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Establishment of an Intelligent Wireless EV Charging System Using the Wireless Power Transfer (WPT) Method

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Abstract

This paper discusses the development of a smart parking system with inductive power transfer for an electric vehicle (EV) prototype using a circular coil configuration. The system uses an induction-based wireless energy transfer technology to provide continuous charging from the parking location to a vehicle. An ESP32 microcontroller is installed in the parking space as the control centre, handling infrared sensor detection, relay module control, and charging startup. Once a vehicle enters the parking lot and its presence is detected by the infrared sensors, the transmitter coil is switched on along with a cooling fan for thermal control. In an electric vehicle, when another ESP32 acts as the main controller and is connected to a charging module (TP4056), an INA219 DC sensor, and a DC voltage sensor to view input voltage, charging current, battery voltage, and battery %. Parameters are examined in real time through the Blynk platform, and the battery level is displayed on an onboard OLED screen. The study also explores coil alignment in inductive wireless power transfer, where increasing the gap between the transmitter and receiver reduces both the input voltage and the charging efficiency. Experimental findings highlighted that coil spacing greatly affects efficiency, with noticeable differences in charging performance between 0.2 mm and 0.6 mm, and no measurable charging beyond that range. The overall system presents a working IoT-based smart parking and wireless charging solution with integrated monitoring and control features.

1. Introduction

The global shift toward environmental sustainability and the urgent need to reduce reliance on fossil fuels have positioned electric vehicles (EVs) as a primary alternative in modern transportation [1]. However, the widespread adoption of EVs is heavily contingent on the development of efficient, user-friendly charging infrastructure [2]. Conventional plug-in charging methods often face several practical challenges, including cable wear and tear, potential safety hazards in outdoor or wet environments, and the inconvenience of manual connection [3].

To address these limitations, Wireless Power Transfer (WPT) technology, specifically through electromagnetic induction, has emerged as a promising solution. This method facilitates energy transmission without direct physical contact between the ground-based charging pad and the vehicle's receiver [3]. Beyond improving operational safety, WPT significantly minimises mechanical degradation associated with wired systems [4]. Nevertheless, the performance of WPT systems is highly sensitive to coil alignment and the air-gap distance, both of which are critical factors that influence the stability and efficiency of the power transfer process [3].

Most existing charging systems lack integrated monitoring and smart control capabilities. Users are often unable to observe real-time charging parameters such as voltage, current, battery condition, and system efficiency, which reduces reliability and overall user confidence [5].
This study presents the development of an IoT-enabled wireless EV charging system based on inductive WPT and automatic control. The setup incorporates ESP32 microcontrollers, infrared detection, relay switching, battery sensing, and Blynk cloud monitoring for real-time performance tracking. The change of coil gap associated with charging inefficiency is then experimentally assessed.

2. Methodology

2.1 Wireless Power Transfer Methods

The implementation of wireless charging systems allows for the transmission of electrical energy without the need for physical connectors, utilising magnetic field coupling between a ground-based transmitter and a vehicle-mounted receiver [6]. This contactless approach significantly enhances operational safety and reliability compared to traditional plug-in systems [7]. Generally, wireless EV charging is categorised into two main architectures: static and dynamic modes [8]. While static charging is currently the most viable solution for vehicles in a stationary position [9], dynamic charging enables power transfer while the vehicle is in motion [10].

The fundamental mechanism of these systems relies on inductive coupling, where an alternating current in the primary coil generates a time-varying magnetic field that induces voltage in the secondary coil [11]. To achieve high energy transfer efficiency, the system must operate at its resonant frequency with precise alignment between the coils [12]. Despite its advantages, the practical deployment of this technology requires careful consideration of efficiency losses and electromagnetic compatibility.

2.2 Inductive Coupling

Inductive coupling is selected as the fundamental wireless power transfer (WPT) technique for this project, enabling contactless energy delivery between the primary Tx coil in the charging pad and the secondary Rx coil beneath the vehicle [4], [12]. This energy transmission occurs when an alternating current in the transmitter generates a time-varying magnetic field, which then induces an electromotive force in the receiver coil across an air gap [13].

The performance of this system is governed by parameters such as mutual inductance, coil geometry, and operating frequency [14]. However, the magnetic coupling is highly sensitive to the relative position of the coils; vertical gaps or lateral displacement can lead to a significant drop in power transfer efficiency [15]. To optimise this process, compensation networks like series-series or series-parallel topologies are often implemented to cancel reactive components and improve overall capacity [19]. Compared to microwave or laser-based methods, inductive coupling provides a safer and more efficient solution for near-field, static EV charging applications [4].
The basic functional configuration of the implemented inductive coupling system is illustrated in Fig. 1, where electrical energy from the supply is converted into an alternating magnetic field at the transmitter and subsequently rectified at the receiver before being delivered to the load [15].

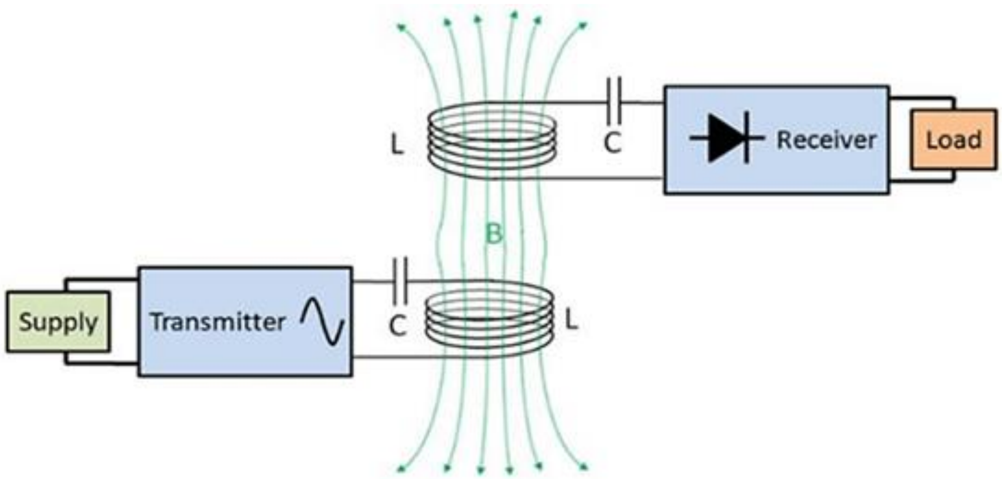


Fig. 1 *Schematic representation of the inductive coupling technique used for wireless energy transmission [15]*

2.3 Coils Shape

Coil geometry is a key design factor in inductive WPT systems, as it directly influences magnetic field distribution, coupling behaviour, and tolerance to misalignment. Various coil configurations have been reported for wireless electric vehicle charging, including circular, square, rectangular, hexagonal, and double-D (DD) structures, as shown in Fig. 2 [16].

Among these geometries, circular coils provide a symmetrical magnetic field distribution about the coil axis, resulting in uniform flux linkage and consistent coupling characteristics in all directions. This symmetry improves tolerance to lateral and angular misalignment, which is particularly important for static charging, where precise vehicle positioning cannot always be guaranteed. Although square and rectangular coils are easier to integrate into planar pads, they exhibit non-uniform field distributions, while DD coils offer improved lateral tolerance at the expense of higher structural complexity [16]. Considering efficiency, simplicity, and robustness, circular coils are selected for both the transmitting and receiving coils in this work.

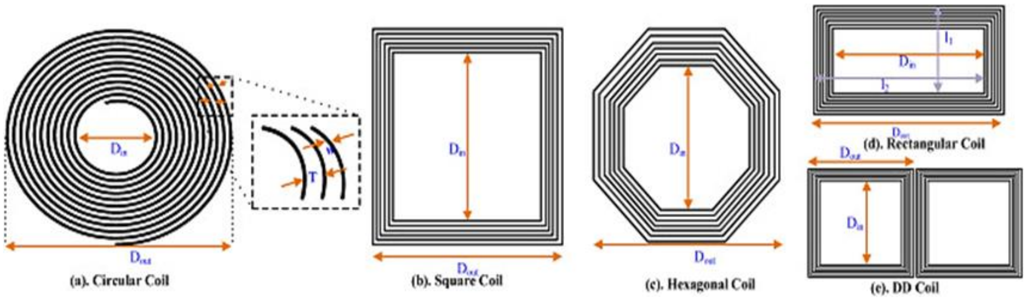


Fig. 2 *Modelled geometries of wireless power transfer pads with different coil shapes: (a) circular, (b) square, (c) hexagonal, (d) rectangular, and (e) double-D [16]*

2.4 Prototype System for Smart Electric Vehicle Charging and Performance Tracking

In this pilot study, circular coil inductive power transmission forms the basis of the proposed EV charging prototype, which integrates automated monitoring and control features. The prototype consists of an intelligent charging parking system integrated with an IoT-based system for monitoring via mobile phone. For the case of an intelligent parking system, an infrared sensor detects the presence of a vehicle and sends a trigger signal to the ESP32 controller. Upon detection, the controller activates the transmitting (Tx) coil to initiate inductive wireless power transfer. The transmitter circuitry is powered through an AC-to-DC converter that supplies regulated DC power to the control and driving components. An ESP32-CAM module is integrated to provide visual monitoring of the parking area, and captured data are transmitted via Wi-Fi for remote access.

A receiving (Rx) coil positioned under the EV prototype intercepts the magnetic field produced by the transmitter, generating an induced AC voltage. This voltage is then rectified and regulated through a TP4056 charging component to ensure safe lithium-ion battery charging under constant-current and constant-voltage modes. Real-time battery voltage is measured using a DC sensor, with the data processed by the ESP32 controller for monitoring.

Both ESP32 units communicate with a cloud-based server through Wi-Fi, enabling real-time visualisation of charging parameters and system status via an Android mobile application. This architecture integrates sensing, wireless power transfer, and IoT connectivity to provide automated charging and remote monitoring within a single platform.

The overall system consists of two main modules, namely the parking spot unit (transmitter side) and the electric vehicle (EV) prototype unit (receiver side), as illustrated in Fig. 3. Both modules are controlled by ESP32 NodeMCU microcontrollers, which handle sensing, power control, data acquisition, and wireless communication.

To study the relationship between coil spacing and charging performance, a series of tests was carried out using several gap distances. The ground unit acted as the transmitter, while the collecting unit was involved to the bottom of the EV model. Various separation distances were tested to achieve a stable 5 V output at the receiver. Since the air gap strongly influences magnetic coupling and transfer efficiency, it was selected as the primary design parameter. The coil specifications are summarised in Table I. For each air gap configuration, the output voltage was measured and recorded over time to assess charging performance.

In addition, a time-voltage investigation was performed to regulate the charging period required to completely charge the lithium-ion battery-operated. Each battery-operated device was considered fully charged at 4.2 V, which corresponds to the standard maximum terminal voltage of a single lithium-ion cell. Although the system operates with a 5 V input supply, this value represents the charging source rather than the battery voltage. The TP4056 charging module regulates the input and applies constant-current, as well as constant-voltage (CC-CV) indicting to limit the battery-operated voltage to 4.2 V, preventing overcharging and ensuring safe operation.

The batteries were attached in parallel to maintain the same voltage level while increasing overall capacity. Therefore, the fully charged voltage remains 4.2 V instead of 5 V. The corresponding charging time and efficiency were then calculated. Detailed performance results are presented in the Results and Discussion section.

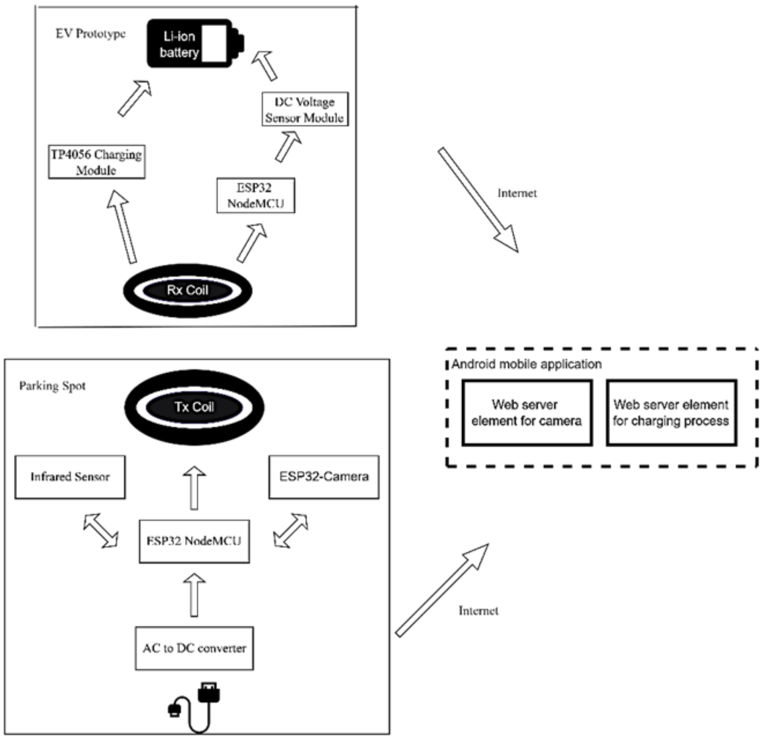


Fig. 3 *Operational block diagram of the projected wireless charging system with integrated sensing and control*

Table 1 *Overview of Coil Parameter*

Parameter	Unit
Input voltage	5.5 V
Receiver output voltage	5 V
Transmitter coil diameter	43 mm
Receiver coil diameter	43 mm
Transmitter coil thickness	2.3 mm
Receiver coil thickness	1.2 mm
Air gap distance (Tx-Rx)	1-7mm

The system operates by continuously monitoring the parking area using an ESP32-CAM module, as shown in Fig. 4, which provides visual surveillance and optional live video streaming to a web-based interface. Vehicle presence is detected using four infrared (IR) sensors positioned around the charging pad, as shown in Fig. 4(a). These sensors provide positional information to the ESP32 NodeMCU to determine vehicle arrival and alignment. Upon detection, the device activates the Tx coil to initiate inductive wireless power transfer. Proper position among the Tx and Rx coils is verified with the IR sensors to ensure efficient magnetic coupling. A DC cooling fan is automatically enabled during operation to maintain safe thermal conditions during charging.

The induced AC power at the receiver is rectified and regulated before being supplied to the lithium-ion battery for charging. Key parameters, such as voltage, current, power, and battery state of charge, are measured continuously and transmitted over Wi-Fi to the Blynk cloud platform to enable instantaneous monitoring. These values are presented on the mobile dashboard and onboard indicators, as illustrated in Fig. 4(b). The charging process ends either through manual control via the application interface or automatically when the battery reaches a pre-set threshold, after which the method shifts to the standby mode. Fig. 4 (c) and (d) show the IR sensor with transmitter (Tx) coils and bottom-mounted receiver (Rx) coil placement on the EV prototype.

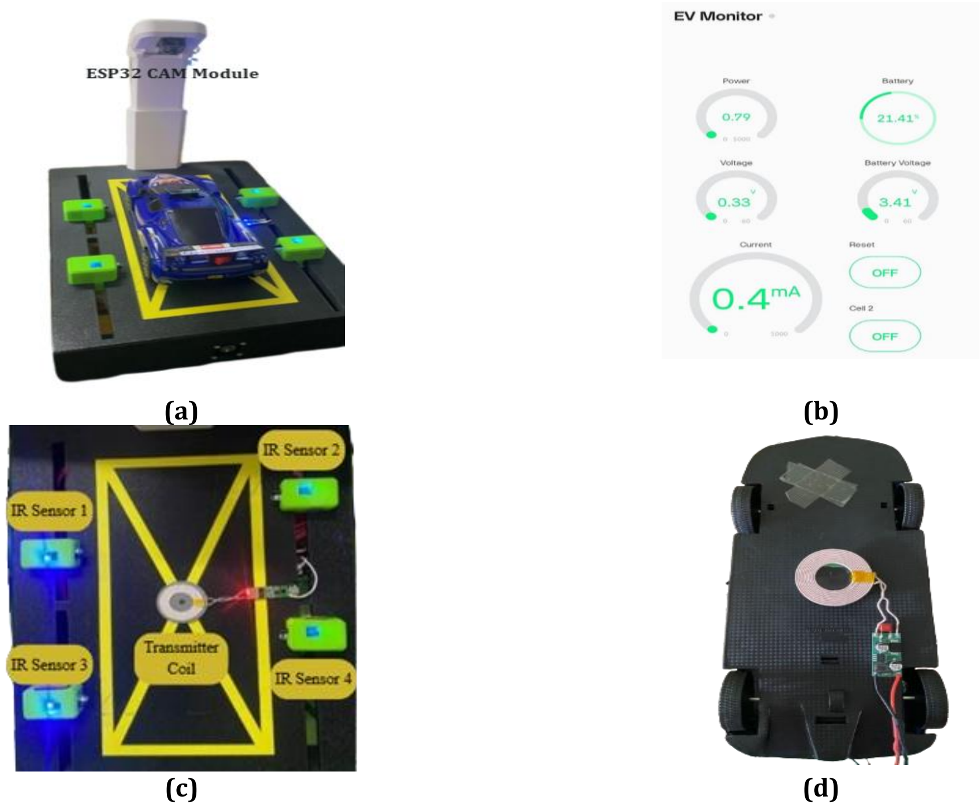


Fig. 4 *Demonstration of the proposed parking system; (a) vision-enabled ESP32-CAM surveillance hardware and (b) mobile application displaying charging information in real time (c) IR sensor with transmitter (Tx) coils (d) bottom-mounted receiver (Rx) coil placement on the EV prototype*

Vehicle detection, charging operations, and monitoring features are integrated into the developed wireless EV charging system, wireless power transfer, and real-time monitoring within a single automated platform. The parking area is continuously supervised using an ESP32-CAM module to provide visual monitoring of the charging space. Infrared sensors installed around the charging pad detect the presence and position of the vehicle to confirm correct placement. When the vehicle is spotted and properly aligned, the ESP32 controller initiates the transmitting coil to initiate inductive wireless power transfer. The received energy is regulated and used to charge the lithium-ion battery. During system operation, battery voltage, current, and state of charge are continuously tracked and uploaded via Wi-Fi to a cloud dashboard for real-time observing. The charging process can be terminated either manually through the monitoring interface or automatically when the battery reaches a predefined charge threshold. After completion, the system returns to standby mode, awaiting the next charging cycle.

3. Result and Discussion

3.1 Charging Technique for the EV Model

The investigational prototype was evaluated to assess the performance of the proposed inductive WPT method. With the ground coil acting as the power source and the onboard coil serving as the receiver, trials were conducted at multiple spacing intervals to study changes in magnetic interaction and energy delivery [4], [13].

The air gap was adjusted between 1 mm and 8 mm to identify the most suitable operating condition. Test results showed that the highest receiving voltage, approximately 5 V, occurred at small separations of 1 to 3 mm, indicating strong magnetic coupling among the coils. As the gap increased, the induced voltage steadily dropped due to weaker flux linkage. When the gap exceeded 7 mm, no measurable charging was detected, suggesting that the coupling was insufficient for effective power transfer.

The system was powered using an AC–DC converter that provided a regulated 5.5 V DC supply to the ESP32 controller, sensors, and transmitter circuitry. During testing, automatic vehicle detection, stable wireless energy transfer, and consistent battery charging were successfully achieved. These results confirm that the prototype can reliably deliver inductive charging within the tested air gap range and demonstrate the practical feasibility of the developed system.

The measured receiving voltage at different air gap distances is summarised in Table 2. A peak voltage of 4.34 V was achieved with minimal spacing between the transmitter and receiver coils. With increasing air gap distance, the received voltage decreased from 4.28 V to 3.40 V, which is attributed to weaker magnetic coupling and reduced mutual inductance involving the coils. When the air gap reached 8 mm, no measurable output voltage was observed, indicating insufficient coupling for effective power transfer. These results are consistent with the theoretical behaviour of inductive Wireless Power Transfer systems, where increasing coil separation reduces magnetic flux linkage and overall transfer efficiency [4], [13].

Table 2 Voltage response versus coil spacing

Coil Spacing (mm)	Output Voltage (V)
0	4.34
1	4.28
2	4.22
3	4.16
4	4.10
5	4.04
6	3.98
7	3.40
8	0

3.2 Battery Charging Performance

Battery charging performance was evaluated by monitoring the voltage rise of a single lithium-ion battery during wireless charging. Based on the air-gap analysis in Section 3.1, a separation distance of 2 mm was selected to provide stable power transfer and relatively high induced voltage. Although the receiver output is approximately 5 V, this voltage serves as the charging supply. The TP4056 module adjusts the battery voltage to a safe maximum of 4.2 V; the battery terminal voltage remains below 5 V during charging. The battery was initially discharged to 3.36 V and charged wirelessly for a total duration of 300 minutes.

Fig. 5 illustrates the battery voltage profile as a function of charging time. The measured results show a gradual and continuous increase in voltage from 3.36 V to 3.97 V, confirming stable energy transfer throughout the charging process. A faster voltage rise was observed during the initial stage of charging, followed by a slower increase as the battery approached higher voltage levels. This behaviour is consistent with the constant-current/constant-voltage characteristics of the TP4056 charging module.

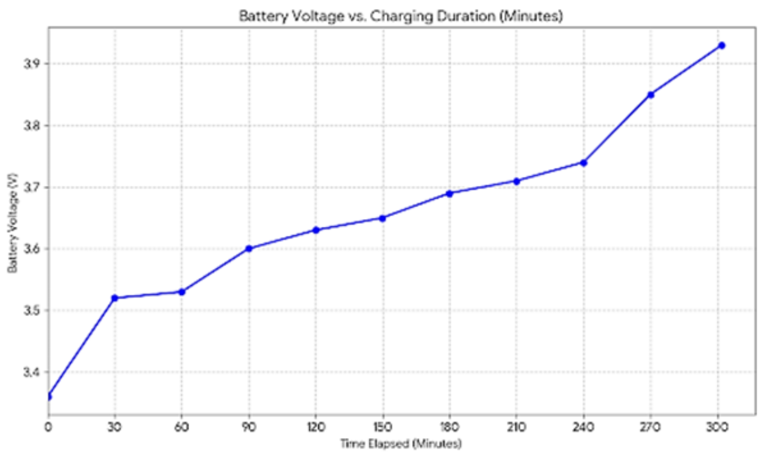


Fig. 5 *Receiving voltage profile plotted as a function of charging time*

The results demonstrate that the inductive Wireless Power Transfer system is able to deliver sufficient power to safely charge the lithium-ion battery under practical operating conditions. The selected 2 mm air gap provides reliable coupling and supports continuous charging without interruption. Table 3 summarises the measured input voltage, battery voltage, and charging efficiency recorded at 30-minute intervals during the experiment. The battery power increased steadily from 3.36 V to 3.97 V over 300 minutes, confirming continuous energy transfer. The calculated efficiency remained relatively stable throughout the charging process, with an average value of

90.85%, indicating effective power conversion and minimal transfer losses at the selected 2 mm air gap. The calculation of efficiency is shown in equation 1.

$$Efficiency\ (\eta) = \frac{voltage\ obtained}{total\ voltage} \times 100 \tag{1}$$

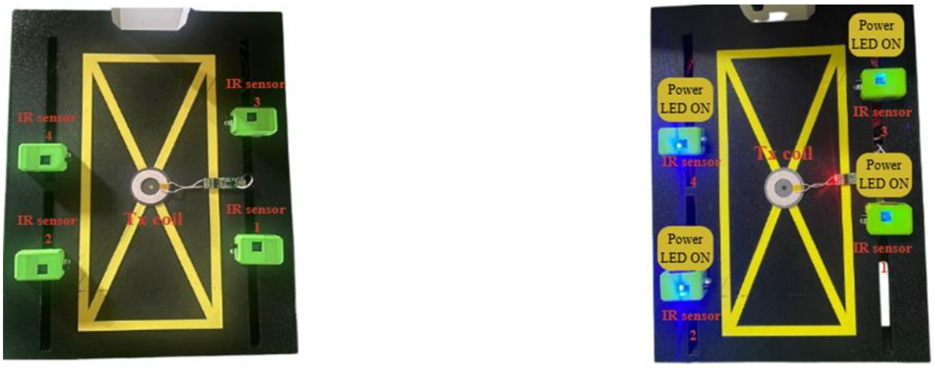
Table 3 *Summary of Input Voltage, Battery Voltage, and Efficiency over time*

Charging time (min)	Voltage (V)	Efficiency (η) (%)
0	3.36	88.42
30	3.47	92.53
60	3.49	94.32
90	3.55	89.20
120	3.58	88.83
150	3.63	90.07
180	3.66	90.15
210	3.71	89.61
240	3.71	90.49
270	3.74	90.78
300	3.97	94.98
Average	3.63	90.85

To certify sufficient magnetic coupling and steady power transfer, the transmitter with receiver coils was optimised for operation within the chosen air gap range. The resulting configuration provided consistent charging performance throughout the experiments. The observed behaviour agrees with established WPT characteristics and reported findings in related studies [4], [13].

3.3 Parking Slot Prototype Scheme for Electric Vehicles

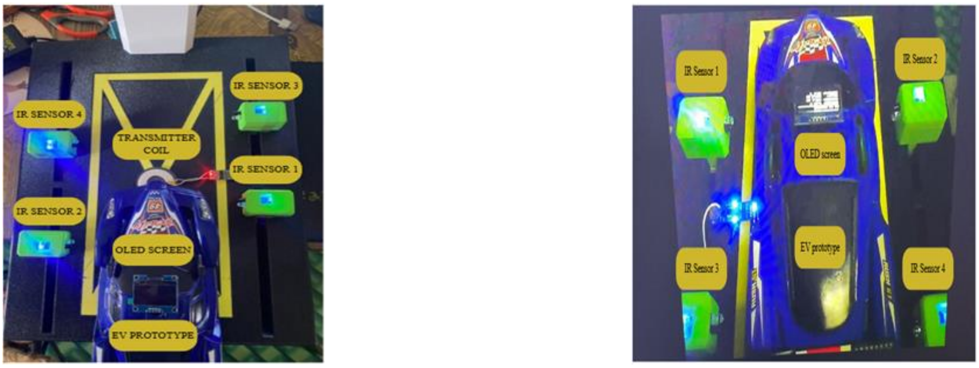
Fig. 6 shows the developed parking slot prototype integrated with four infrared (IR) sensors and a centrally positioned transmitting (Tx) coil for vehicle detection and wireless power transfer. The IR sensors are interfaced with the ESP32 microcontroller to monitor the presence and alignment of the EV within the charging area. A relay-controlled power circuit connects to the Tx coil to start the inductive charging process. When the system is powered, the LEDs on the IR sensor modules illuminate, indicating active sensing and readiness for detection. Upon successful vehicle detection and correct positioning, the ESP32 processes the sensor signals and automatically enables the transmitter coil to begin energy transfer. The experimental setup demonstrates reliable detection, proper sensor coordination, and stable activation of the wireless charging process.



(a) **(b)**

Fig. 6 *Demonstration of the parking module; (a) hardware configuration including infrared detectors and the power coil, and (b) energised condition with status indicators visible*

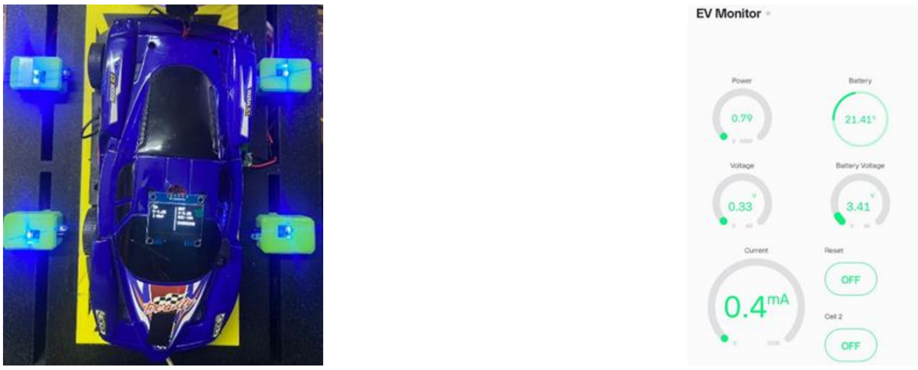
The proposed system integrates IoT features and internet connectivity to improve reliability and maintain stable operation, while minimising the alignment issues typically encountered in conventional wireless power transfer (WPT) systems. Vehicle entry into the parking slot is detected using multiple infrared (IR) sensors, enabling accurate presence detection and proper positioning within the charging area. Once detected, the signal triggers the ESP32-CAM through a relay circuit, allowing real-time visual monitoring of the parking space. As shown in Fig. 7(a), the IR sensors are placed around the vehicle to track its position and alignment, while Figure 7(b) presents the live video feed captured by the ESP32-CAM for continuous observation.



(a) **(b)**

Fig. 7 *Parking spot prototype showing the arrangement of four infrared sensors and the transmitting coil with (a) the system powered off and (b) powered on*

Once all sensors confirm correct placement, the system begins wireless charging. Throughout the charging process, the battery status is continuously updated and displayed on the web dashboard and the vehicle's OLED screen. The charging cycle continues until either the user manually stops it or the battery reaches a predetermined threshold (such as 50%). When either condition is met, the charging process terminates, and the system returns to standby, marking the end of the flow. The vehicle position within the parking space and the corresponding charging parameters, including battery percentage, voltage, current, and power consumption, are monitored and visualised in real time, as presented in Fig. 8(a) and Fig. 8(b).



(a) **(b)**

Fig. 8 *System demonstration: (a) EV model correctly stationed within the parking bay and (b) live charging data presented on the mobile monitoring application*

4. Conclusion

This project presents the plan and operation of a prototype wireless EV charging method with integrated IoT monitoring and control. Vehicle detection, alignment guidance, and continuous battery performance tracking are incorporated into the system. By combining inductive wireless power transfer with infrared-based positioning, stable and efficient energy delivery was achieved, demonstrating the practicality of the proposed smart charging approach. Once the vehicle is correctly positioned, charging starts automatically, and key battery information is displayed on the onboard monitoring interface and OLED screen. The combination of wireless power transfer and IoT capabilities provides a reliable, user-friendly solution that enhances the convenience and efficiency of EV charging. Beyond automotive applications, the prototype also shows potential for other low-power wireless charging uses, including telecommunications and biomedical devices. Future work will focus on optimising coil design and adjusting the air gap between the transmitter and receiver to further improve productivity and reduce charging time.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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