

Wireless charging and monitoring system utilizing internet of things technology for electric vehicle application

Prabakaran A/L Kalaihrasan¹, Nurfarina Zainal^{1,2}, Nor Hafizah Ngajikin¹, Syarfa' Zahirah Sapuan^{1,2}, Warsuzarina Mat Jubadi¹, Hing Wah Lee³

¹Department of Electrical and Electronic Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

²Advanced Sensing Device and Technology (ASDT) Focus Group, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

³MIMOS Berhad, MRANTI Technology Park, Kuala Lumpur, Malaysia

Article Info

Article history:

Received Apr 27, 2024

Revised Dec 23, 2024

Accepted Mar 9, 2025

Keywords:

Electric vehicle

Electric vehicle charging

Inductive wireless power transfer

Internet of things-based system

Wireless charging

ABSTRACT

Internal combustion engine (ICE) vehicles are major contributors to climate change and pollution, driving the transition to electric vehicles (EVs) as a cleaner alternative. However, EVs encounter challenges with charging infrastructure, notably the need for physical cables and issues with alignment for efficient charging. To address these problems, a wireless EV charging system has been developed using internet of things (IoT) technology for real-time monitoring and control. This system incorporates ESP32 and ESP8266 microcontrollers, infrared sensors, inductive coils, an OLED display, an ESP32-CAM module, relay modules, an AC to DC converter, a TP4056 charging module, a DC voltage sensor, and lithium-ion batteries. It employs a 20-turn coil for inductive coupled wireless power transfer (WPT), enabling the full charging of two lithium-ion batteries within 60 minutes. The system can detect an EV's presence, display battery status on an OLED screen, and provide real-time images of the vehicle's position through the SWEVCS mobile app. Infrared sensors ensure proper and precise alignment for effective charging. This advanced wireless charging solution enhances EV charging efficiency and convenience while supporting a more sustainable energy approach.

This is an open access article under the [CC BY-SA](#) license.



Corresponding Author:

Nurfarina Zainal

Advanced Sensing Device and Technology (ASDT) Focus Group

Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia

Parit Raja, 86400, Batu Pahat, Johor, Malaysia

Email: nurfarina@uthm.edu.my

1. INTRODUCTION

Greenhouse gas emissions have become a global concern over the last few decades because they have a negative impact on the ecosystem and ecology. The change in environmental conditions, known as climate change, causes global warming with effects such as glacier melting, ocean level increasing, floods, droughts, wildlife, or water life declining and becoming extinct [1], [2]. Motor vehicle exhaust emissions were the main contributor to greenhouse gases, where they produced carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (NH₄) gasses. This has caused gases to be trapped in the ozone and produce a heat imbalance in the atmosphere, thus creating global warming [2]. According to the National Oceanic and Atmosphere Administration (NOAA), the United States government believes that most of the total heating imbalance on earth is due to CO₂. It was reported that the heating imbalance of CO₂ versus time has

increased to 66% in 2021 as compared to 60% in 1999 [3]. Under the United Nations Kyoto Protocol, developed countries and industries worldwide have started working together to reduce emissions of heat-trapping gases in the atmosphere to minimize and control climate change disasters [4]. Developing countries such as Malaysia also have strategies for supporting the global effort towards decarbonizing for a better and more sustainable environment, namely the low-carbon mobility blueprint [5]. One of the efforts to minimize vehicle carbon dioxide emissions is using fuel or oil combustion with an alternative and sustainable energy source, such as electric energy. The awareness of this environmental issue, the fluctuation of oil prices, and the depletion of petroleum resources have recently increased the sales of electric vehicles (EVs) among land transportation users [1], [2]. EVs are believed to produce low-carbon energy and are smoke-free [6], [7].

EVs are cars with one or more electric motors that use electricity stored in alternate energy storage systems or rechargeable batteries. EVs dramatically reduce pollution compared to conventional internal combustion engine (ICE) vehicles since they run on electricity instead of fossil fuels. They are becoming more popular because of their higher performance and favorable environmental impact [6]–[9]. In response to the problems posed by climate change and global warming, the Malaysian government has recently aggressively encouraged the use of EVs through several regulations and initiatives meant to stimulate market expansion. These programs support local production capacity and ease the importing of EVs by offering tax exemptions and incentives. Additionally, the government has taken several actions to promote the use of EVs, including reducing import taxes on EV components, exempting EVs from road tax, and launching a green finance program for EV purchases [5], [9]. Malaysia has 2214 EV-installed charging stations, which is anticipated to rise to 10,000 by 2025 [10]. To increase the availability of EV charging infrastructure, the government has set aside funds for the construction of charging stations across the country, including in public spaces and business buildings. Fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), and plug-in hybrid electric cars (PHEVs) are the three main categories of EVs. In contrast to BEVs, which only use electrical energy, and FCEVs, which use a highly efficient electrochemical process to convert hydrogen into electricity that powers an electric motor, the PHEV concept combines electrical and fuel combustion energies [11].

The similarities between PHEVs and BEVs are that both EVs can be recharged from external sources and can operate with zero tailpipe emissions. All types of EVs need traction batteries to store and supply electrical energy. Thus, it requires the charging equipment infrastructure, such as regenerative charging and the plug-in concept. The PHEVs are more efficient and convenient for short-distance drivers, such as city users, as they can benefit from and maximize the regenerative braking charging because they frequently stop. However, BEVs and FCEVs, such as short- and long-distance travelers, exhibit disadvantages, especially when charging the battery, where they need to bring along their connecting cable and plug it into a selected charging wall outlet station [12]. Nevertheless, EV charging station infrastructure can be divided into several groups according to the charging methods they employ, such as Level 1 Trickle Charge (120 V or 220 V), Level 2 AC Charge (208 V to 240 V), and DC Charge (400 V to 900 V) [13]. The contemporary method of charging EVs entails connecting the vehicle to a standard 120 V or 240 V outlet. Users must visit an EV charging station compatible with their vehicles and utilize the appropriate charging cable. However, challenges persist due to the necessity for extensive charging infrastructure and the relatively high initial costs of EVs compared to conventional ICE vehicles. Along with possible risks during the charging process, like an electrical shock from unfavorable weather, these issues also cause customers to experience inconveniences. The creation of a wireless EV charging system offers a viable substitute to address these problems and has the potential to disrupt the charging paradigm as it stands today completely.

Recent developments indicate that the inductive power transfer (IPT) technique may be used to construct wireless EV charging systems successfully [12], [14]–[16]. As opposed to FCEVs, PHEVs, and conventional ICE vehicles, problems including leakage and inductance still impair BEVs mileage performance despite these advancements [12], [14], [15]. Methods for inductive coupled wireless power transmission (WPT), especially inductive coupled power transmission (ICPT) that uses magnetic fields, have been proposed to overcome these constraints. As opposed to traditional systems that share a magnetic core, ICPT reduces leakage inductance by using an air gap between the primary and secondary coils [12], [14], [15]. This inductive coupling enables effective energy transfer via magnetic fields from an inductive coil to the vehicle's battery [6], [13], [15], [16]. Numerous studies have been conducted to develop ICPT systems to increase output power and charging efficiency. Studies cover several elements, such as coupler coil topologies, stationary and dynamic inductive pad designs, reduced air gaps, and wireless charging technology developments [17], [18]. Regardless of the topologies or designs used, Vu *et al.* [17] stress that ideal charging performance depends on the alignment between the coupler coils. To address these alignment challenges and reduce reliance on physical charging cables, the proposed project aims to integrate an internet of things (IoT)-based sensing and monitoring system with the ICPT technique.

In this wireless charging system, the secondary receiving coil is integrated into the vehicle battery, and the primary transmitting coil is located beneath the parking space at the charging station. A magnetic field is created when these coils are properly oriented, which makes power transfer easier. The elimination of physical cables and the reduction of related concerns, including electrical shocks, tripping, falling, fire threats, and weather-related problems, this technology potentially improves user convenience. Using inductive coupling and including cutting-edge features like remote charging control and real-time monitoring, the project aims to create a smart wireless EV charging system. The system uses IoT technology to provide real-time data monitoring and control through an Android mobile application. This invention could promote the shift to electric mobility by improving accessibility and user-friendliness, thereby revolutionizing EV charging. The need for smart wireless charging solutions is anticipated to increase dramatically over the next few decades as the market for electric and hybrid vehicles continues to develop.

2. METHOD

2.1. Inductive wireless power transfer and charging system

One of the most important technologies in wireless power transfer (WPT) is inductive coupling, which allows electrical energy to be sent without a physical connection [13], [19], [20]. A magnetic field, which develops when two conductors are inductively or magnetically connected, is used in this method to transfer power between wire coils. This phenomenon is defined by a change in one wire's current that, using the electromagnetic induction principle, creates a voltage across the other wire's terminals. According to Ampere's circuital law, a fluctuating current in the first wire creates a magnetic field around it. Faraday's law of induction causes an electromotive force (EMF) to be induced in the second wire due to this fluctuating magnetic field [20]. In electromagnetics, the mutual inductance parameter is used to quantify the degree of inductive coupling between two conductors. A transmitting coil and a receiving coil are the two main components of the process. Figure 1(a) shows a power source, typically an AC power supply, connected to the transmitting coil [21]. When an AC flows through the transmitting coil, it creates a time-varying magnetic field [18], [21]. The receiving coil, which is placed near the transmitting coil, is designed to resonate at the same frequency as the transmitting coil. This resonance is achieved by tuning the capacitive and inductive elements of the receiving coil. When the time-varying magnetic field from the transmitting coil interacts with the receiving coil, it induces an AC in the receiving coil. The received coil's induced current could power electronic devices or charge batteries. Inductive coupling is the most widely used wireless technology; its applications include charging handheld devices like phones and electric toothbrushes, RFID tags, induction cooking, and wirelessly charging or continuous WPT in implantable medical devices like artificial cardiac pacemakers [22], [23].

Efficient power transfer over short distances in inductive coupling power transfer (ICPT) systems can be optimized by adjusting coil design parameters, including size, number of turns, and resonance frequency [24], [25]. In ICPT, mutual coupling occurs between the primary inductor (L_p) and the secondary inductor (L_s), characterized by mutual inductance (M_{ps}) and the coupling factor (k), as detailed in (1) [18], [25]. The equivalent circuit representation is shown in Figure 1(b). The coupling factor, k , varies between 0 and 1 based on the flux linkage between the primary and secondary charging pads, which is particularly relevant for loosely coupled systems like wireless EV chargers [18]. To assess coupling performance under various alignment conditions, the efficiency (η) of the uncompensated inductive link can be evaluated independently of the other circuits, as expressed in (2), where Q_p is the primary coil quality, and Q_s is the secondary coil quality [18]. This efficiency is influenced by the coil quality factors (Q_p and Q_s), mutual conductance, and coupling behavior, with coil quality factors defined by (3) and (4), where ω_o represents the operating frequency and R_p and R_L denote resistances at the primary and secondary sides [18]. Notably, IPT adheres to the inverse square law, meaning power transfer efficiency declines rapidly with increasing distance. Therefore, maintaining a minimal distance between transmitting and receiving coils is crucial for optimal power transfer.

$$k = \frac{M_{ps}}{\sqrt{L_p L_s}} \quad (1)$$

$$\eta = \frac{k^2 Q_p Q_s}{(1 + k^2 Q_p Q_s)^2} \quad (2)$$

$$Q_p = \frac{\omega_o L_p}{R_p} \quad (3)$$

$$Q_s = \frac{\omega_o L_s}{R_s} \quad (4)$$

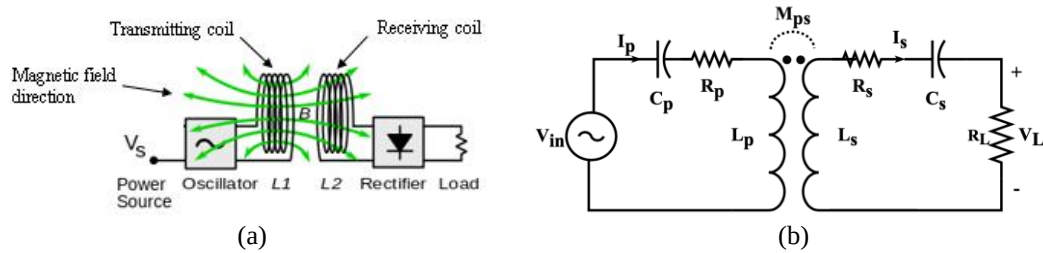


Figure 1. Generic block diagram of; (a) an inductive wireless power system [21] and (b) schematic diagram of the network connected to the primary and secondary coils [18]

In this project, the coil shapes are reviewed to identify the suitable design for a WPT system that is suitable for the development of a smart wireless EV charging system. An air-core wireless transformer design is used in the WPT system to enable electrical power flow from the source to the receiver sides. There are several planar coil shapes, such as circular, rectangular, and hybrid configurations, that are used to improve the performance and solve the misalignment problems between the transmitter and receiver of a wireless charging system [26]. Rectangular and hybrid configuration coils suffer from high impedance and hot spots, thus making them unsuitable for high-power applications [26], [27].

Square and circular coils are less tolerant of horizontal misalignment than rectangular coils [26], [27]. Conversely, the circular coil design is a well-known and extensively utilized design in wireless transformers due to its lack of sharp edges and ability to minimize eddy currents. The coil's internal diameter can be changed to adjust the magnetic flux distribution. Smaller center diameters can increase the coupling coefficient because of the spike-like form of the magnetic field. Increasing the center diameter, on the other hand, addresses possible misalignment problems by providing a wider magnetic flux distribution area, albeit at the sacrifice of amplitude [28]. Consequently, it can be concluded that the circular coil configuration is the more advantageous design for this project aimed at WPT, as it minimizes misalignment between the transmitter and receiver coils.

Dynamic wireless electric vehicle charging systems (D-WEVCS) and static wireless electric vehicle charging systems (S-WEVCS) are the two primary categories into which recent research has divided wireless EV charging systems [26], [29]. Under S-WEVCS, a primary coil is installed underground or beneath the ground, and it is augmented by electronics and power converters to improve its performance [28], [29]. Usually, the secondary coils are found beneath different parts of the electric car, such as the front, back, or center. This setup makes it easier for the power converter to transform the received energy from AC to DC, which is then stored in the vehicle's battery bank. Power control and battery management systems are combined with a wireless communication network that offers primary feedback to assure safety and efficiency. The duration of the charging process is governed by elements such as the source's power level, the diameters of the charging pads, and the air gap distance between the primary and secondary coils.

In static systems, the secondary coil remains mounted beneath the vehicle, where it captures the magnetic field generated by the primary coil to convert the energy into DC and charge the battery through the power converter and management system. Compared to conventional EVs, frequent charging with static systems can reduce the overall battery requirement by approximately 20% [29]. Conversely, D-WEVCS are designed for dynamic charging, where the primary coils are embedded into the road surface at predetermined intervals. These coils operate with high voltage and high-frequency AC sources, along with compensation circuits connected to the microgrid [29]. The installation of transmitter pads and power supply segments must be meticulously planned along specific routes to facilitate this type of charging. Despite its advantages, the higher costs associated with D-WEVCS lead to the preference for S-WEVCS in current project developments and proof-of-concept demonstrations.

At present, EV charging methods predominantly rely on manual processes, with a significant gap in fully automated technologies and monitoring systems. To address the challenges of misalignment and infrastructure limitations associated with charging cables, this study conducts a thorough investigation into the performance of wireless charging through inductive coupled WPT, with particular emphasis on the ICPT methodology. In this research, a circular configuration was selected for both the primary (Tx) and secondary (Rx) coils, which have been integrated into a prototype EV and an intelligent parking system. The study explores the concept of S-WEVCS and evaluates battery charging performance through the proposed integration of this parking system with IoT-based technology. Notably, the integration system developed and proposed in this study represents a novel approach, as it has not been previously addressed by other

researchers. This integration aims to ensure precise alignment of the EV during parking and charging processes facilitated by the advanced IoT system. The anticipated efficacy of this approach indicates substantial potential for its application in future EV technologies. Detailed information regarding the integration system is elaborated in subsection 2.2.

2.2. Prototype of wireless electric vehicle charging and monitoring system with internet of things technology

To clarify the operational principles and functionality of a wireless charging and monitoring system utilizing IoT technology for EV applications, this project has developed two distinct circuit systems: a parking spot system and a prototype EV model. Both systems are equipped with Wi-Fi connectivity and are integrated with an Android mobile application. The design incorporates circular coil shapes with static wireless charging systems for EVs.

By enabling wireless charging and real-time monitoring, the suggested system seeks to greatly improve user convenience by doing away with the need for a physical charging cable and expediting the process of finding appropriate charging stations. An ESP32 NodeMCU microcontroller controls the parking spot circuit system, which consists of transmitting (Tx) coils, relays, an AC-to-DC converter, infrared sensors, and a camera for EV detection. The camera turns on and sends a real-time image of the parking space to the mobile application over a web server when the infrared sensors identify an EV.

A TP4056 charging module, lithium-ion batteries, an OLED display, a DC voltage sensor, and receiving (Rx) coils are all part of the prototype EV circuit system, which is controlled by an ESP8266 NodeMCU microcontroller. After detecting an EV in the assigned parking space and verifying that the Tx and Rx coils are precisely aligned, the infrared sensor initiates wireless charging, resolving any misalignment issues that can reduce charging efficiency. The designed wireless EV charging and monitoring system, which uses inductive coupling WPT techniques, has a detailed block diagram illustrated in Figure 2. By using an electromagnetic field, this technique transfers electrical energy without the use of wires or physical contacts.

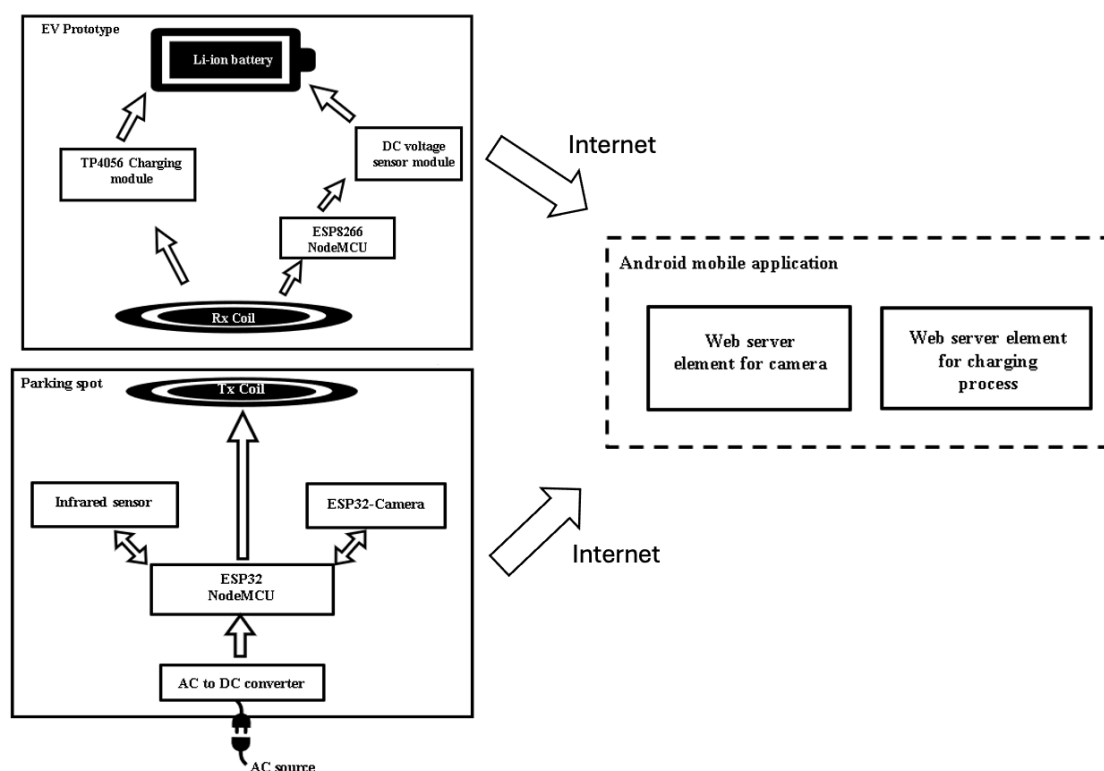


Figure 2. Overview block diagram of the wireless EV charging and monitoring system

To assess the effectiveness of electromagnetic field transfer between the Tx and Rx coils, this study explored the optimal air gap distance between them. The Tx coils are strategically positioned at the parking spot, while the Rx coils are installed within the prototype EV. Various air gap distances were tested to determine the configuration that achieves an optimal 5 V output. As underscored in the theoretical

framework, the air gap between the Tx and Rx coils is a critical factor for efficient power transfer; therefore, identifying the optimal configuration was a key focus of this investigation. Table 1 outlines the parameters for the 20-turn coils utilized in this investigation. Furthermore, a time versus voltage analysis was conducted to determine the duration necessary for fully charging the lithium-ion batteries and to assess their overall efficiency. For this research, each lithium-ion battery was considered fully charged at 3.2 V. Detailed findings from this analysis are thoroughly discussed in the results and discussion section.

Table 1. Overview of coil parameters

Parameter	Unit
Input voltage	9–12 V
Operating current	1.3 A
Receiver output voltage	5 V/2 A
Transmitter coil size	43 mm
Receiver coil size	43 mm
Transmitter coil thickness	2.3 mm
Receiver coil thickness	1.2 mm
Receiver common distance	3–6 mm

Figures 3 and 4 illustrate the prototype model of the wireless EV charging system associated with parking spots and Android mobile, the SWEVCS app developed in this study. This system comprises four infrared sensors, Tx and Rx coils, and an ESP32 camera module, all employed to detect the presence of an EV. The sensor operation, camera, and mobile application are synchronized through IoT-based technology to ensure seamless functionality. As depicted in Figure 3(a), the circuit system, integrated with the camera, enables real-time monitoring of the EV while it is parked. This feature is essential for effectively managing and overseeing the vehicle's status within the parking spot. The real-time image of the parking position is accessible via a mobile application. The Android mobile application, referred to as the SWEVCS app and illustrated in Figure 3(b), includes a graphical user interface (GUI) with four user-controlled buttons for operating the camera, initiating and halting battery charging, and monitoring the battery level.

Upon detection of an EV entering the parking spot by the sensors, the camera is activated to monitor the vehicle's alignment and parking position. When the EV is correctly positioned, the inductive coupling coil begins charging. Electrical energy is transferred from the transmitting coil, located under the parking spot, as shown in Figure 4(a), to the receiving coil within the prototype EV model as Figure 4(b). The EV user can monitor the charging percentage via both the Android mobile application and the OLED display on the EV model. The system utilizes an ESP32 NodeMCU module as the primary control unit, managing the infrared sensors, relay module, ESP32 camera, and transmitter coil. A secondary ESP8266 NodeMCU module controls the charging module, OLED display, and DC voltage sensor. The entire system is powered by an AC source, which is converted to a DC supply by an AC-DC converter module.

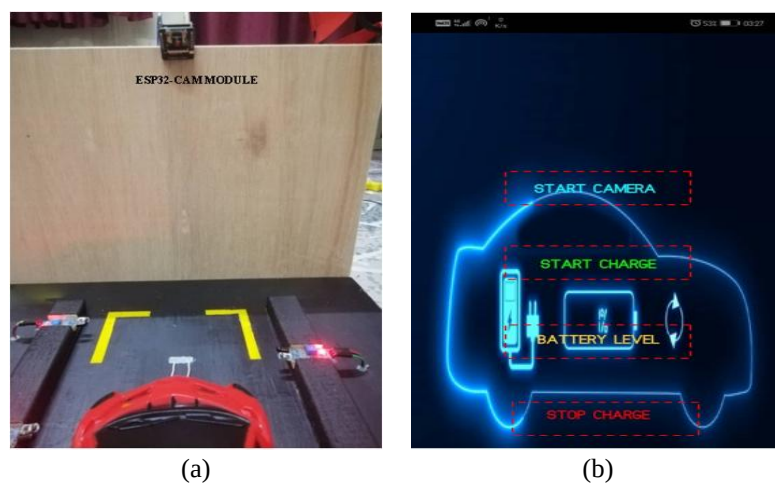


Figure 3. Prototype EV parking spot model equipped with; (a) camera ESP32 module mounted at the parking wall and (b) image GUI of SWEVCS app display on a mobile application

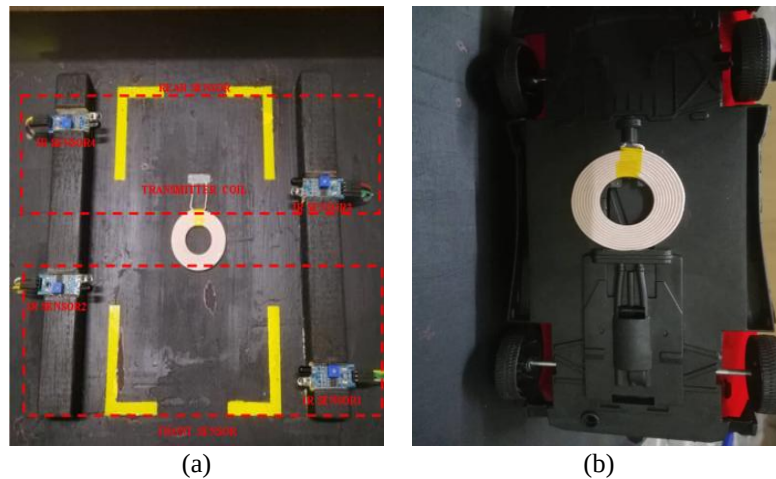


Figure 4. Prototype EV parking spot model equipped with; (a) four sensors and Tx coils and (b) Rx coils located at the bottom of EV prototype model

The wireless EV charging and monitoring system developed in this study enables users to oversee the positioning of their EVs within the parking spot through the SWEVCS app, as illustrated in Figure 3(b). Upon detection of the EV's front by an infrared sensor positioned at the front of the parking spot, the ESP32 camera is activated. If the user selects the "start camera" option, the system initiates camera streaming via the app, allowing the user to monitor the vehicle's position in real-time. Should the user opt not to activate the camera, the system promptly advances to the next stage, which involves detection by the rear infrared sensors. Once all four infrared sensors, both front and rear, confirm the presence of the EV, the camera is deactivated. To begin the charging process, the user must click the "start charge" button in the program. This button engages the transmitter coil, which uses the inductively coupled WPT method to charge the EV. Both the SWEVCS app and the OLED screen allow users to keep an eye on the battery percentage. Users can view the current battery percentage and voltage measurements by choosing the "battery level" button within the application. Additionally, the app provides the option to press the "stop charge" button to end the charging process once the desired battery level is reached. If this option is not used, the charging process will end automatically when the battery is fully charged.

3. RESULTS AND DISCUSSION

3.1. Electric vehicle prototype charging model system

The experimental prototype model for a wireless EV charging and monitoring system using the inductive WPT technology is verified in this part as a proof of concept. In the setting of 20-turn coils, the development and testing of the parking slot systems and the EV prototype were conducted with an emphasis on the change of the air gap distance between the Tx and Rx coils. According to earlier studies, one of the most important factors in attaining effective charging performance is the air gap distance between the Tx and Rx [17], [18], [25]–[30]. This study aimed to get a maximum battery charging voltage of 5 volts by analyzing air gap distances from 0 mm to 14 mm. Power for the system is supplied by an AC-DC converter circuit, which transforms 240 V AC into 5 V DC, essential for the operation of the ESP32 microcontroller and infrared sensors.

The results indicate a maximum receiving voltage of 5 V was attained for air gaps between 0 mm and 10 mm. However, as the air gap increased from 12 mm to 14 mm, the receiving voltage decreased to 4.5 V and ultimately reached zero volts, as illustrated in Table 2. This decline in voltage with increasing air gap distance aligns with theoretical expectations, given that a wider gap diminishes the strength of the electromagnetic field, as discussed in section 2.1. These findings corroborate trends observed in similar studies [26], [30], thus validating the methodology employed in this investigation. The results suggest that further in-depth research, potentially examining additional parameters such as the number of coil turns, could yield valuable insights into their effects on system performance, particularly concerning varying air gap distances.

Table 2. Results of the receiving voltage with a different air gap between Tx and Rx coils

Gap (mm)	Voltage (V)
0	5
2	5
4	5
6	5
8	5
10	5
12	4.5
14	0

This study provides a comprehensive analysis of battery charging times and efficiency within a wireless EV charging system. The experimental configuration employed a 6 mm air gap between the coupling coils (Tx and Rx), which was chosen for its ability to deliver a maximum receiving voltage of 5 volts. The observed charging times varied from 20 minutes to 160 minutes and involved testing two lithium-ion batteries, each with a capacity of 3.2 volts, resulting in a combined total of 7.4 volts.

The results, presented in Table 3, indicate a significant increase in voltage with prolonged charging durations. Specifically, after 20 minutes, the battery reached a minimum receiving voltage of 1.12 volts, while achieving a full charge of 7.4 volts for both batteries required a total of 160 minutes. The efficiency of the received voltage values from the lithium-ion batteries was calculated using (5), with the results depicted in Figure 5. The study determined that full battery efficiency, defined as 100% charge, was attained within 160 minutes. This efficiency was positively impacted by the alignment system between the Tx and Rx coils, facilitated by the IoT-based sensing system employed in this project.

Table 3. Results of time charging versus voltage and efficiency

Charging tim (mins)	Voltage (V)	Efficiency (η) (%)
20	1.12	13.51
40	2.38	32.16
60	3.46	46.76
80	4.22	57.03
100	5.41	73.11
120	6.13	82.84
140	6.89	93.11
160	7.40	100

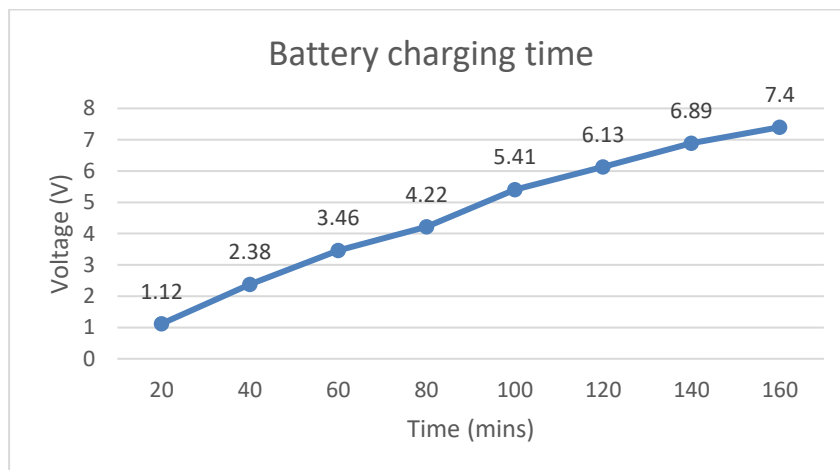


Figure 5. Graph of receiving voltage versus charging time

The system used 20-turn coils; variations in coil size are expected to influence charging times, with more turns potentially resulting in shorter charging durations and fewer turns necessitating longer times, given the fixed air gap distance, which can be investigated further in this project. These findings are consistent with the results reported by other researchers [18], [25], [30], underscoring the system's effectiveness in optimizing battery performance for wireless EV charging.

$$\text{Efficiency } (\eta) = \frac{\text{Voltage obtained}}{\text{Total voltage}} \times 100 \quad (5)$$

3.2. Electric vehicle prototype parking slot model system

Figure 6 illustrates the prototype parking space equipped with four infrared sensors and a transmitter coil, as observed during the pilot testing phase of the LED condition. The four infrared sensors interface with the ESP32 microcontroller, while the transmitter coil is connected to a relay module, which in turn is linked to the ESP32. In the absence of power, the LED remains in the off state, as depicted in Figure 6(a). Conversely, when power is supplied, the power LED on the infrared sensor illuminates, as shown in Figure 6(b). This indicates that the infrared sensor has been activated and is prepared to detect the EV.

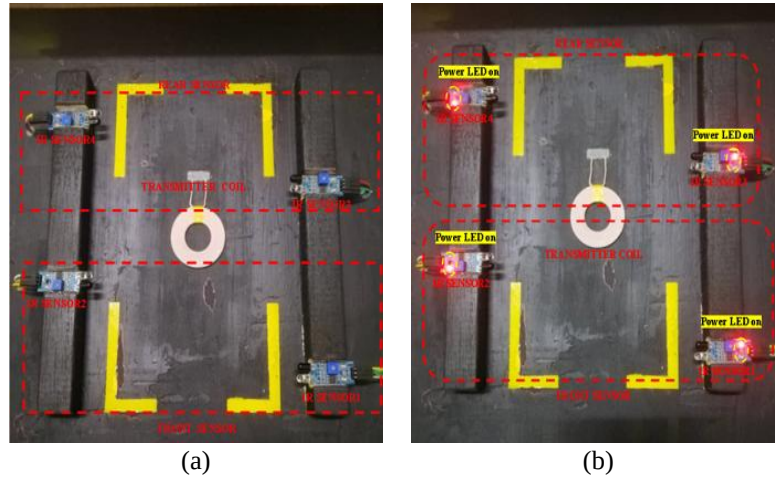


Figure 6. Parking spot with four infrared sensors and transmitter coil when; (a) power off and (b) power on

The integration of IoT technology and internet connectivity within the circuit system designed and developed in this study has demonstrated successful functionality, as evidenced by the results in Figures 7 and 8. This advancement effectively addresses and mitigates the alignment issues commonly associated with current WPT methods. As illustrated in Figure 7(a), the entry of the EV model into the parking spot is detected by the front infrared sensors (IR sensor 1 and IR sensor 2). This detection activates the ESP32-CAM module through the relay module, enabling the live streaming of the parking spot to the mobile application. Upon pressing the “start camera” button in the SWEVCS app, as shown in Figure 7(b), the camera stream initiates, and Figure 7(c) displays the streaming view of the entire parking area via the mobile SWEVCS application.

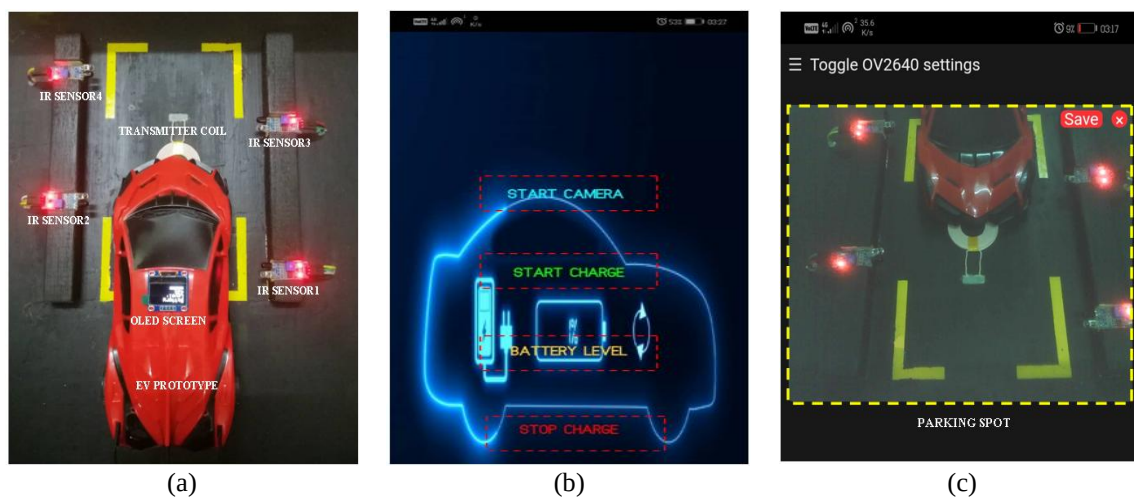


Figure 7. Parking spots that are streaming via the SWEVCS application; (a) parking spot with four infrared sensors and transmitter coil, (b) GUI of mobile SWEVCS app, and (c) streaming image on mobile phone

Once both the front and rear infrared sensors confirm the proper alignment of the EV prototype model with the coupling coils, the ESP32-CAM module is deactivated. The charging process is initiated by pressing the “start charge” button in the SWEVCS app. This action activates the transmitter coil, connected to the relay module, to commence charging the EV prototype. Results in Figure 8(a) depict the fully parked EV prototype with aligned coupling coils, while Figure 8(b) illustrates the SWEVCS app displaying the battery percentage and voltage alongside the OLED display located on the EV prototype model. Users have the option to terminate the charging process by selecting the “stop charge” button in the SWEVCS app. If the “stop charge” button is not pressed, the system will automatically cease charging upon reaching the full charge capacity of the EV prototype.

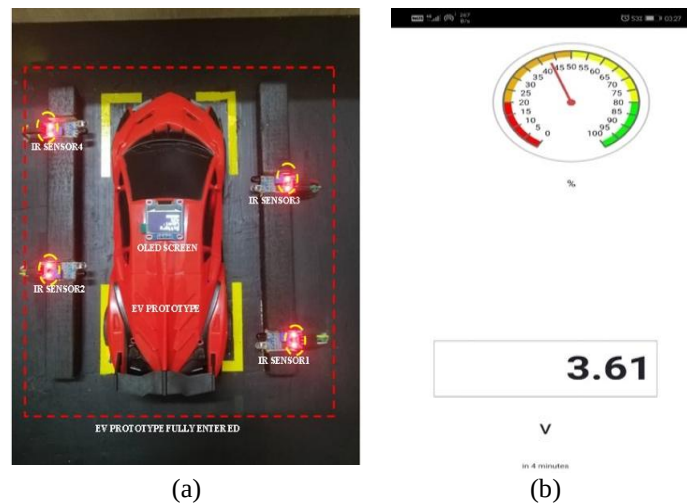


Figure 8. Car position in the parking spot and charging status of; (a) EV prototype model fully entered the parking spot and (b) display of the battery percentage and voltage on SWEVCS app

4. CONCLUSION

This project has successfully designed and developed a prototype wireless EV charging system that offers real-time monitoring and control of the charging process through an Android mobile application, leveraging IoT technology. The system effectively detected EVs in designated parking spots and displayed battery status in real-time via the SWEVCS app, as intended. Utilizing inductive WPT with a 20-turn coil and inductive coupling (Tx and Rx) in a circular pattern, along with static-WEVCS, the system's infrared (IR) sensors accurately identified the presence of EVs. Upon proper and precise alignment of the Tx and Rx coils, the system-initiated charging and the battery percentage were displayed on both the Android SWEVCS mobile app and an OLED screen. The successful integration of WPT with IoT technology demonstrates the system's capability to address current EV charging challenges, providing a reliable, practical, and convenient solution. This technology also holds promise for applications beyond EV charging, including potential uses in the telecommunication industry and implantable biomedical devices. Future research will explore different coil turns and air-gap distances between Tx and Rx to enhance charging efficiency and reduce charging times.

ACKNOWLEDGMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through research grant TIER 1 (Vot. Q371).

FUNDING INFORMATION

This research was funded by Universiti Tun Hussein Onn Malaysia (UTHM) under the TIER 1 research grant scheme. The specific grant awarded for this project is identified as Vot. Q371. TIER 1 grants are typically allocated to support internal research initiatives and promote academic advancement within the university.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Prabakaran A/L Kalaihrasan			✓			✓	✓		✓		✓			
Nurfarina Zainal	✓	✓		✓	✓		✓	✓	✓	✓		✓		✓
Nor Hafizah Ngajikin						✓	✓			✓				✓
Syarfa' Zahirah Sapuan					✓					✓			✓	✓
Warsuzarina Mat Jubadi				✓	✓					✓				
Hing Wah Lee	✓									✓		✓		✓

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nterpretation

R : **R**esources

D : **D**ata Curation

O : **O**riginal Draft

E : **E**diting

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article [and/or its supplementary materials].

REFERENCES

- [1] A. E. Atabani, I. A. Badruddin, S. Mekhilef, and A. S. Silitonga, "A review on global fuel economy standards, labels and technologies in the transportation sector," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9, pp. 4586–4610, Dec. 2011, doi: 10.1016/j.rser.2011.07.092.
- [2] N. Mohamed *et al.*, "A new wireless charging system for electric vehicles using two receiver coils," *Ain Shams Engineering Journal*, vol. 13, no. 2, pp. 1–15, Mar. 2022, doi: 10.1016/j.asej.2021.08.012.
- [3] R. Lindsey, "Climate Change: Annual greenhouse gas index," www.climate.gov. [Online]. Available: <https://www.climate.gov/news-features/understanding-climate/climate-change-annual-greenhouse-gas-index>. (Date accessed: Apr. 26, 2024).
- [4] Y. D. Boer, "Kyoto Protocol, Reference Manual on Accounting of Emissions and Assigned Amount," unfccc.int. [Online]. Available: https://unfccc.int/sites/default/files/08_unfccc_kp_ref_manual.pdf. (Date accessed: Dec. 15, 2024).
- [5] Ministry of Environment and Water (KASA), "Low Carbon Mobility Blueprint 2021–2030 Decarbonizing Land Transportation," www.mgmc.gov.my. [Online]. Available: <https://www.mgmc.gov.my/wp-content/uploads/2021/11/Low-Carbon-Mobility-Blueprint-2021-2030.pdf>. (Date accessed: Dec. 15, 2024).
- [6] R. W. Wimbadi, R. Djalante, and A. Mori, "Urban experiments with public transport for low carbon mobility transitions in cities: A systematic literature review (1990–2020)," *Sustainable Cities and Society*, vol. 72, p. 103023, Sep. 2021, doi: 10.1016/j.scs.2021.103023.
- [7] S. Mittal, H. Dai, and P. R. Shukla, "Low carbon urban transport scenarios for China and India: A comparative assessment," *Transportation Research Part D: Transport and Environment*, vol. 44, pp. 266–276, May 2016, doi: 10.1016/j.trd.2015.04.002.
- [8] F. Alanazi, "Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation," *Applied Sciences (Switzerland)*, vol. 13, no. 10, p. 6016, May 2023, doi: 10.3390/app13106016.
- [9] Sustainable Energy Development Authority (SEDA) Malaysia, "Malaysia Renewable Energy Roadmap (MYRER), Pathway Towards Low Carbon Energy System," www.seda.gov.my. [Online]. Available: https://www.seda.gov.my/reportal/wp-content/uploads/2021/12/MyRER_webVer-1.pdf. (Date accessed: Dec. 15, 2024).
- [10] Malaysian Investment Development Authority (MIDA), "MITI maintains 10,000 EV Chargers target by 2025, 2,214 installed so far," www.mida.gov.my. [Online]. Available: <https://www.mida.gov.my/mida-news/miti-maintains-10000-ev-chargers-target-by-2025-2214-installed-so-far/>. (Date accessed: Dec. 15, 2024).
- [11] B. Tanç, H. T. Arat, E. Baltacıoğlu, and K. Aydın, "Overview of the next quarter century vision of hydrogen fuel cell electric vehicles," *International Journal of Hydrogen Energy*, vol. 44, no. 20, pp. 10120–10128, Apr. 2019, doi: 10.1016/j.ijhydene.2018.10.112.
- [12] K. A. Kalwar, M. Aamir, and S. Mekhilef, "Inductively coupled power transfer (ICPT) for electric vehicle charging - A review," *Renewable and Sustainable Energy Reviews*, vol. 47, pp. 462–475, Jul. 2015, doi: 10.1016/j.rser.2015.03.040.
- [13] A. Rachid *et al.*, "Electric Vehicle Charging Systems: Comprehensive Review," *Energies*, vol. 16, no. 1, pp. 1–38, Dec. 2023, doi: 10.3390/en16010255.

- [14] A. F. A. Aziz, M. F. Romlie, and Z. Baharudin, "Review of inductively coupled power transfer for electric vehicle charging," *IET Power Electronics*, vol. 12, no. 14, pp. 3611–3623, Nov. 2019, doi: 10.1049/iet-pel.2018.6011.
- [15] J. Xu, Y. Xu, and Q. Zhang, "Calculation and analysis of optimal design for wireless power transfer," *Computers and Electrical Engineering*, vol. 80, p. 106470, Dec. 2019, doi: 10.1016/j.compeleceng.2019.106470.
- [16] J. Sallán, J. L. Villa, A. Llombart, and J. F. Sanz, "Optimal design of ICPT systems applied to electric vehicle battery charge," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 6, pp. 2140–2149, Jun. 2009, doi: 10.1109/TIE.2009.2015359.
- [17] V. B. Vu *et al.*, "Operation of Inductive Charging Systems Under Misalignment Conditions: A Review for Electric Vehicles," *IEEE Transactions on Transportation Electrification*, vol. 9, no. 1, pp. 1857–1887, Mar. 2023, doi: 10.1109/TTE.2022.3165465.
- [18] E. Elghanam, M. Hassan, A. Osman, and H. Kabalan, "Design and performance analysis of misalignment tolerant charging coils for wireless electric vehicle charging systems," *World Electric Vehicle Journal*, vol. 12, no. 3, p. 89, Jun. 2021, doi: 10.3390/wevj12030089.
- [19] C. A. Baguley, S. G. Jayasinghe, and U. K. Madawala, "Theory and control of wireless power transfer systems," in *Control of Power Electronic Converters and Systems*, 2018, vol. 2, pp. 291–307, doi: 10.1016/B978-0-12-816136-4.00023-3.
- [20] C. Degen, "Inductive coupling for wireless power transfer and near-field communication," *Eurasip Journal on Wireless Communications and Networking*, no. 1, pp. 1–20, Dec. 2021, doi: 10.1186/s13638-021-01994-4.
- [21] D. Ustun, S. Balci, and K. Sabanci, "A parametric simulation of the wireless power transfer with inductive coupling for electric vehicles, and modelling with artificial bee colony algorithm," *Measurement: Journal of the International Measurement Confederation*, vol. 150, p. 107082, Jan. 2020, doi: 10.1016/j.measurement.2019.107082.
- [22] M. Haerinia and R. Shadid, "Wireless Power Transfer Approaches for Medical Implants: A Review," *Signals*, vol. 1, no. 2, pp. 209–229, Dec. 2020, doi: 10.3390/signals1020012.
- [23] S. R. Khan, S. K. Pavuluri, G. Cummins, and M. P. Y. Desmulliez, "Wireless power transfer techniques for implantable medical devices: A review," *Sensors*, vol. 20, no. 12, pp. 1–58, Jun. 2020, doi: 10.3390/s20123487.
- [24] C. T. Rim, "Wireless Charging of Electric Vehicles," in *Power Electronics Handbook, Fourth Edition*, Elsevier, 2017, pp. 1113–1137, doi: 10.1016/B978-0-12-811407-0.00038-6.
- [25] Y. Geng, T. Wang, S. Xie, and Y. Yang, "Analysis and Design of Wireless Power Transfer Systems Applied to Electrical Vehicle Supercapacitor Charge Using Variable-Resistance-Based Method," *Energies*, vol. 15, no. 16, pp. 1–15, Aug. 2022, doi: 10.3390/en15165867.
- [26] M. Amjad, M. Farooq-i-Azam, Q. Ni, M. Dong, and E. A. Ansari, "Wireless charging systems for electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 167, p. 112730, Oct. 2022, doi: 10.1016/j.rser.2022.112730.
- [27] W. Chen, C. Liu, C. H. T. Lee, and Z. Shan, "Cost-effectiveness comparison of coupler designs of wireless power transfer for electric vehicle dynamic charging," *Energies*, vol. 9, no. 11, p. 906, Nov. 2016, doi: 10.3390/en9110906.
- [28] W. Xie, Q. G. Chen, and S. Z. Lei, "An Optimized Design of an Electric Vehicle Wireless Charging Coupling Coil," *Journal of Physics: Conference Series*, vol. 2125, no. 1, pp. 1–12, Nov. 2021, doi: 10.1088/1742-6596/2125/1/012035.
- [29] C. Panchal, S. Stegen, and J. Lu, "Review of static and dynamic wireless electric vehicle charging system," *Engineering Science and Technology, an International Journal*, vol. 21, no. 5, pp. 922–937, Oct. 2018, doi: 10.1016/j.jestch.2018.06.015.
- [30] A. A. S. Mohamed, A. A. Shaier, H. Metwally, and S. I. Seleem, "Wireless charging technologies for electric vehicles: Inductive, capacitive, and magnetic gear," *IET Power Electronics*, vol. 17, no. 16, pp. 3139–3165, Dec. 2023, doi: 10.1049/pel2.12624.

BIOGRAPHIES OF AUTHORS



Prabakaran A/L Kalaihrasan    received his Diploma in Electronic Engineering from Ungku Omar Polytechnic, Ipoh, Malaysia in 2020. He continues undergraduate studies at Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) and received Bachelor of Electronic Engineering in 2024. He experienced in troubleshooting, designing, and building automation solutions for industrial at Chinga Light Industries Sdn Bhd as a part-time assistance engineer in 2023-2024. His research interest mainly on automation, monitoring and sensing system, electric vehicle (EV) and IoT-based technology. He can be contacted at email: prabakaran.kalaihrasan@gmail.com.



Nurfarina Zainal    is senior lecturer at the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). She received her Master of Engineering (M.Eng.) in Electrical and Electronic Engineering from Swansea University, United Kingdom, 2008. She continues postgraduate study and receives her Ph.D. in Electrical and Electronic Engineering at Queen's University of Belfast, United Kingdom in 2014. Currently she is member of Advanced Sensing Device and Technology (ASDT) Focus Group and advisor for the clean room laboratory. Her research interests include novel semiconductor, micro and nanofabrication, nanotechnology, sensor technology (microelectronics, biosensor, antenna at TeraHz), monitoring and sensing system, electric vehicle (EV) and IoT-based technology. She can be contacted at email: nurfarina@uthm.edu.my.



Nor Hafizah Ngajikin    is currently senior lecturer at the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). She received her Bachelor and Master Engineering from Universiti Teknologi Malaysia (UTM) in 2001 and 2003, respectively. She was awarded a Ph.D. from UTM for her work on MEMS Fabry-Perot optical tunable filter. From 2004–2017, she served as a senior lecturer and researcher at Lightwave Communication Research Group (LCRG), UTM. Her research interests are primarily included optical devices and sensors. She can be contacted at email: norhafizah@uthm.edu.my.



Syarfa' Zahirah Sapuan    is currently Associate Professor at the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). She received her Bachelor Engineering (B.Eng.) in Electrical engineering from Kolej Universiti Tun Hussein Onn (KUiTTTHO), Malaysia, in 2006. She continues postgraduate study and receives Master of Science (M.Sc.) in Communication Engineering from Nanyang Technological University (NTU), Singapore, in 2009, and her Ph.D. from Universiti Tun Hussein Onn Malaysia (UTHM) in 2014. Previously, she was the principal researcher of the EMC Cluster under EMCenter, UTHM. She is involved with several EMC projects and consultations. Her research interests include EMC, EMI, EMF radiation to humans, antenna calibration and design, and RF. She can be contacted at email: syarfa@uthm.edu.my.



Warsuzarina Mat Jubadi    is currently senior lecturer at the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). She received her Bachelor and Master Engineering from Universiti Teknologi Malaysia (UTM) in 2001 and 2006, respectively. She was awarded a Ph.D. from University of Manchester, United Kingdom in 2015. Her research interests are primarily included analog and digital IC design, semiconductor device modeling, device fabrication and process simulation, and IoT-based technology. She can be contacted at email: suzarina@uthm.edu.my.



Hing Wah Lee    is Principle researcher and Head of Semiconductor R&D, MIMOS Berhad. He received his Bachelor of Engineering (B.Eng.) in Mechanical Engineering from Universiti Sains Malaysia (USM) in 2004. He continues postgraduate study and receives Master of Science (M.Sc.) in Mechanical Engineering in 2006, and Ph.D. in MEM and NEM Nanotechnology in 2010 from Universiti Sains Malaysia (USM), respectively. He has more than 19 years of industrial experience as a researcher in area semiconductor technology, nanomaterials synthesis and characterization, device platform for sensors and electronics application. He has produced 20 granted patents and 50 journals publications. He is currently Technical Executive/Manager at Selangor Information Technology and Digital Economy (Sidec), Malaysia. He can be contacted at email: highwah.lee@mimos.my or hingwah@sidec.com.my.