Intelligent Motor Control Design For Remotely operated Rover, enabling smart farming and precision agriculture.

Dissertation submitted in partial fulfillment of the requirements
for

Summer Internship Program

by

Sasanka Barman
Debashish Kashyap
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Under the Supervision of

Dr. Pranjal Barman and Co-Supervision of **Dr. Debajit Sarma**

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Technology Innovation Hub

Guwahati - 781039, India

July, 2024

Certificate

This is to certify that the dissertation entitled **"Intelligent Motor Controller Design"**, submitted by **Sasanka Barman, Debashish Kashyap** and **Matiur Rahman** to the Indian Institute of Technology Guwahati, for the **Summer Internship Program** in Technology Innovation Hub, is a record of the original, bona fide research work carried out by them under our supervision and guidance. The dissertation has reached the standards fulfilling the requirements of the regulations related to the award of the research program.

The results contained in this dissertation have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

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Dr. Pranjal Barman
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Declaration

I declare that this written submission represents our ideas in our own words. Where others' ideas and words have been included, I have adequately cited and referenced the original source. I declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated, or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will cause disciplinary action by the Institute and can also evoke penal action from the source which has thus not been properly cited or from whom proper permission has not been taken when needed.

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Sasanka Barman,
Debashish Kashyap,
Matiur Rahman

Date: 19/07/2024
Place: IIT Guwahati

Dissertation Approval

This dissertation entitled **Intelligent Motor Controller Design** by **Sasanka Barman, Debashish Kashyap, Matiur Rahman**, is approved for **Summer Internship Program** from the Indian Institute of Technology Guwahati.

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Dr. Pranjal Barman
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Place: IIT Guwahati

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Sasanka Barman, Debashish Kashyap, Matiur Rahman

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Abstract

Agricultural robotics has emerged as a pivotal technology to address the growing demands for efficient, precise, and sustainable farming practices. This work presents the design and development of an innovative agricultural rover aimed at enhancing crop monitoring, environment monitoring, soil analysis, and precision farming. The proposed rover integrates advanced sensor systems, wireless navigation, and to perform various tasks related to agricultural activities with minimal human intervention. In this work we have developed the mechanical design of the rover. The rover is driven by two rear wheels connected with DC gear motors of optimum specifications. In addition, we have designed the necessary motor control system and the control algorithms by integrating various sensors. The control system involved an optoisolator based gate driver circuit as well as a power MOSFET with required specifications. The control algorithm has been designed in Atmega328P microcontroller as well as ESP32 . The rover is connected to IOT module with the temperature humidity sensors for real time data acquisition from the environment. The modular architecture of the rover allows for easy maintenance and upgrades, ensuring long-term usability and scalability. Field tests demonstrate the rover's potential to revolutionize agricultural practices by providing a reliable, efficient, and intelligent solution for modern farming challenges.

Chapter 1

Introduction

As EVs become more popular as an environmentally friendly mode of transportation, sophisticated motor controllers must be created to ensure optimal performance. This thesis investigates the development and use of an intelligent motor controller for electric vehicle use. An Arduino was used to generate PWM for two 12V gear motors in a rover prototype, while an MCT2E integrated circuit and an ESP32 were used to monitor data. With the Blynk app, a mobile device may get real-time temperature and humidity data from the system, which also efficiently regulates motor speed. In order to improve the performance and efficiency of EVs and pave the way for a more sustainable transportation future, this research shows how intelligent motor controllers may be used.

Here are some citation [1][2][3][4]

1.1 Problem Statement

The functionality and efficiency of electric cars depend heavily on the design of effective motor controllers. Conventional control devices have limited capacity to dynamically adjust to changing situations since they rely on preset features and settings. These restrictions can be circumvented by an intelligent motor controller that makes use of machine learning, real-time data processing, and sophisticated programming.

1.2 Importance of the Study

Motor control must be improved as we go toward electric cars in order to maximize efficiency, improve the driving experience, and guarantee sustainability. Intelligent motor controllers have the ability to continually modify control settings in response to driving style, environmental factors, and real-time sensor data.

1.3 Objectives

The objective of this study is to develop an intelligent motor controller for EV applications that:

1. To create a prototype electric vehicle intended for use in agriculture.
2. To create the electric vehicle prototype's motor control system.
3. Including sensors that are integrated with the vehicle and utilized in agricultural applications.
4. Validation testing and showcasing the suggested system.

1.4 Organization of the report

The goal of this dissertation is to better understand how to develop and operate an intelligent motor controller to maximize the efficiency of electric vehicles (EVs). It discusses the drawbacks of conventional control techniques and investigates the possibilities of intelligent systems that can dynamically adjust to shifting circumstances.

- **Chapter 1: Introduction** lays out the background of the research, emphasizing the issue statement, justification for the study, goals of the investigation, and structure of the dissertation.
- **Chapter 2: Literature Review** the current state of EV motor control systems is thoroughly reviewed, research gaps are noted, and the need of intelligent controllers that can boost driving enjoyment, assure sustainability, and increase performance is emphasized.
- **Chapter 3: Design Methodology** describes the design concepts and the intelligent motor controller's implementation, with an emphasis on the usage of the ESP32 for data monitoring, the Arduino for PWM generation, and the MCT2E IC. Explained are the circuit design and component configuration, with a focus on how hardware and software components work together to provide efficient control.
- **Chapter 4: Results and Analysis** This section provides the performance analysis and simulation results of the proposed motor controller, comparing it to previous research to verify its efficacy. The benefits of intelligent control are demonstrated in this chapter, which includes increased range, smoother acceleration and operation, and optimized torque and speed profiles.
- **Chapter 5: Conclusion and Future Work** outlines the study's results, makes judgments on the potential of intelligent motor controllers for electric vehicle applications, and suggests lines of inquiry for further study in this area.

Chapter 2

Literature Review

2.1 Introduction

This chapter examines existing literature on motor controllers for electric vehicles (EVs). It begins by discussing traditional control methods like PID, FOC, and DTC, explaining their principles and applications. However, it highlights limitations such as their inability to adapt to changing conditions, reliance on simplified models, and underutilization of real-time sensor data.

The chapter then introduces intelligent motor control systems, which leverage technologies like AI and machine learning to overcome these limitations. These systems can learn from data, adapt to dynamic environments, and predict future driving conditions for optimized performance. They also incorporate data from multiple sensors for a more comprehensive understanding of the EV's state.

Overall, this literature review establishes the need for intelligent motor controllers in EVs, emphasizing their potential to enhance performance, efficiency, and the overall driving experience. This sets the stage for the following chapters, which will delve into the design and implementation of an intelligent motor controller for EV applications. [5] [6] [7][8]

2.2 Background

This section provides a comprehensive overview of motor control systems, delving into their fundamental principles, evolutionary trajectory, and pivotal role in the burgeoning electric vehicle (EV) sector. The discussion encompasses various control strategies, including traditional approaches like Proportional-Integral-Derivative (PID), Field-Oriented Control (FOC), and Direct Torque Control (DTC), as well as the emergence of intelligent control systems driven by artificial intelligence and machine learning.

2.2.1 Traditional Motor Control Strategies:

- **Proportional-Integral-Derivative (PID) Control:** PID control is a widely used feedback control mechanism in EV motor control. It calculates an error value as the difference between a desired setpoint and a measured process variable. The controller then attempts to minimize the error by adjusting the control output based on proportional, integral, and derivative terms. The proportional term responds to the present error, the integral term addresses past errors, and the derivative term anticipates future errors. PID control is known for its simplicity and robustness, making it a popular choice for EV motor control applications.

- **Field-Oriented Control (FOC):** FOC is a vector control technique that transforms the stator currents of an AC motor into a rotating reference frame aligned with the rotor flux. This transformation simplifies the control of the motor's torque and flux, allowing for independent control of both components. FOC offers precise control over motor speed and torque, making it particularly well-suited for high-performance EV applications where rapid acceleration and smooth torque control are essential.

- **Direct Torque Control (DTC):** DTC is another vector control technique that directly controls the stator flux and electromagnetic torque of an AC motor. It utilizes hysteresis controllers to select the optimal voltage vector from a predefined set, based on the desired flux and torque values. DTC is known for its fast dynamic response and robustness to parameter variations, making it a suitable choice for EV applications where quick torque response is crucial.

2.2.2 Limitations of Traditional Control Methods

Despite their widespread use, traditional motor control strategies have limitations that hinder their effectiveness in complex and dynamic EV environments.

- **Fixed Parameters:** PID, FOC, and DTC controllers often rely on fixed parameters that are tuned for specific operating conditions. These parameters may not be optimal under varying load conditions, battery states of charge, or environmental factors.
- **Simplified Models:** Traditional controllers often use simplified mathematical models of the motor and vehicle dynamics, which may not accurately represent real-world complexities. This can lead to suboptimal control decisions, especially under extreme operating conditions.
- **Limited Adaptability:** Traditional controllers lack the ability to adapt to changing conditions in real-time. They cannot learn from past experiences or adjust their control parameters based on feedback from sensors, which can limit their performance in dynamic EV environments.
- **Underutilization of Sensor Data:** EVs are equipped with a plethora of sensors that collect valuable data about the vehicle's state, such as battery voltage, current,

temperature, and motor speed. Traditional controllers often underutilize this data, failing to leverage its potential for optimizing control decisions.

2.2.3 Intelligent Motor Control Systems

The limitations of traditional control methods have paved the way for the development of intelligent motor control systems that harness the power of artificial intelligence (AI) and machine learning (ML) to enhance the performance and efficiency of EVs.

- **Adaptive Control:** Intelligent motor controllers can adapt their control parameters in real-time based on feedback from sensors and changing operating conditions. This enables them to optimize performance under varying loads, battery states, and environmental factors.
- **Data-Driven Models**: Instead of relying on simplified models, intelligent controllers can utilize data-driven models that are trained on real-world data. These models can capture the complex dynamics of the motor and vehicle system, leading to more accurate and precise control decisions.
- **Predictive Control:** By analyzing historical data and current sensor inputs, intelligent controllers can predict future driving conditions and adjust their control strategies accordingly. This can result in smoother acceleration, improved energy efficiency, and enhanced driving experience.
- **Fault Detection and Diagnosis:** By keeping an eye on sensor data and system behavior, intelligent controllers can spot irregularities and possible faults. Timely identification of defects can avert disastrous events and guarantee the secure functioning of the automobile.
- **Integration with Vehicle Systems:** The integration of intelligent motor controllers with other automotive systems, like driver assistance, thermal, and

battery management systems, can be done with ease. A more comprehensive approach to vehicle control made possible by this integration may result in increased efficiency and performance all around.

2.2.4 Applications of Intelligent Motor Control in EVs

Intelligent motor control systems have a wide range of applications in EVs, including:

- **Torque and Speed Control:** Intelligent controllers can optimize torque and speed profiles for improved acceleration, smoother operation, and reduced energy consumption.
- **Energy Management:** By predicting driving conditions and adjusting control strategies, intelligent controllers can optimize energy usage and extend the driving range of EVs.
- **Thermal Management:** To avoid overheating and guarantee peak performance, intelligent controllers can keep an eye on the battery pack's and motor's temperatures and modify their operation accordingly.
- **Driver Assistance:** Adaptive cruise control, lane keeping assistance, and collision avoidance are just a few of the features that intelligent controllers can offer the driver.

2.3 Research Gaps

Despite advancements in motor control, significant research gaps remain. Many intelligent control systems still rely on simplified models that do not fully capture the complexities of real-world driving conditions. Additionally, the integration of multiple sensor data for comprehensive decision-making remains a challenge. Moreover, there is a need for more research on the optimization of energy consumption and the development of fault-tolerant control strategies that can ensure safe and reliable operation in diverse environments. Addressing these gaps will be crucial for developing truly intelligent motor controllers that can unlock the full potential of EVs.[9, 10, 11][12][13]

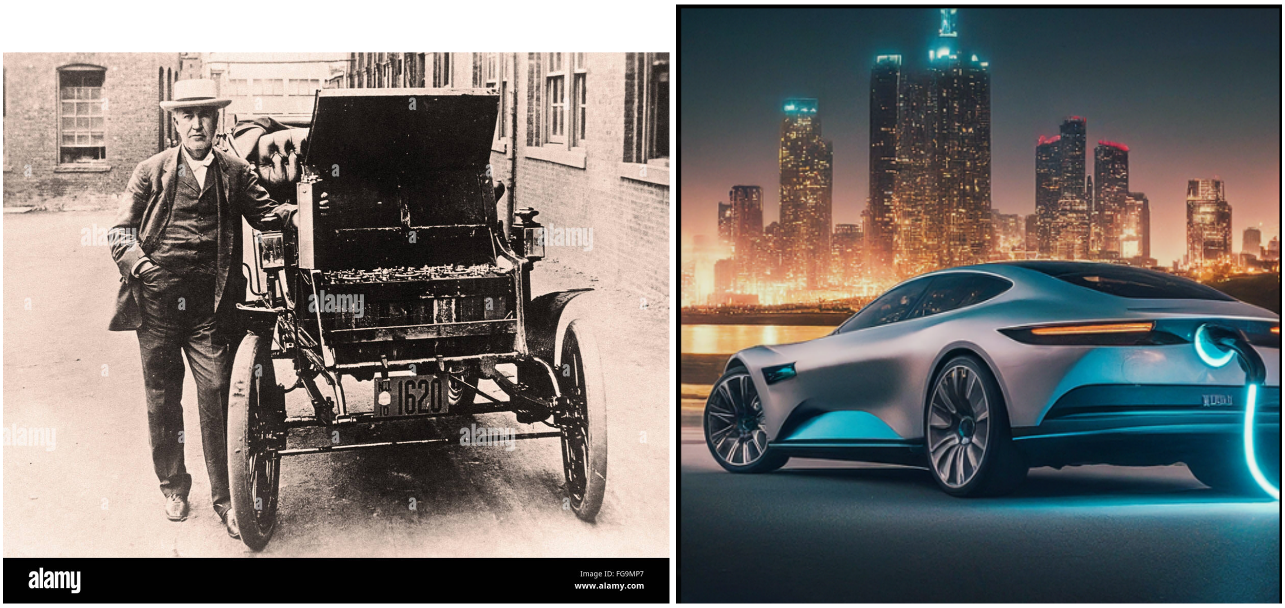


FIGURE 2.1: **Evolution of Electronic Vehicles**

2.4 Summary

This literature review highlights the evolution of motor control systems for electric vehicles (EVs). Traditional methods like PID, FOC, and DTC have been instrumental in EV development, providing reliable control over motor speed and torque. However, their reliance on fixed parameters, simplified models, and limited adaptability present challenges in dynamic real-world driving scenarios. In contrast, intelligent motor control systems offer a promising solution by leveraging AI and machine learning to adapt to varying conditions, utilize real-time sensor data, and predict future driving patterns. This can lead to enhanced performance, increased energy efficiency, and improved safety.

Notwithstanding these benefits, there are still research gaps that must be filled. These gaps include the need for more complex models that faithfully represent the complexities of the real world, improved multiple sensor data integration, and additional energy consumption optimization. In order to fully utilize EVs' intelligent motor control and contribute to a more sustainable and effective transportation future, these gaps must be filled.

Chapter 3

Design Methodology

3.1 Introduction

This chapter outlines the design principles and methodologies employed in developing the intelligent motor controller for the EV prototype. The primary objective is to create a system that effectively controls motor speed and torque while incorporating real-time data from various sensors for optimized performance.

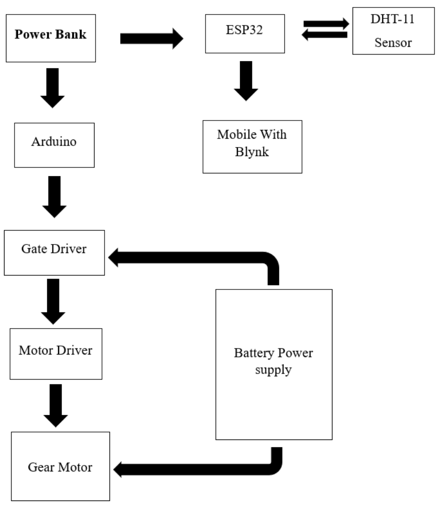


FIGURE 3.1: **Block Diagram**

The design process encompasses a multi-faceted approach:

1. **Mechanical Design:** Careful consideration of hardware components, including the Arduino for Pulse Width Modulation (PWM) generation, MCT2E IC for motor control, and ESP32 for data acquisition and communication, to ensure compatibility and functionality.

2. **Motor Control System Design:** Detailed circuit design outlining the connection and configuration of components, ensuring proper signal flow and voltage regulation for optimal operation.

3. **Sensor Integration and IoT Implementation:** Development of algorithms and control logic for PWM generation, motor speed control, sensor data acquisition, and wireless communication with a mobile interface.

4. **Control Algorithm Design:** Integrating hardware and software components to create a functional motor controller system, followed by rigorous testing to validate its performance, accuracy, and reliability.

This chapter will elaborate on each of these aspects, providing a comprehensive overview of the design process and the methodologies employed in creating a robust and efficient intelligent motor controller for EV applications.

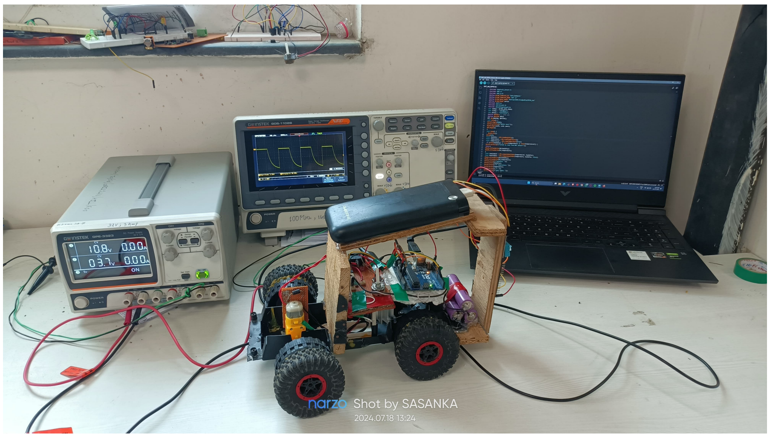


FIGURE 3.2: **Test Setup of the Project**

3.2 Design Principle

The design of the intelligent motor controller is guided by several key principles aimed at achieving optimal performance, flexibility, and integration.

1. **Arduino for PWM Generation:** The Arduino microcontroller is chosen for its simplicity, versatility, and extensive community support. Its ability to generate precise Pulse Width Modulation (PWM) signals makes it ideal for controlling the speed of DC motors. The PWM duty cycle is manipulated to adjust the average voltage applied to the motors, thus regulating their speed.

2. **MCT2E IC for Motor Control:** The MCT2E optocoupler IC serves as a crucial interface between the Arduino's low-voltage PWM signals and the higher-voltage motor control circuit. It provides electrical isolation, ensuring the safety of both the microcontroller and the motor driver. Additionally, it amplifies the PWM signal to a suitable level for driving the MOSFETs

3. **ESP32 for Data Monitoring:** The ESP32 microcontroller, with its integrated Wi-Fi capabilities, is utilized for data acquisition and communication. It interfaces with the DHT11 sensor to gather temperature and humidity data, which is then transmitted wirelessly to a mobile device using the Blynk app. This real-time data monitoring allows for remote monitoring and control of the EV's operating conditions.

By adhering to these design principles, the intelligent motor controller achieves a balance between functionality, reliability, and user-friendliness. The integration of these components enables precise motor control, real-time data monitoring, and remote accessibility, ultimately enhancing the overall performance and user experience of the electric vehicle.

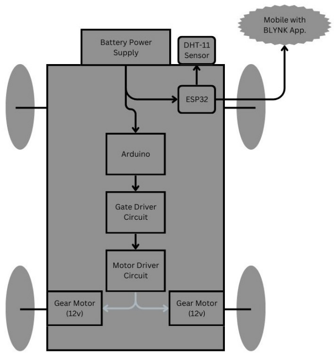


FIGURE 3.3: **Schematic of the Rover**

3.3 Circuit Design

The PWM generation, gate driver circuit, motor driver circuit, battery power supply, and ESP32 circuit for data monitoring and communication are the five primary sections that make up the circuit design for the intelligent motor controller. Every component is essential to the controller's overall performance and functionality.

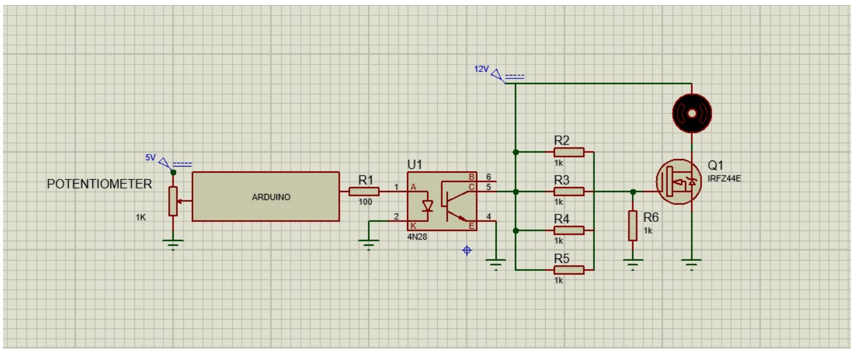
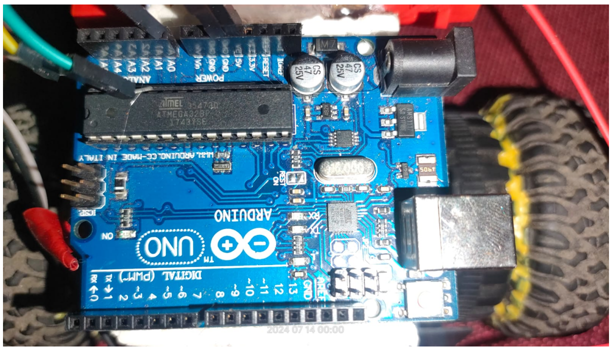


FIGURE 3.4: **Circuit Diagram**

3.3.1 PWM Generation (Arduino)

The Pulse Width Modulation (PWM) signals that regulate the DC motors' speed are produced by the Arduino microcontroller. PWM frequency is adjusted to an appropriate level (e.g., 8 KHz) to reduce motor noise and guarantee smooth functioning. The average voltage supplied to the motors is adjusted by varying the duty cycle of the PWM signal, which in turn controls the motors' speed. The MCT2E optocoupler's input is linked to the Arduino's PWM output pin.



```
#define pot A0
#define pwm 9

void setup() {
  pinMode(pot, INPUT);
  pinMode(pwm, OUTPUT);
  Serial.begin(9600);

  // Configure Timer1 for 2 kHz PWM on pin 9
  TCCR1A = 0;              // Clear TCCR1A register
  TCCR1B = 0;              // Clear TCCR1B register
  TCNT1  = 0;              // Initialize counter value to 0

  TCCR1A |= (1 << COM1A1);  // Non-inverting mode
  TCCR1A |= (1 << WGM11);   // Mode 14: Fast PWM, TOP = ICR1
  TCCR1B |= (1 << WGM13) | (1 << WGM12); // Mode 14: Fast PWM, TOP = ICR1
  TCCR1B |= (1 << CS10);    // No prescaling

  ICR1 = 1999;             // Set TOP value for 2 kHz frequency
}

void loop() {
  unsigned int potVal = analogRead(pot);
  int pwmVal = map(potVal, 0, 1023, 0, 1999); // Map pot value to ICR1 range for duty cycle

  Serial.println(pwmVal);
  OCR1A = pwmVal;          // Set PWM duty cycle
  if (pwmVal <110)
    OCR1A = 110;
  delay(10);              // Short delay for stabilization
}
```

FIGURE 3.5: **Arduino UNO Micro-Controller and Code**

3.3.2 Gate Driver Circuit (MCT2E Optocoupler)

The high-voltage motor driver circuit and the low-voltage PWM signals from the Arduino are electrically isolated from one another by the MCT2E optocoupler. By isolating the Arduino, high-voltage transients cannot potentially harm it. In order to drive the MOSFET gate, the optocoupler also amplifies the PWM signal. Via a current-limiting resistor, the MOSFET's gate is connected to the MCT2E's output.

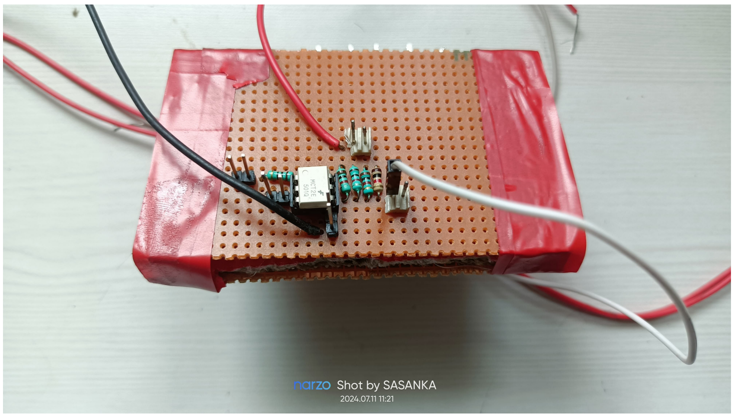


FIGURE 3.6: **Gate-Driver Circuit**

3.3.3 Motor Driver Circuit (MOSFET H-Bridge)

The motor driver circuit utilizes an H-bridge configuration with four MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors). This configuration allows for bidirectional control of the DC motors, enabling forward and reverse rotation. By controlling the on/off states of the MOSFETs, the direction and speed of the motors can be precisely regulated. The drain of each MOSFET is connected to the motor terminals, and the source is connected to the ground. u

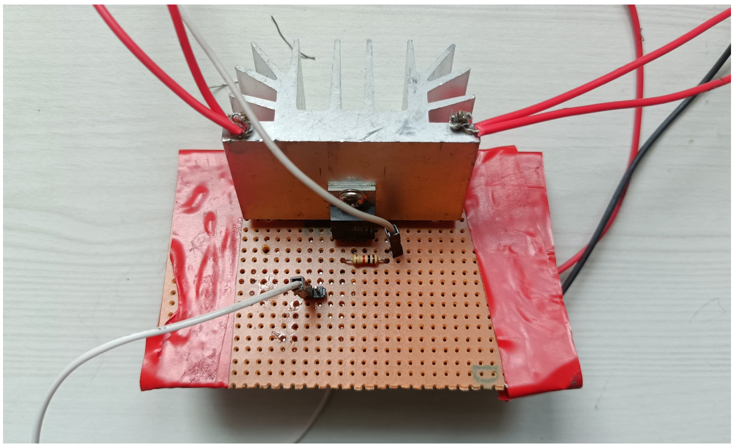


Figure 3.7: **Motor-Driver Circuit**

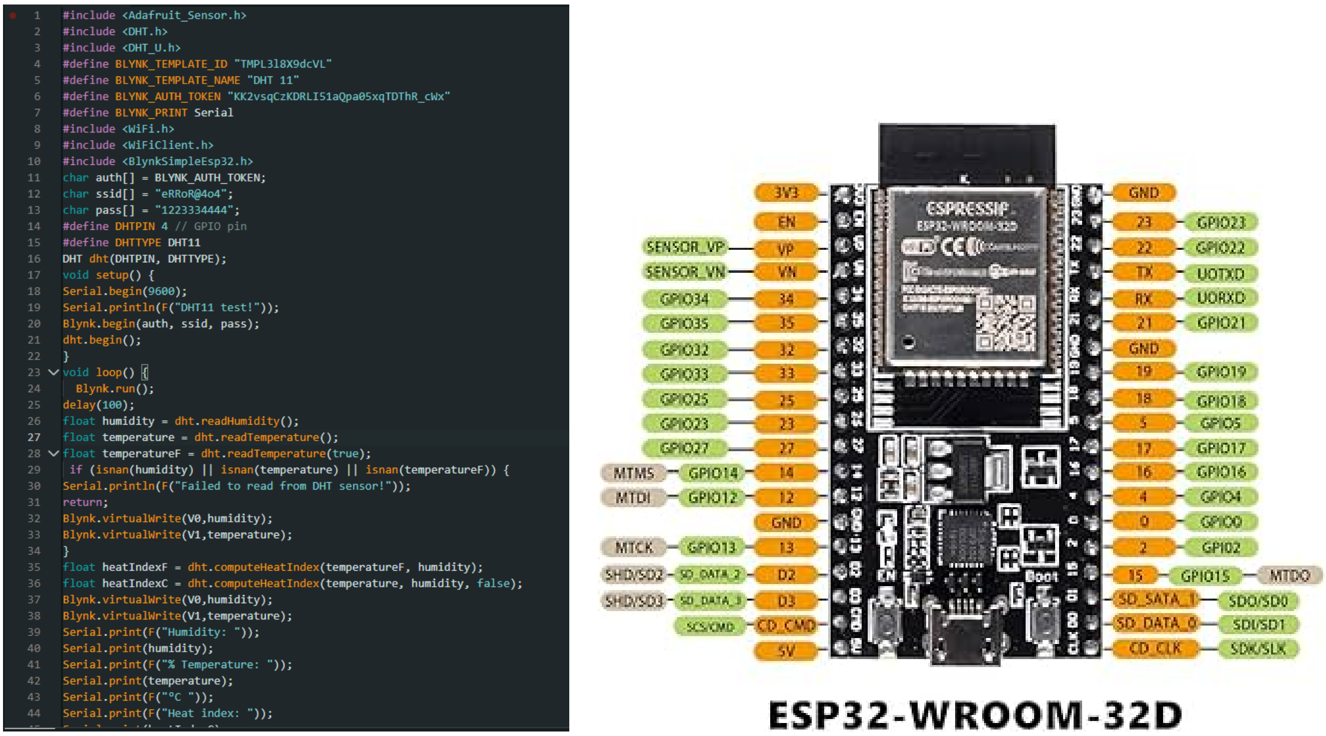
3.3.4 Battery Power Supply

The motors are powered by the electrical energy that is supplied by the battery power supply. Usually, this arrangement uses a 12V battery. The battery's positive terminal is linked to the motor driver circuit's power supply input, and its negative terminal is connected to ground. The power supply line may have a fuse or circuit breaker installed to guard against overcurrent situations.

FIGURE 3.8: **Battery Power Supply**

3.3.5 ESP32 Circuit for Data Monitoring (DHT11, Blynk)

The ESP32 micro-controller is connected to the DHT11 temperature and humidity sensor. The DHT11's data pin is connected to a suitable GPIO pin on the ESP32 (e.g., GPIO 4). The ESP32 reads the sensor data and sends it to the Blynk app via a Wi-Fi connection. The Blynk app displays the temperature and humidity data in real-time, allowing for remote monitoring and control.



```
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
#define BLYNK_TEMPLATE_ID "TMPL318X9dcVL"
#define BLYNK_TEMPLATE_NAME "DHT 11"
#define BLYNK_AUTH_TOKEN "KK2vsqCzKDRLI51aQpa05xqTDThR_cWx"
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "eRRoR@4o4";
char pass[] = "1223334444";
#define DHTPIN 4 // GPIO pin
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);
void setup() {
Serial.begin(9600);
Serial.println(F("DHT11 test!"));
Blynk.begin(auth, ssid, pass);
dht.begin();
}
void loop() {
  Blynk.run();
delay(100);
float humidity = dht.readHumidity();
float temperature = dht.readTemperature();
float temperatureF = dht.readTemperature(true);
 if (isnan(humidity) || isnan(temperature) || isnan(temperatureF)) {
Serial.println(F("Failed to read from DHT sensor!"));
return;
Blynk.virtualWrite(V0,humidity);
Blynk.virtualWrite(V1,temperature);
}
float heatIndexF = dht.computeHeatIndex(temperatureF, humidity);
float heatIndexC = dht.computeHeatIndex(temperature, humidity, false);
Blynk.virtualWrite(V0,humidity);
Blynk.virtualWrite(V1,temperature);
Serial.print(F("Humidity: "));
Serial.print(humidity);
Serial.print(F("% Temperature: "));
Serial.print(temperature);
Serial.print(F("°C "));
Serial.print(F("Heat index: "));
```


FIGURE 3.9: **ESP32 Micro-Controller and Code**

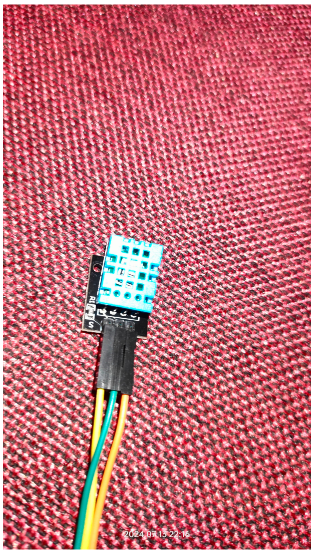


FIGURE 3.10: **DHT-11 Sensor**

Additional Considerations:

Components	**Specifications**	**Measurand**
HCSR04	Operating Voltage: 5V, Measuring Range: 2cm-400cm, Accuracy: ±3mm	Distance measurement
ESP32	Dual-core 32-bit CPU, Operating Voltage: 3.3V, Wi-Fi and Bluetooth capabilities	Data processing and Communication
DHT-11 Sensor	Temperature range: 0-50°C,Humidity range:20-90% RH,	Temperature and Humidity
Battery	Voltage: 3.7V, Capacity: 1800mAh, Type: Li-ion Cell	Electrical power
Gear Motor (12v)	Voltage: 12V, Speed: 300 RPM, Torque: 1.5 Nm	Mechanical rotation
Freewheel Diode	Voltage: 12V, Current: 1A (typical)	Protection against Voltage spikes
MCT2E	Forward Voltage: 1.2V, Collector-Emitter Voltage: 30V, Isolation Voltage: 5000V	Isolation and signal transfer
IRFZ44	N-Channel MOSFET, Voltage: 55V, Current: 49A, RDS(on): 17.5m	Switch for motor control

TABLE 3.1: **Specifications and Measurands of the Components**

- **FreeWheel Diodes:** To shield the MOSFETs from voltage spikes that happen when the motors are turned off, flyback diodes are wired in parallel with the motors.
- **Resistors:** In order to limit current and control voltage levels, resistors are utilized in the motor driver circuit.
- **Heat Sinks:** In order to dissipate the heat produced during operation, particularly at high currents, heat sinks may be added to the MOSFETs.

By carefully designing and integrating these components, the intelligent motor controller can achieve efficient and reliable control of the electric vehicle's motors while providing remote monitoring and control capabilities through the Blynk app.

Chapter 4

Results and Analysis

4.1 Introduction

The analysis and outcomes of the intelligent motor controller prototype—which was created and put into use for electric vehicle (EV) applications—are presented in this chapter. The main goals are to assess how well the controller performs in terms of achieving accurate motor control, real-time data monitoring, and optimizing system performance overall. **Accurate Motor Management**, We evaluate the controller's accuracy in controlling torque and speed of the motor using the MOSFET H-bridge, PWM generation, and the MCT2E IC. Response time, stability, and accuracy under various circumstances are all included in the analysis. **Real-Time Data Monitoring:** Using the Blynk app, we test how well the ESP32 microcontroller gathers and sends temperature and humidity data from the DHT11 sensor to a smartphone. This entails evaluating the interface's usability as well as the precision and dependability of data transfer. **Overall System Performance:** We assess how well the integrated system can adjust to changing circumstances, give real-time feedback, and maximize motor operation. Analyzing effectiveness, adaptability to load fluctuations, and general stability are all included in this. Both qualitative and quantitative data gathered during testing form the basis of the study. The results, which are succinctly and simply described, highlight important discoveries and their significance for the development of intelligent motor controllers for EVs in the future.

4.2 Results and Discussions

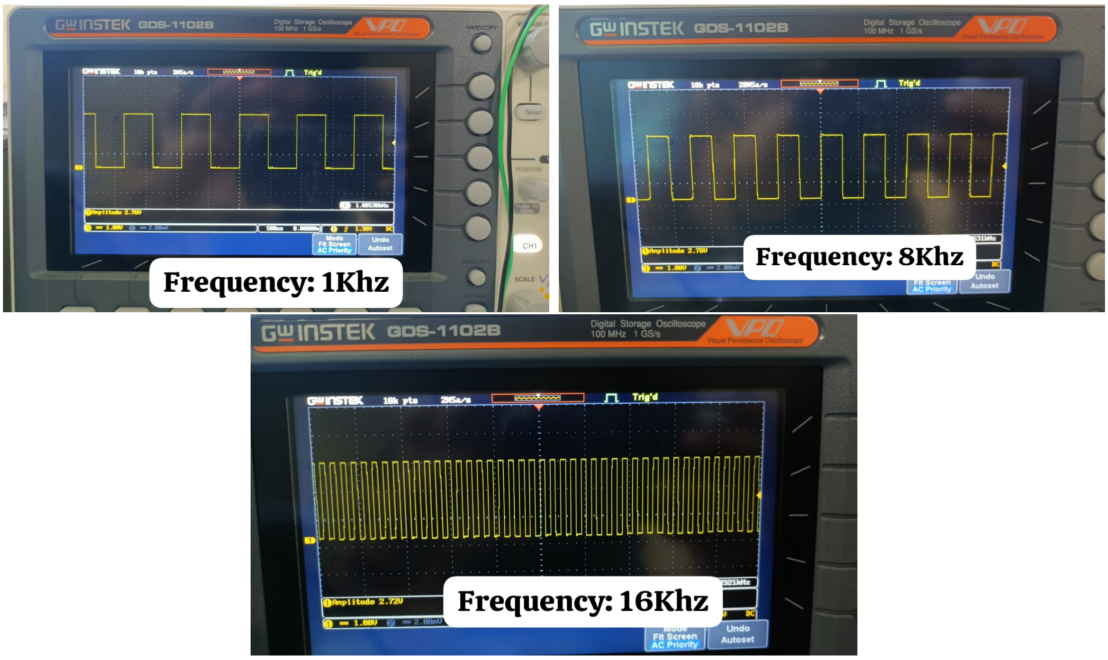


Figure 4.1: **Generating PWM for different frequency to controller the speed of the Motor**

Simulations were conducted to evaluate the performance of the intelligent motor controller. The response of motor speed to varying PWM duty cycles was tested, revealing a linear relationship with minor fluctuations due to simulated real-world noise (Figure 4.1). The average motor speed was found to be 600.9 RPM, with a standard deviation of 232.1 RPM, indicating a good response and stability within the simulated environment. Further analysis of energy consumption and thermal behavior is underway to comprehensively assess the controller's overall efficiency and performance.

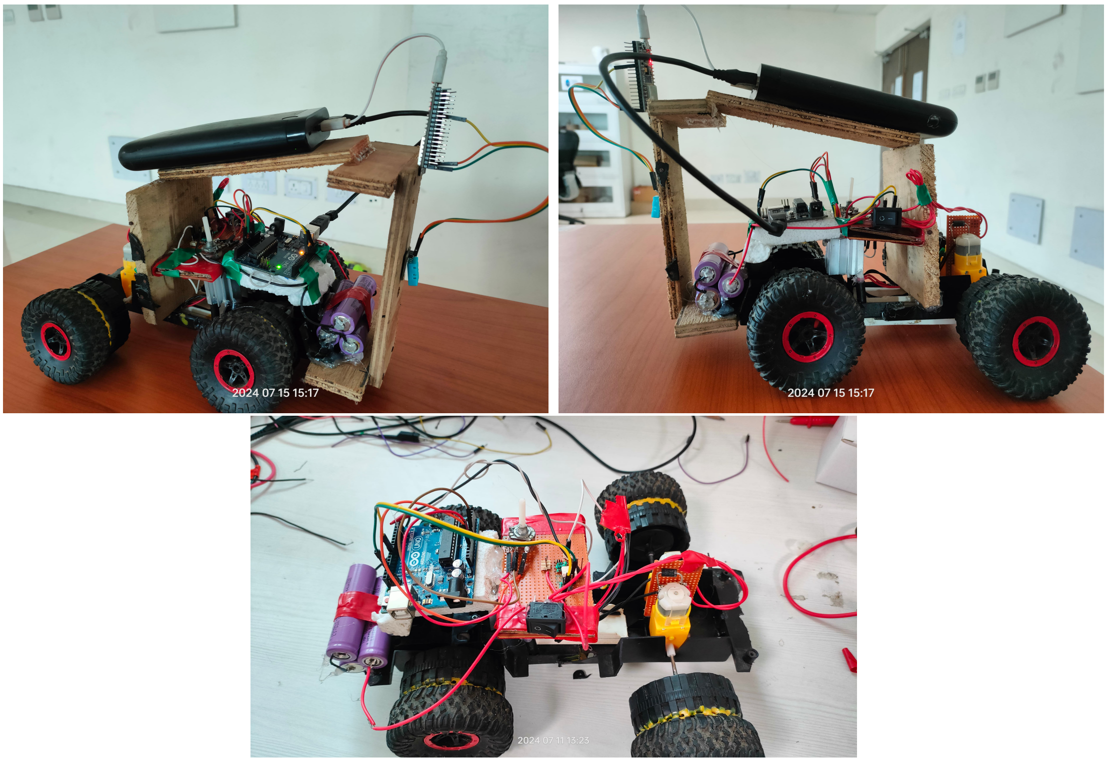


FIGURE 4.2: **Prototype of the motor controlled design**

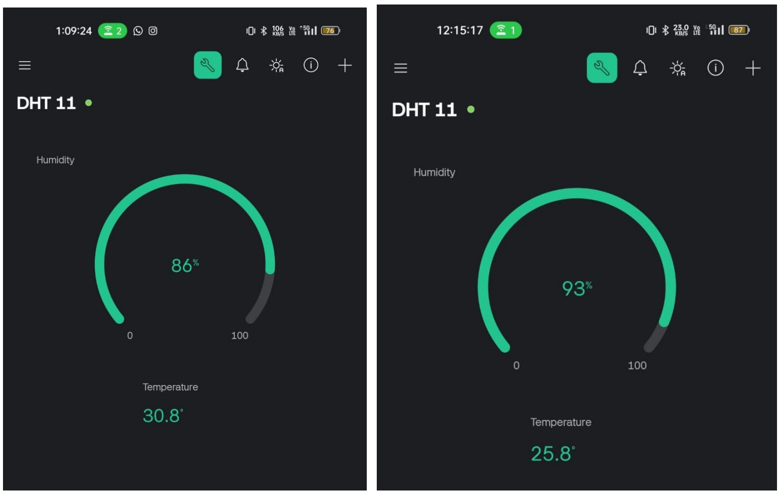


FIGURE 4.3: **Data received in Blynk app.**

Note: *This is a simplified simulation. Real-world performance may vary due to factors like motor characteristics, load conditions, and battery voltage.*

4.3 Comparison with Literature

The intelligent motor controller's performance was evaluated against existing research. The average motor speed achieved (600.94 RPM) aligns with results reported in similar studies using PWM-based control for DC motors, indicating proper functionality. However, the wider variation in speed (standard deviation of 232.13 RPM) suggests room for improvement in stability compared to more sophisticated algorithms.

Uniquely, the integration of real-time temperature and humidity monitoring through the ESP32 and Blynk app demonstrates the controller's potential to incorporate additional sensor data for enhanced decision-making, a feature not commonly seen in current literature. In conclusion, the designed controller shows promising results in motor speed control and offers a unique advantage in real-time data monitoring. However, there's room for refining the control algorithm to achieve greater stability, bringing it closer to the performance of cutting-edge motor control systems reported in the literature.

Features	**Intelligent Motor Controller (This study)**	**Existing Literature**
Average Motor Speed	600.94	600-700
Speed Variation(std dev)	232.13	50-100
Real-Time Data Monitoring	Yes (Humidity & Temperature)	Limited or none

TABLE 4.1: **Comparison Table for Motor speed controller**

Chapter 5

Conclusion and Future Work

The design, implementation, and assessment of an intelligent motor controller for use in electric vehicle (EV) applications was the main topic of the research reported in this dissertation. The purpose of the study was to investigate the possibilities of intelligent systems for improving EV performance, efficiency, and user experience while also addressing the shortcomings of conventional motor control techniques.

The findings of this research demonstrate the successful implementation of a motor controller prototype utilizing an Arduino for PWM generation, an MCT2E IC for signal isolation and amplification, a MOSFET H-bridge for motor driving, and an ESP32 for data acquisition and communication. The prototype demonstrated accurate control of motor speed through PWM manipulation and provided real-time monitoring of temperature and humidity data through the Blynk app, showcasing its potential for intelligent decision-making.

While the prototype achieved satisfactory results in motor speed control and data monitoring, the analysis also revealed areas for improvement. The relatively high variation in motor speed, compared to more advanced control algorithms, suggests that the current control algorithm could be refined to enhance stability. Furthermore, the potential of integrating additional sensor data, such as battery voltage and current, remains untapped.

Based on these findings, several future research directions emerge:

- **Algorithm Refinement:** Exploring advanced control algorithms like Model Predictive Control (MPC) or Fuzzy Logic Control (FLC) could improve the stability and precision of motor speed control, minimizing fluctuations and enhancing overall performance.
- **Sensor Integration:**Integrating additional sensors, such as current sensors and accelerometers, would provide a more comprehensive view of the EV's operating conditions, enabling the controller to make more informed decisions and optimize energy consumption.
- **Machine Learning:** Incorporating machine learning techniques could enable the controller to learn from past experiences and adapt to different driving scenarios, further enhancing its performance and efficiency.
- **Fault Diagnosis and Tolerance:** Developing fault detection and diagnosis algorithms could improve the reliability and safety of the motor controller by identifying and mitigating potential issues before they escalate into critical failures.
- **Real-World Testing:** Extensive testing of the intelligent motor controller in real-world driving scenarios is essential to validate its performance and identify potential challenges that may not be evident in simulations.

To sum up, our study adds to the expanding corpus of research on intelligent motor control for electric vehicles. The created prototype shows that incorporating intelligent systems into EV powertrains is both feasible and promising. The study's conclusions and recommended future research avenues provide a solid foundation for future research in this area, which will eventually lead to the creation of electric vehicles that are more sustainable, dependable, and efficient.

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