignment systems to ensure optimal coil positioning before power transfer begins [2][10].

Various sensing technologies have been investigated for misalignment detection in wireless charging systems. Al Dahhan et al. proposed a sensor switching-based automatic misalignment detection and correction system utilizing ultrasonic and infrared sensors

[1]. These sensors are widely employed due to their cost-effectiveness, millimeter-level accuracy, and immunity to lighting conditions [1]. Camera-based vision systems, on the other hand, provide wide-angle detection capability and enable simultaneous multi-axis positioning [8]. Javed et al. demonstrated a fisheye camera-based system for charging pad detection and alignment that offers improved field of view compared to conventional cameras [8]. Louca et al. designed auxiliary misalignment detection coils specifically for dynamic wireless charging systems to provide real-time feedback during vehicle motion [11].

Automatic alignment strategies can be broadly classified into vehicle-side actuation and ground-side actuation approaches. Hwang et al. developed an autonomous coil alignment system for dynamic wireless charging that minimizes lateral misalignment through motorized positioning [2]. Ground-side alignment employs a motorized platform on the charging pad that repositions itself based on feedback from the vehicle [2][6]. This approach transfers the mechanical complexity to the stationary infrastructure, making it more suitable for practical deployment. Rozman et al. presented a smart wireless power transmission system that integrates autonomous charging capabilities with intelligent positioning control [6]. The integration of wireless communication modules enables coordination between the vehicle-side sensors and ground-side actuators without requiring physical connections [1][6].

Compensation circuit topology selection significantly influences the system's tolerance to coil misalignment [research paper [3][4][5]. Abdulhameed et al. designed an LCC-compensated wireless charger specifically for misalignment tolerance in roadway-powered electric vehicles [3]. The LCC configuration provides improved voltage regulation and reduced sensitivity to load variations compared to basic series-series compensation [3]. Zhang et al. proposed a field enhancement integration design using LCL topology that maintains high coupling efficiency even under lateral displacement conditions [4]. Ramakrishnan et al. implemented a high misalignment-tolerance wireless charger with constant current/voltage control that demonstrates robust performance across varying alignment conditions [5]. Abdulhameed et al. further validated the improved lateral misalignment tolerance through extensive experimental testing of their wireless charging system design [10].

Control algorithms for automatic alignment typically employ feedback control strategies to iteratively reduce positioning error [1][2]. The sensor switching approach proposed in [1] enables dynamic selection between different sensor modalities to optimize detection accuracy under varying environmental conditions. Threshold-based algorithms with safety interlocks are commonly implemented to prevent coil energization during platform movement, ensuring operator safety and preventing damage to power electronics [2][6]. Real-time display interfaces provide visual feedback to users regarding alignment status and charging readiness [6].

Despite significant advances in wireless EV charging alignment technologies, several critical gaps remain that limit practical implementation. Most existing solutions focus on complex, high-cost approaches suitable primarily for commercial or industrial-scale deployment [2][6], creating barriers for residential and small-scale public charging applications. While sophisticated methods such as multi-camera vision systems [8] and auxiliary detection coils [11] achieve high accuracy, they require substantial computational resources and specialized hardware that increase system complexity and cost. Furthermore, existing sensor switching systems [1] primarily focus on detection methodology but provide limited discussion on the complete integration of sensing, wireless communication, actuation, and safety interlocking within a unified, modular architecture. The integration of low-cost microcontroller platforms with distributed control remains underexplored, particularly for Arduino-based implementations using readily available components. Additionally, most research emphasizes dynamic charging scenarios [2][11] or high-power industrial applications [3][10], leaving a gap in practical, static alignment solutions suitable for standard Qi-compatible charging at moderate power levels. This work addresses these limitations by developing a modular, low-cost automatic alignment system that integrates ultrasonic sensing, Bluetooth wireless coordination, Arduino-based control, and motorized actuation in a complete prototype suitable for residential deployment and scalable to various EV platforms.

III. SYSTEM ARCHITECTURE

The high-level architecture is presented in the block diagram below, depicting the main subsystems: power supply and conversion, dual microcontrollers (Arduino and Raspberry Pi), sensing module (ultrasonic sensor), user authentication (RFID), actuator modules (motor drivers for DC and stepper), relay switching, Qi wireless charging transmitter, and user interface (OLED display). The system receives power from a DC supply, distributes it to all blocks, and coordinates self-alignment and charging.

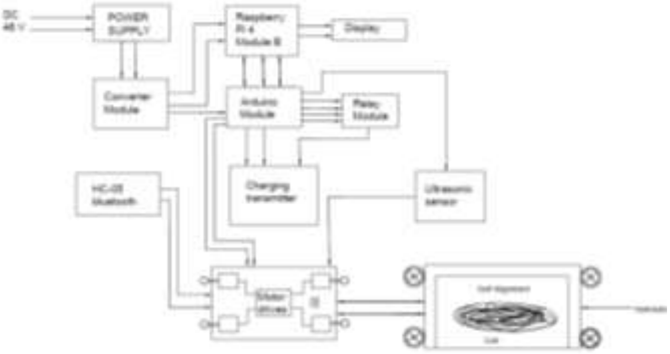

Figure 1 Block Diagram of Self Aligning Wireless EV Charging System

A. Explanation:

- The Raspberry Pi communicates with Arduino via UART for commands; handles UI and RFID authentication over GPIO/SPI.
- Arduino manages sensors and actuators:
- HC-SR04s feed into digital pins for misalignment feedback.
- A4988 is driven on step/direction pins for Y-movement; L298N controls X-motors.
- Relay module receives triggers; its contacts switch high-current supply to Qi transmitter.

- DC and stepper motor loads are powered directly from the main supply, with control separated by drivers.
- Power is distributed via regulated 12V and 5V rails ensuring logic and actuator compatibility.

B. Working:

- The system enables an electric vehicle (EV) to automatically align its receiver coil with a stationary charging pad for optimal wireless charging:
- Once started, the user authenticates via RFID, confirmed by the Raspberry Pi and displayed on the OLED.
- Ultrasonic sensors, polled by Arduino, measure coil misalignment.
- The Arduino calculates required adjustments and commands the DC and stepper motors to move the coil platform in X and Y directions.
- If the coils are within the alignment threshold, Arduino enables the relay—powering the Qi wireless charging module.
- Raspberry Pi and Arduino update display/status, continuously monitoring system state until completion or fault is detected.

IV. METHODOLOGY

System Power-Up and Initialization

- Once the system is powered on, all controllers and peripherals (microcontrollers, sensors, actuators, display, authentication modules) initialize and perform basic self-checks.
- The user interface/display shows a standby or "Ready" state, indicating the system awaits user authorization.

User Authentication

- The user interacts with the charging station by presenting an RFID tag or card.
- The system reads and verifies the user's credentials.
- Access is only granted if authentication is successful; otherwise, the system remains in standby and blocks further operations.

Sensing Vehicle Position

- After successful authentication, the system activates its alignment routine.
- Sensors (such as ultrasonic modules) are polled to measure the current alignment error between the transmitter coil on the ground and the receiver coil on the EV. These measurements represent how far off the coils are in X and Y coordinates.

Calculating Alignment Error

- The control algorithm processes sensor data to compute the magnitude and direction of the misalignment.
- If the coils are already well-aligned, the system skips to charging. Otherwise, correction steps are initiated.

Actuating Motors for Alignment

- Based on calculated errors, the system commands the motors responsible for moving the coil platform (such as a stepper motor for Y-axis and a DC motor for X-axis).
- Motors incrementally reposition the platform in closed-loop steps, reducing the alignment error.
- After each move, sensors are polled again for an updated reading.

Alignment Verification

- This feedback loop continues: sense → compute → move → sense, until the measured alignment error falls within a pre-set threshold (e.g., $\pm$2 mm).
- If the error cannot be reduced after multiple attempts or if a fault is detected (such as a sensor or motor error), the system displays a fault message and halts.

Charging Enabling Logic

- When aligned, and only after successful authentication and all safety checks, the system allows wireless charging to begin.
- The charging module is enabled, starting the power transfer from the transmitter to the receiver coil without physical contact.

Status Display and User Feedback

- Throughout the session, the display outputs relevant updates such as "Aligning," "Charging," "Session Complete," or "Fault."
- These notifications keep the user informed of progress and any issues.

Monitoring During Charging

- The system continuously monitors alignment, sensor status, authentication, and power flow.
- If misalignment or any unsafe condition is detected mid-session, the system pauses charging, alerts the user, and attempts to re-align or awaits manual intervention.

Session Completion and System Reset

- Once charging is finished (battery full, timeout, or user-end), the system safely disables charging and sets all actuators to their neutral state.
- The user is notified, and the system returns to standby, ready for the next charging request.
- This approach provides structured, automated, and user-centric wireless EV charging using modern sensing, actuation, and control

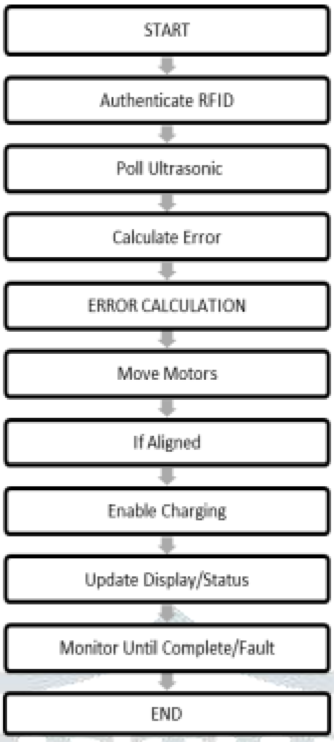

Figure 2 Flowchart of Self Aligning Wireless EV Charging System

V. FUTURE SCOPE

The current system addresses lateral XY misalignment, but significant opportunities exist for enhancement and expansion. One critical area for future development is the integration of three-dimensional alignment through Z-axis actuation. Vertical distance between coils significantly affects coupling efficiency, and different vehicle models, loading conditions, and suspension states result in varying ground clearances. By incorporating Z-axis positioning capability, the system can dynamically adjust the vertical gap between transmitter and receiver coils to maintain optimal air gap across diverse vehicle types and operating conditions. This enhancement would enable consistent high-efficiency power transfer regardless of vehicle ride height variations, further improving the practical applicability of the system.

Advanced control strategies offer another promising avenue for improvement. Integration of machine learning algorithms can enable predictive alignment based on historical parking patterns, vehicle type recognition, and environmental conditions. Neural network models trained on previous alignment attempts can optimize motor speed profiles and reduce convergence time by learning optimal control parameters for different scenarios. This adaptive approach would continuously improve system performance over time, achieving faster and more accurate alignment with each charging session. Additionally, sensor fusion techniques combining ultrasonic, infrared, and inductive sensing modalities can provide redundancy and sub-millimeter positioning accuracy, enhancing reliability under challenging environmental conditions such as rain, snow, or debris obstruction.

The system architecture can be extended to support multi-coil array configurations where multiple transmitter coils are embedded in the charging pad. Intelligent electronic switching can select and activate the coil closest to the receiver position, eliminating mechanical movement entirely and providing instantaneous alignment. This approach would significantly reduce alignment time and mechanical complexity while enabling simultaneous charging of multiple vehicles. Furthermore, adaptation for dynamic wireless charging scenarios where vehicles charge while driving over embedded road coils represents a transformative application. Real-time tracking algorithms and high-speed actuation systems would maintain alignment with moving vehicles, enabling continuous charging on highways and urban roads.

Integration with emerging smart transportation infrastructure presents substantial opportunities. Cloud connectivity and IoT platform integration can enable remote monitoring, diagnostics, and over-the-air firmware updates, reducing maintenance costs and improving system reliability. Integration with smart grid systems can optimize charging schedules based on electricity pricing, renewable energy availability, and grid load conditions, contributing to demand response management and reducing charging costs for users. Vehicle-to-grid (V2G) capability with bidirectional power flow implementation can enable vehicles to supply power back to the grid during peak demand periods, supporting grid stabilization while providing revenue opportunities for EV owners.

Enhanced safety features represent another critical development area. Foreign object detection systems using additional sensors or thermal imaging can identify metallic objects, animals, or debris between coils before energization, preventing damage and safety hazards. Living object protection protocols can detect human or animal presence in the charging zone, automatically disabling power transfer when necessary. These safety enhancements are essential for deployment in public spaces and residential areas where children, pets, and other living beings may be present.

Full integration with autonomous vehicle navigation systems offers the potential for seamless, hands-free charging experiences. The vehicle can communicate its exact position and orientation to the charging infrastructure, receiving guidance signals to park precisely over the charging pad with minimal initial misalignment. This integration reduces alignment time and energy consumption while enabling fully autonomous charging operations essential for future robotaxi fleets and autonomous delivery vehicles. Augmented reality user interfaces through smartphone applications can provide visual guidance during parking, showing real-time alignment status, optimal parking position, and charging progress through the device camera.

Scaling the system to higher power levels for fast charging applications requires enhanced thermal management, improved compensation topologies, and more robust mechanical platforms capable of handling larger, heavier coil assemblies while maintaining precise alignment. Support for 11 kW, 22 kW, and higher power transfer rates would significantly reduce charging times, making wireless charging competitive with conventional plug-in fast charging infrastructure. Development of modular platform designs supporting different vehicle classes including sedans, SUVs, commercial vehicles, buses, and two-wheelers through interchangeable modules and standardized interfaces would expand market applicability.

Performance optimization for extreme environmental conditions including temperatures ranging from -40°C to +85°C, high humidity, heavy rain, snow accumulation, and dust exposure through enhanced weatherproofing and environmental sealing would extend system reliability across diverse climates and geographic regions. Transition from prototype to production-ready design with optimized component selection, PCB integration, and manufacturing process development can leverage economies of scale to reduce per-unit costs by 50-70%, making the technology accessible for mass-market residential deployment. These comprehensive enhancements would transform the current prototype into an intelligent, robust, and cost-effective charging solution suitable for next-generation smart transportation infrastructure and widespread commercial

VI. CONCLUSION

This paper presented a low-cost automatic alignment system for wireless electric vehicle charging that integrates ultrasonic sensing, Bluetooth coordination, Arduino-based control, and motorized XY actuation. The distributed architecture separates vehicle-side sensing from ground-side actuation, enabling wireless coordination without physical connections. The system demonstrates that effective automatic alignment can be achieved using readily available components and simple proportional feedback control, without requiring complex algorithms or specialized hardware. Comprehensive safety interlocking prevents coil energization during movement, ensuring operator protection and system reliability.

The modular design addresses identified research gaps by providing a practical solution suitable for residential and small-scale public charging infrastructure. Unlike existing high-cost vision systems and complex detection coils, this approach offers cost-effectiveness and simplicity while maintaining reliable performance. The use of standard Qi wireless charging modules ensures compatibility with existing standards, while the Arduino platform provides accessibility for further development and customization.

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