ARTIFICIAL INTELLIGENCE

AI-Based Dynamic Wireless Charging Lane for Electric Vehicles

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Abstract

The increasing adoption of electric vehicles (EVs) has created a growing demand for efficient and convenient charging technologies. Conventional plug-in charging systems require vehicles to remain stationary for extended periods, limiting operational flexibility and contributing to range anxiety. To address these challenges, this paper proposes an AI-Based Dynamic Wireless Charging Lane for Electric Vehicles, which enables wireless power transfer to moving electric vehicles through inductive coupling. The proposed system utilizes transmitter and receiver coils to transfer electrical energy without physical connections. An intelligent vehicle detection and coil alignment mechanism is incorporated using infrared (IR) and Hall effect sensors to identify vehicle presence and determine the alignment condition between the coils. A machine learning-based decision tree classification model is employed to analyze sensor data and classify the coil position as aligned or misaligned. Based on the classification outcome, the charging control mechanism regulates the activation of the wireless power transfer system to ensure efficient energy transmission. The received electrical energy is processed through a power conditioning circuit and supplied to the rechargeable battery. By integrating artificial intelligence with dynamic wireless power transfer, the proposed approach aims to improve charging convenience, reduce dependency on stationary charging infrastructure, and support the development of intelligent electric vehicle transportation systems.

Keywords: Artificial Intelligence; Coil Alignment Detection; Decision Tree Classification; Dynamic Wireless Power Transfer (DWPT); Electric Vehicles; Hall Effect Sensor; Inductive Coupling; Machine Learning

1 Introduction

The rapid growth in the adoption of Electric Vehicles (EVs) has increased the demand for efficient, reliable, and convenient charging technologies. Electric vehicles are considered a promising alternative to conventional fuel-based vehicles due to their reduced greenhouse gas emissions, lower operating costs, and contribution towards sustainable transportation. However, the limited driving range, long charging duration, and dependency on stationary charging stations remain significant challenges affecting the widespread adoption of electric vehicles. Conventional plug-in charging systems require vehicles to stop at designated charging points, resulting in charging delays and limiting continuous vehicle operation. Therefore, the development of advanced charging technologies that can overcome these limitations has become increasingly important.

Dynamic Wireless Power Transfer (DWPT) is an emerging technology that enables electric vehicles to receive electrical energy while moving over specially equipped charging lanes. This technology is

based on the principle of electromagnetic induction, in which electrical energy is transferred from a transmitter coil embedded beneath the road surface to a receiver coil installed in the vehicle. When alternating current flows through the transmitter coil, it generates a varying magnetic field that induces voltage in the receiver coil. The received electrical energy is subsequently processed through a power conditioning circuit and supplied to the vehicle battery. This approach eliminates the requirement for direct physical connections and provides the possibility of charging electric vehicles during motion.

Despite its advantages, the performance of dynamic wireless charging systems is significantly influenced by the alignment between transmitter and receiver coils. Misalignment caused by vehicle movement, variations in positioning, and changes in the distance between coils can reduce power transfer capability and affect charging performance. Therefore, accurate vehicle detection and coil alignment monitoring are essential for reliable wireless energy transfer. Conventional sensor-based approaches may provide basic detection capabilities but lack intelligent decision-making mechanisms for analyzing changing operating conditions.

To address these challenges, Artificial Intelligence (AI) and Machine Learning (ML) techniques can be integrated into wireless charging systems to improve monitoring and control operations. In the proposed system, infrared (IR) and Hall effect sensors are utilized to detect vehicle presence and monitor the magnetic field conditions associated with coil alignment. A Decision Tree classification algorithm is employed to analyze the sensor data and classify the alignment condition as either aligned or misaligned. Based on the classification result, the charging control mechanism determines whether the wireless power transfer process should be activated. This intelligent approach helps improve alignment detection and provides a structured mechanism for controlling the charging operation.

This paper presents an AI-Based Dynamic Wireless Charging Lane for Electric Vehicles, integrating inductive wireless power transfer, sensor-based detection, and machine learning-based alignment classification. The proposed approach aims to establish an intelligent charging mechanism that can support energy transfer without requiring vehicles to stop at conventional charging stations. By combining wireless charging technology with AI-based monitoring, the system contributes towards the development of efficient, intelligent, and sustainable electric vehicle charging infrastructure.

2 Literature survey

Yambar et al. [1] proposed an AI-assisted dynamic wireless charging system for on-road electric vehicles by integrating a resonant inverter with a weighted optimized k-Nearest Neighbor (kNN) algorithm. The proposed approach estimates operating parameters and addresses coil misalignment during vehicle movement. The study highlights the potential of combining artificial intelligence with resonant power conversion to improve dynamic wireless charging performance.

Behnamfar et al. [2] investigated machine learning-based vehicle position detection for dynamic wireless charging systems. The authors evaluated eight machine learning algorithms under different vehicle speeds and ground clearance conditions. The results identified Random Forest as the best-performing algorithm among the evaluated methods. Accurate vehicle position estimation can support selective activation of transmitter coils and improve charging control during vehicle movement.

Mahalingam and Kuppan [3] introduced an AI-driven adaptive resonance compensation technique for wireless power transfer in electric vehicle charging systems. Their approach combines Feedforward Neural Networks (FNN), Temporal Convolutional Networks (TCN), and Particle Swarm Optimization (PSO) to address resonance detuning, coil misalignment, and load variations. The study demonstrates the potential of intelligent algorithms for maintaining stable wireless power transfer under varying operating conditions.

Issi [4] presented a machine learning-based wireless charging system with high misalignment tolerance. The research investigates the effects of transmitter and receiver coil misalignment on mutual inductance and transferred power. Different operating conditions were analysed to improve power transfer performance under misaligned conditions. The study emphasizes the importance of intelligent techniques in addressing alignment-related challenges in wireless charging systems.

Hwang et al. [5] proposed an Autonomous Coil Alignment System (ACAS) for dynamic wireless charging of electric vehicles. The system utilizes a sensor coil to identify the relative position of the receiver coil through voltage-phase variations. An automatic steering mechanism adjusts the vehicle's lateral position to maintain proper coil alignment. The research demonstrates the importance of maintaining alignment between transmitter and receiver coils for effective wireless power transfer during vehicle movement.

Aurongjeb et al. [6] investigated the design and analysis of a high-efficiency dynamic wireless power transfer system for electric vehicles in motion. The research focuses on coil configuration and magnetic coupling characteristics to reduce the effects of misalignment and variations in the air gap. Electromagnetic modelling and circuit-level co-simulation were used to analyse magnetic field distribution, mutual inductance, and power transfer performance. The study provides an important foundation for designing efficient dynamic wireless charging systems.

Das et al. [7] proposed an intelligent adaptive vehicle motion control system using a Long Short-Term Memory (LSTM) network for dynamic wireless charging applications. The approach predicts electromagnetic field distribution and assists in controlling the lateral position of the vehicle to improve magnetic coupling. The study highlights the application of deep learning techniques in maintaining suitable vehicle alignment and improving charging performance during movement.

Song et al. [8] presented a comprehensive review of dynamic wireless power transfer technologies for in-motion electric vehicles and electric trains. The study discusses magnetic coupler configurations, transmitter arrangements, segmented power supply systems, circuit topologies, impedance matching, and charging control techniques. It also identifies important challenges related to electromagnetic interference and practical deployment. The review provides a theoretical foundation for the development of dynamic wireless charging infrastructure.

Latha et al. [9] conducted a systematic review of wireless electric vehicle charging technologies and their future developments. The study covers different power transfer techniques, compensation topologies, power converter configurations, and dynamic charging infrastructure. It also discusses existing technical limitations and future research opportunities. The findings provide useful insights into the design requirements and challenges associated with wireless charging systems.

Almulla [10] proposed a smart dynamic wireless charging lane for electric vehicles powered by hybrid renewable energy sources. The system integrates inductive transmitter coils with renewable energy sources, including solar and hydrogen power, to support sustainable charging. The research also considers energy management, monitoring, and safety aspects of dynamic charging infrastruc-

ture. This study highlights the importance of integrating renewable energy sources with intelligent electric vehicle charging systems.

The study presented in [11] investigated intelligent power control for dynamic wireless charging of moving electric vehicles. It developed a mathematical model to analyse variations in magnetic coupling between transmitter and receiver coils during vehicle movement. A phase-shift control technique was employed to regulate the transferred power and maintain stable output under changing operating conditions. The research provides useful insights into developing reliable power regulation techniques for dynamic wireless charging applications.

The study presented in [12] investigated smart vehicle alignment techniques for improving dynamic wireless charging efficiency. The approach estimates lateral misalignment using wireless power transfer current measurements and data obtained from an onboard Inertial Measurement Unit (IMU). A vehicle motion control mechanism adjusts steering and wheel movement to improve alignment between transmitter and receiver coils. The study demonstrates the significance of vehicle positioning and orientation in maintaining effective wireless power transfer.

3 Research gap

The existing literature demonstrates significant developments in dynamic wireless power transfer for electric vehicles, particularly in machine learning-based vehicle position detection, adaptive resonance compensation, coil alignment techniques, and intelligent power control. Several researchers have explored advanced machine learning algorithms, including Random Forest, k-Nearest Neighbors, Feedforward Neural Networks, and Long Short-Term Memory networks, to improve charging performance under varying operating conditions. However, many of these approaches involve computationally complex algorithms, specialized sensing arrangements, and advanced vehicle motion control mechanisms, which may increase system complexity and implementation cost.

Furthermore, there is a need for a simplified and cost-effective approach that integrates vehicle detection, coil alignment monitoring, and intelligent charging control within a single dynamic wireless charging system. Existing studies provide valuable solutions for individual aspects of wireless charging, but the integration of low-cost sensor-based alignment detection with lightweight machine learning classification requires further investigation.

To address these research gaps, the proposed work presents an AI-Based Dynamic Wireless Charging Lane for Electric Vehicles using infrared (IR) and Hall effect sensors. The system employs a Decision Tree classification algorithm to analyse sensor readings and identify whether the transmitter and receiver coils are properly aligned. Based on the classification result, the charging control mechanism determines whether wireless power transfer should be activated. The proposed approach focuses on simplifying coil alignment detection and providing intelligent charging control through a lightweight machine learning model, contributing towards the development of an accessible and efficient dynamic wireless charging system for electric vehicles.

4 System design and methodology

4.1 System overview

Fig. 1 illustrates the architecture of the proposed AI-Based Dynamic Wireless Charging Lane for Electric Vehicles. The system consists of four sequential charging zones, C1, C2, C3, and C4, arranged

along a laboratory-scale roadway. The STM32F103C6T6A microcontroller acts as the central processing unit and receives inputs from the IR sensor, Hall effect sensor, wheel encoder, and receiver-side voltage and current measurement circuits.

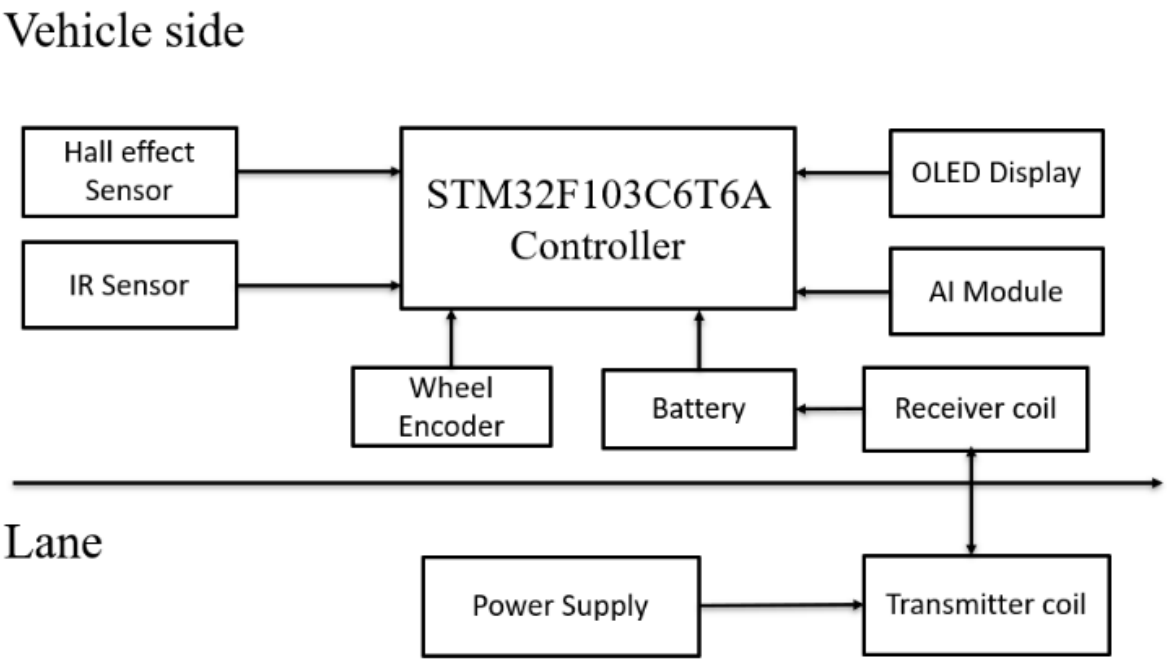


Figure 1. Block Diagram of the Proposed AI-Based Dynamic Wireless Charging System for Electric Vehicles.

The IR sensor detects vehicle presence and physical roadway references, while the Hall effect sensor identifies magnetic reference points and monitors coil alignment conditions. The wheel encoder measures vehicle movement by generating pulses corresponding to wheel rotation. These sensor measurements are processed by the microcontroller to determine vehicle position, speed, and travelled distance.

The transmitter coils installed beneath the roadway transfer electrical energy to the receiver coil mounted on the vehicle through electromagnetic induction. The received voltage and current are measured to monitor charging behaviour. The collected experimental data are used to train a supervised machine learning classification model. The trained model identifies different charging conditions, and its classification output is considered by the charging control mechanism along with vehicle-position information and safety limits.

An OLED display provides real-time information about the charging zone, vehicle movement, electrical measurements, battery condition, and AI classification results. The overall architecture integrates wireless power transfer, embedded monitoring, and intelligent charging control.

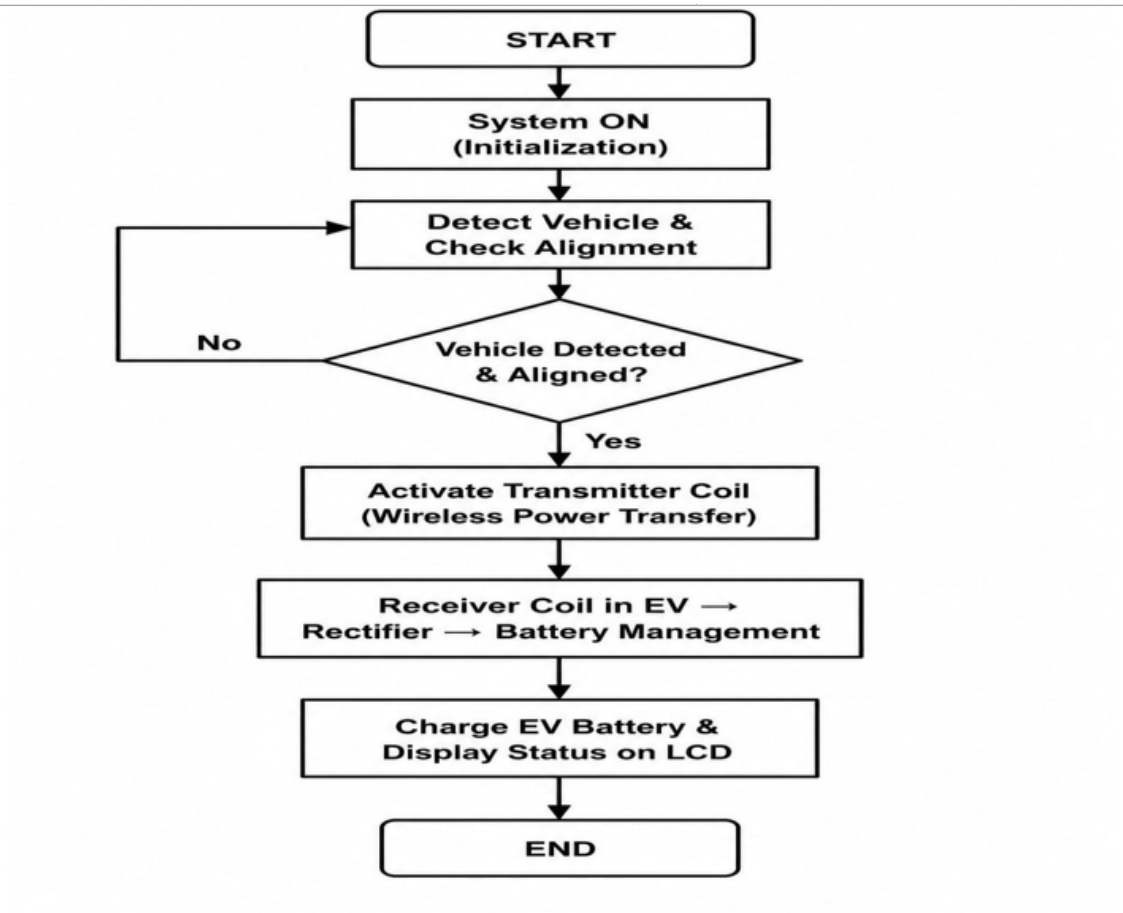


Figure 2. Flowchart illustrating the operational sequence of the proposed dynamic wireless charging system.

Fig. 2 illustrates the operational flow of the proposed AI-Based Dynamic Wireless Charging System for Electric Vehicles. The process begins with system initialization, during which the microcontroller and connected sensors are activated. The system then detects the presence of the electric vehicle and checks the alignment condition between the transmitter and receiver coils using the sensor inputs. The detected information is processed to determine whether the vehicle is present and properly aligned. If the vehicle is not detected or the alignment condition is not satisfied, the system continues monitoring the vehicle position. If both conditions are satisfied, the transmitter coil is activated to initiate wireless power transfer through electromagnetic induction. The receiver coil mounted on the electric vehicle captures the transferred electrical energy, which is processed through a rectifier and battery management circuit before being supplied to the battery. During the charging process, the system updates the charging status on the display. Finally, the process reaches the end state after the illustrated charging sequence is completed.

4.2 Hardware

Table 1. Hardware components.

Component	Role
STM32F103C6T6A	Central processing and control
IR sensor	Vehicle detection and physical reference detection
Hall effect sensor	Magnetic reference and alignment monitoring

Component	Role
Wheel encoder	Vehicle speed and distance measurement
Transmitter coils	Generation of alternating magnetic field
Receiver coil	Wireless energy reception
Voltage and current sensors	Receiver-side electrical measurement
OLED display	System status and measurement display
Buck converter	DC voltage regulation
PWM DC motor controller	Prototype vehicle speed control
Lithium-ion battery	Energy storage

4.3 Hardware specifications

The major hardware components used in the proposed prototype are described below.

- **STM32F103C6T6A:** The STM32F103C6T6A is based on the ARM Cortex-M3 processor and operates at a maximum clock frequency of 72 MHz. It provides 32 KB Flash memory and 10 KB SRAM. It processes sensor signals, monitors vehicle movement, manages charging-related control operations, and communicates with the OLED display.
- **IR Sensor:** The infrared sensor detects vehicle presence and physical reference points along the charging roadway. Its output is provided to the microcontroller for vehicle-position monitoring.
- **Hall Effect Sensor:** The Hall effect sensor detects magnetic field variations near the charging coils. Its measurements help identify magnetic reference points and assess the alignment conditions between transmitter and receiver coils.
- **Wheel Encoder:** The wheel encoder generates pulses during wheel rotation. These pulses are processed by the microcontroller to calculate vehicle speed and travelled distance.
- **Transmitter and Receiver Coils:** The transmitter coils are arranged beneath the charging roadway in four sections, C1, C2, C3, and C4. The receiver coil is mounted on the vehicle. Electrical energy is transferred between the coils through electromagnetic induction.
- **OLED Display:** The 0.96-inch OLED display communicates with the microcontroller through the I^2C interface. It presents vehicle position, charging status, sensor measurements, and AI classification results.
- **Rechargeable Battery:** The prototype uses two lithium-ion cells, each rated at 3.7 V and 1200 mAh. When connected in series, the nominal battery voltage is 7.4 V, with a capacity of 1200 mAh.
- **Power Conditioning Circuit:** The receiver-side power conditioning circuit processes the induced electrical energy through rectification and voltage regulation before supplying it to the battery charging circuit.

4.4 Software environment

The proposed system uses different software tools for embedded programming, sensor interfacing, data processing, and machine learning development.

The STM32CubeIDE is used to develop and debug the embedded firmware for the STM32F103C6T6A microcontroller. Embedded C is used to program sensor interfacing, vehicle movement monitoring, charging control, and OLED communication.

Python is used for experimental data processing, dataset preparation, machine learning model training, and performance evaluation. The trained classification model is prepared for embedded execution through a suitable model conversion process, subject to the memory and processing limitations of the microcontroller.

The OLED display driver handles communication between the controller and the display using the I^2C protocol. Peripheral drivers such as GPIO, ADC, timers, and interrupts support communication with the connected hardware components.

4.5 Dataset and AI model development

The AI-based classification model is developed using experimental data collected from the proposed dynamic wireless charging system. The dataset consists of sensor measurements and vehicle movement parameters obtained under different operating conditions. The input features include vehicle position, vehicle speed, travelled distance, Hall effect sensor readings, receiver-side voltage, receiver-side current, battery condition, and charging state.

The collected data are labelled according to four operating conditions: normal alignment, partial alignment, missing charging-zone reference, and abnormal charging behaviour. These labelled samples are used to develop a supervised machine learning classification model.

Python is used for dataset preparation, data processing, model training, and performance evaluation. The trained model analyses the input measurements and predicts the corresponding charging condition. The classification results can be used by the embedded control system to support intelligent charging decisions. The model is intended to be converted into a compact representation suitable for the STM32F103C6T6A microcontroller, considering its available memory and processing capabilities.

4.6 Intelligent charging control

The intelligent charging control unit coordinates vehicle detection, coil alignment monitoring, and wireless power transfer. The STM32F103C6T6A microcontroller receives the signals from the IR sensor, Hall effect sensor, and wheel encoder to monitor vehicle position and movement along the charging lane.

The collected sensor measurements and electrical parameters are analyzed by the AI classification model to identify the current charging condition. Based on the classification output, vehicle-position information, and predefined safety limits, the controller determines the permitted charging operation.

When the vehicle reaches the appropriate charging section and the required operating conditions are satisfied, the corresponding transmitter coil can be activated through a suitable power-electronics driver. The receiver coil captures the transmitted energy through electromagnetic induction. If an alignment issue, missing charging-zone reference, or abnormal charging condition is identified, the controller applies the corresponding charging-control response.

The OLED display provides information regarding the vehicle position, charging zone, sensor readings, electrical measurements, and system operating status. This integration provides an intelligent approach to monitoring and controlling the dynamic wireless charging process.

4.7 Experimental setup

The experimental setup consists of a laboratory-scale electric vehicle model and a dedicated charging roadway designed to demonstrate dynamic wireless power transfer. The roadway is divided into four sequential charging sections, C1, C2, C3, and C4, with transmitter coils arranged along the charging path. A receiver coil is mounted on the vehicle to receive electrical energy through electromagnetic induction.

The vehicle model consists of a chassis, DC geared motors, rechargeable lithium-ion battery, STM32F103C6T6A microcontroller, IR sensor, Hall effect sensor, wheel encoder, and power-regulation circuitry. The IR sensor detects roadway reference points, while the Hall effect sensor monitors magnetic-field variations near the charging arrangement. The wheel encoder generates pulses corresponding to wheel rotation, enabling the microcontroller to estimate vehicle speed and travelled distance.

A PWM DC motor speed controller is used to regulate the movement speed of the prototype vehicle. The receiver-side electrical output is monitored through voltage and current measurement circuits. The STM32 microcontroller processes the sensor information and coordinates the programmed control operations. The OLED display provides a visual indication of the system status and measured parameters.

The experimental arrangement provides a platform for evaluating vehicle movement, charging-zone detection, coil alignment, and wireless power transfer under different operating conditions. The collected measurements can also be used for preparing and validating the AI-based classification model.

5 Results

5.1 Prototype development

The proposed AI-Based Dynamic Wireless Charging Lane for Electric Vehicles was developed as a laboratory-scale prototype to demonstrate the concept of wireless power transfer and sensor-based vehicle monitoring. The prototype integrates the STM32F103C6T6A microcontroller, IR sensor, Hall effect sensor, wheel encoder, rechargeable battery, and supporting power-regulation circuitry.

The vehicle model consists of a mechanical chassis, DC motors, electronic control components, and sensor modules. The charging roadway provides a defined path for evaluating vehicle movement and positioning with respect to the transmitter coil sections.

The prototype photographs illustrate the overall vehicle arrangement, mechanical assembly, electrical connections, and charging roadway. These observations provide a basis for evaluating the integration of the hardware components and the proposed system architecture.

5.2 Vehicle model: Top view

The top view of the vehicle model illustrates the arrangement of the STM32F103C6T6A microcontroller, TTL converter, OLED display, rechargeable battery pack, and motor-control circuitry on the vehicle chassis. The STM32 microcontroller acts as the main control unit, while the TTL converter supports serial communication. The OLED display provides system status information, and the PWM motor-control circuit regulates the speed of the DC motors for vehicle movement. The arrangement

demonstrates the integration of the embedded controller, display, communication, and power components required for the proposed charging system.

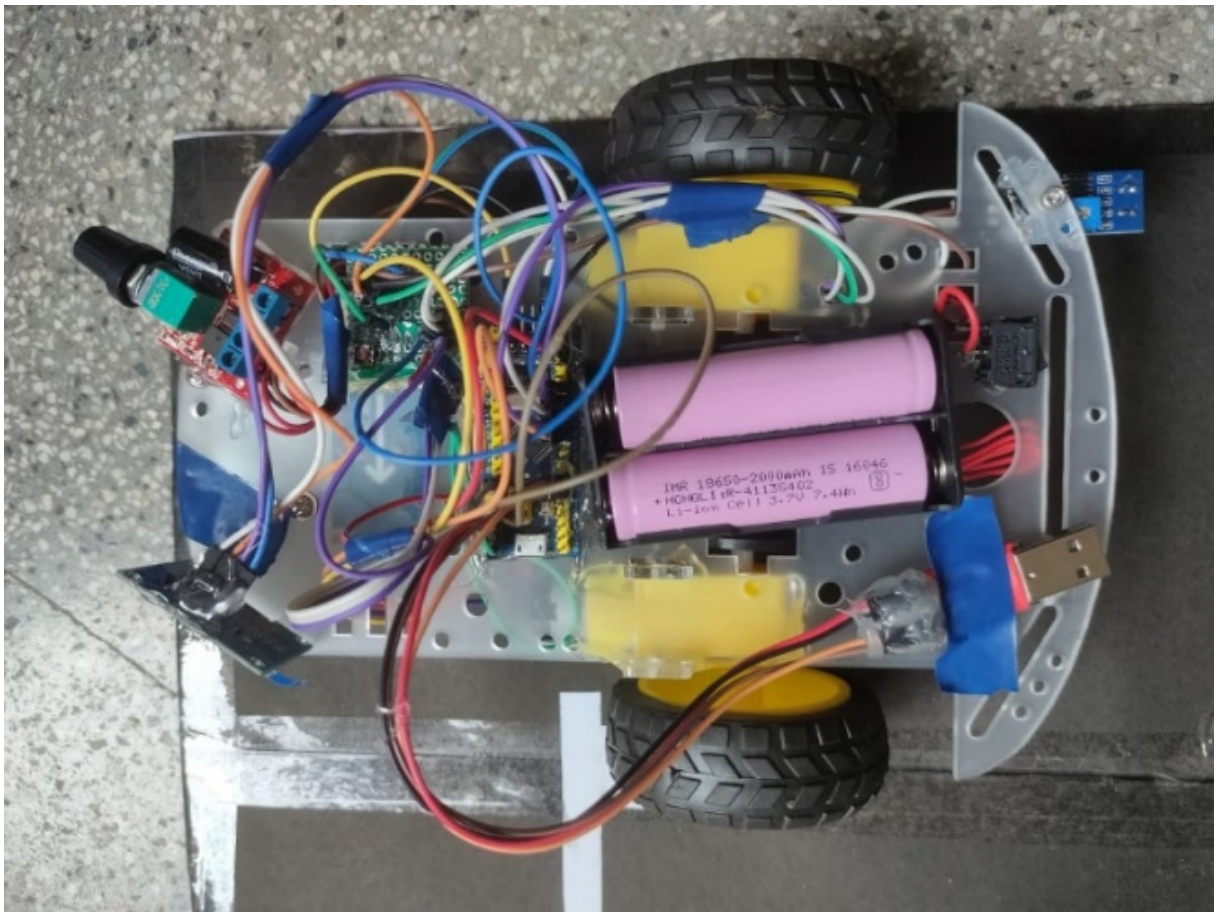


Figure 3. Top View of the Vehicle Model.

5.3 Vehicle model: Back view

The back view of the vehicle model illustrates the arrangement of the Hall effect sensor, IR sensor, wheel encoder, buck converter, and receiver coil mounted on the vehicle chassis. The IR sensor is used for object detection, while the Hall effect sensor helps identify the alignment between the transmitter and receiver coils. The wheel encoder monitors the rotation of the wheels to track vehicle movement. The receiver coil captures wireless power from the transmitter coil, and the buck converter regulates the received voltage to a suitable level for the charging circuit. These components work together to support vehicle detection, alignment monitoring, movement tracking, and wireless power reception in the proposed dynamic charging system.

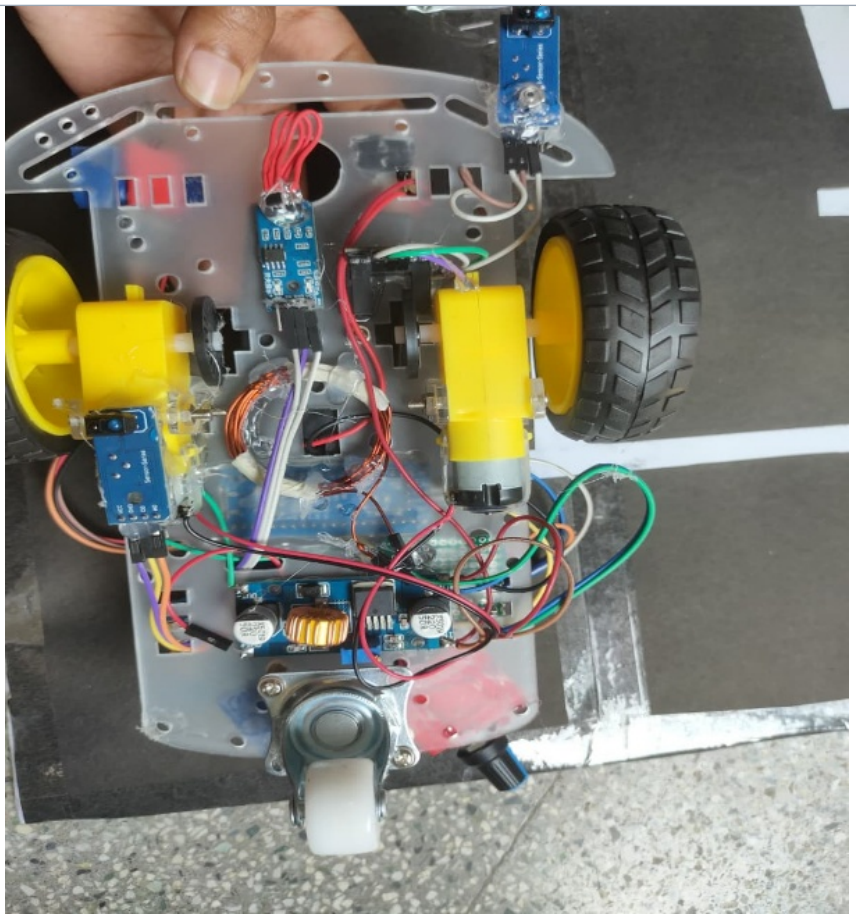


Figure 4. Back View of the Vehicle Model.

5.4 Dynamic wireless charging lane

The charging lane is constructed as a laboratory-scale roadway with defined path markings and designated charging positions. It provides a testing platform for observing the movement of the vehicle model and its position relative to the charging sections C1, C2, C3, and C4. The transmitter coils are intended to be positioned beneath the roadway, while the receiver coil is mounted on the vehicle. This arrangement provides the physical foundation for evaluating wireless energy transfer during vehicle movement.

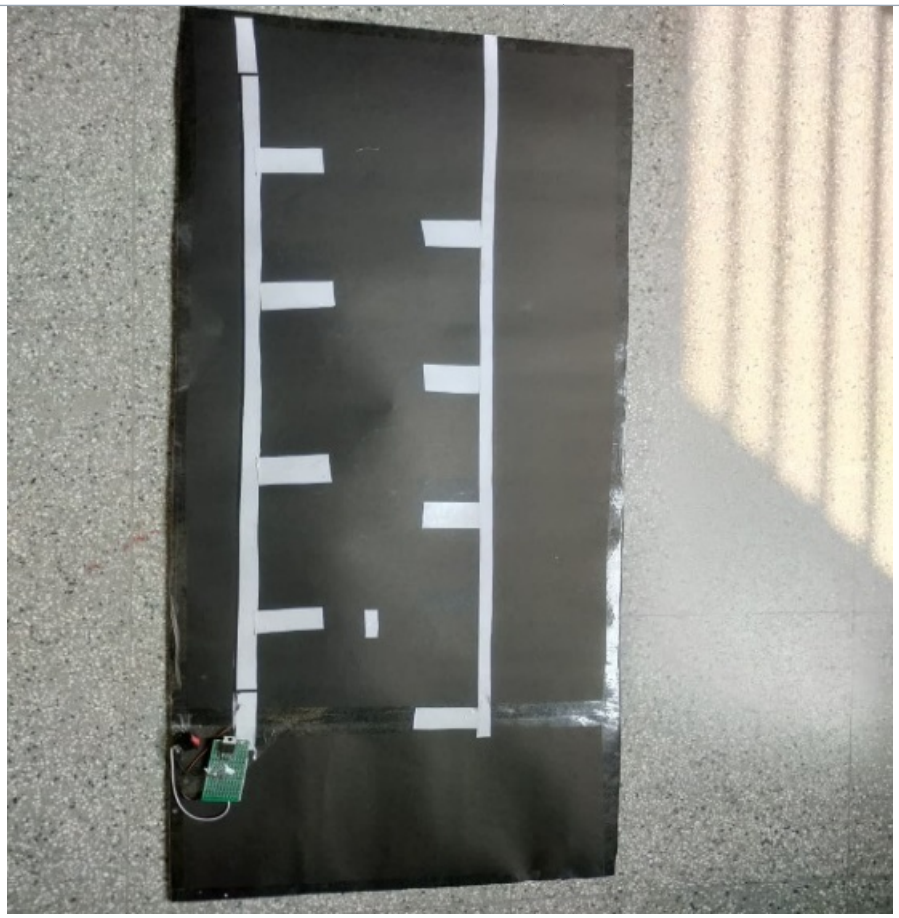


Figure 5. Model Lane for Dynamic Wireless Charging.

5.5 OLED display output

The OLED display provides real-time coil alignment status during vehicle movement. It displays "OK" when the transmitter and receiver coils are properly aligned, indicating suitable conditions for wireless power transfer. If the coils are not properly aligned, the display shows "MISS", indicating the position where proper alignment has not been achieved. This helps monitor the alignment status and supports effective wireless power transfer. The display also indicates the vehicle distance, charging percentage, and battery voltage, allowing the user to monitor the overall charging status of the system.

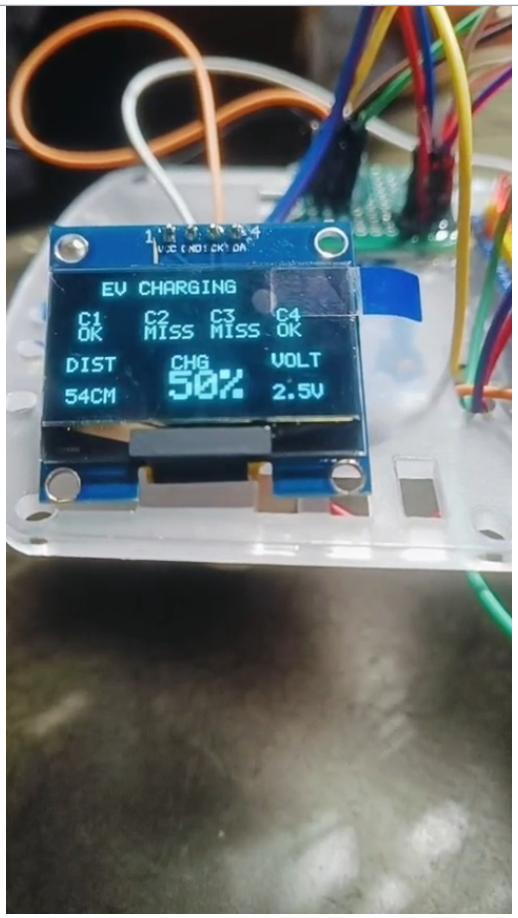


Figure 6. OLED Display Output Showing Real-Time Coil Alignment Status and Charging Parameters.

5.6 Overall performance discussion

The proposed system combines wireless power transfer, embedded sensor monitoring, vehicle movement detection, and AI-based charging-condition classification. The four-section charging lane provides a modular arrangement for studying the relationship between vehicle position and wireless energy transfer.

The IR sensor and Hall effect sensor support vehicle and magnetic-reference detection, while the wheel encoder provides movement-related information. The microcontroller coordinates the sensor inputs and charging-related control operations. The AI classification approach is intended to identify different charging conditions using the collected experimental measurements.

The prototype demonstrates the proposed system architecture and provides a platform for further evaluation. Quantitative performance assessment requires additional measurements of receiver-side voltage, current, transferred power, charging efficiency, and AI classification accuracy under different operating conditions.

6 Conclusion and future scope

6.1 Conclusion

This paper presents an AI-Based Dynamic Wireless Charging Lane for Electric Vehicles using wireless power transfer, embedded systems, and intelligent sensor-based monitoring. The proposed system consists of four transmitter coil sections (C1, C2, C3, and C4) arranged along a charging lane and a

receiver coil mounted on the electric vehicle. The system uses the STM32F103C6T6A microcontroller to coordinate vehicle detection, movement monitoring, coil alignment detection, and charging-related operations.

The integration of IR and Hall effect sensors enables vehicle detection and magnetic alignment monitoring, while the wheel encoder provides information about vehicle speed and travelled distance. The AI-based classification approach analyses the collected sensor measurements to identify different charging conditions and support intelligent charging decisions. An OLED display is used to present the operating status and charging-related information.

The developed prototype demonstrates the concept of dynamic wireless power transfer through inductive coupling and provides a platform for studying intelligent electric vehicle charging. The combination of wireless charging, sensor monitoring, embedded control, and AI-based classification provides a foundation for developing more efficient and intelligent EV charging systems. Further experimental validation is required to evaluate power transfer efficiency, AI classification accuracy, and overall system reliability under different operating conditions.

6.2 Future scope

The proposed system can be further enhanced by improving the AI classification model using a larger dataset containing different vehicle positions, coil alignment conditions, and charging parameters. The transmitter and receiver coil designs can be optimized to improve magnetic coupling, increase power transfer efficiency, and minimize energy losses. Additional transmitter coil sections can be incorporated to extend the charging lane and support longer vehicle movement paths.

Furthermore, additional sensors can be integrated to monitor temperature, voltage, current, and power consumption during charging. Wireless communication can be introduced for remote monitoring of vehicle position and charging status. Advanced safety mechanisms can also be developed to detect abnormal current conditions, overheating, and foreign objects near the charging coils. Further testing under different vehicle speeds, electrical loads, and coil positions can improve the reliability and practical applicability of the proposed system for electric cars, buses, and other electric transportation systems.

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