FACULTY OF ENGINEERING

MULTIMEDIA UNIVERSITY

April 2016

The project report is prepared for

Faculty of Engineering

Multimedia University

in partial fulfilment for

Bachelor of Engineering (Hons) Electronics

majoring in Telecommunications

**A Servo Controller for Brushed DC Motor**

by

BASHIR TAWFIG BASHIR ABUGHARSA

1181102921

Session 2023/2024

© 2016 Universiti Telekom Sdn. Bhd. ALL RIGHTS RESERVED.

Copyright of this report belongs to Universiti Telekom Sdn. Bhd. as qualified by Regulation 7.2 (c) of the Multimedia University Intellectual Property and Commercialisation Policy. No part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise), or for any purpose, without the express written permission of Universiti Telekom Sdn. Bhd. Due acknowledgement shall always be made of the use of any material contained in, or derived from, this report.

DECLARATION

I hereby declare that this work has been done by myself and no portion of the work contained in this report has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning.

I also declare that pursuant to the provisions of the Copyright Act 1987, I have not engaged in any unauthorised act of copying or reproducing or attempt to copy / reproduce or cause to copy / reproduce or permit the copying / reproducing or the sharing and / or downloading of any copyrighted material or an attempt to do so whether by use of the University’s facilities or outside networks / facilities whether in hard copy or soft copy format, of any material protected under the provisions of sections 3 and 7 of the Act whether for payment or otherwise save as specifically provided for therein. This shall include but not be limited to any lecture notes, course packs, thesis, text books, exam questions, any works of authorship fixed in any tangible medium of expression whether provided by the University or otherwise.

I hereby further declare that in the event of any infringement of the provisions of the Act whether knowingly or unknowingly the University shall not be liable for the same in any manner whatsoever and undertakes to indemnify and keep indemnified the University against all such claims and actions.

A black line drawing on a white background

Description automatically generated

Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name: BASHIR TAWFIG BASHIR ABUGHARSA

Student ID: 1181102921

Date: 11-06-2024

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my supervisor, Dr. Lo Yew Chiong, for his invaluable guidance, support, and encouragement throughout the duration of this project. His expertise in Robotics and Embedded Systems, as well as IoT, has been instrumental in shaping the direction and success of this research. His insightful advice and continuous motivation have been crucial in overcoming the challenges faced during the project.

I am also profoundly grateful to my moderator, Dr. Cham Chin Leei, for his insightful feedback and constructive criticism. His extensive knowledge in Control and Identification and Microcontroller Applications has provided a solid foundation for the evaluation and enhancement of this project. Dr. Cham's detailed and thoughtful comments have significantly improved the quality and depth of my work.

Special thanks to the Faculty of Engineering at Multimedia University for providing the necessary resources and support. The facilities and academic environment have been conducive to conducting my research effectively. I also appreciate the assistance provided by the technical staff, whose expertise ensured the smooth operation of the equipment used in this project.

I would like to extend my appreciation to my peers and colleagues who have provided me with valuable discussions, suggestions, and moral support throughout this journey. Their camaraderie and collaboration have made this experience enjoyable and fulfilling.

Lastly, I would like to thank my family and friends for their unwavering support and encouragement throughout my academic journey. Their belief in me has been a constant source of inspiration and strength, enabling me to persevere and achieve my goals.

ABSTRACT

TODO: Typical format of abstract usually begins with a short introduction to the project that you have done. It is normally covered in 2 to 3 sentences. It should not include what have not been done or what will be done. Furthermore, it is definitely not a general introduction that is not directly related to your project.

This is followed by a brief and concise description of the project implementation. This is basically a synopsis of ‘methodology’ or ‘design’ used in your project. It can include the operation of your project product (for hardware or software type) in brief. Specific model or rare items (hardware or software) can be mentioned. This part is limited to 150 words.

Next, the summary of significant results and findings of your project is presented. This usually comes from the chapter ‘data presentation’ and/or ‘discussion of findings’. The results or data and the discussion can be combined and presented in this part. Data/results can be mentioned in form of relative manner, e.g. x is proportional to y with proportional constant of w, or x = wy. Performance of hardware or software can be either quantitative or qualitative (descriptive) but the descriptive form should be result-oriented. Important comparisons between theoretical or ideal cases and practical cases can also be included.

Finally, the abstract ends with important or overall conclusion. Only the important or significant conclusions from chapter ‘conclusion’ are presented here. Alternatively, an overall conclusion which combines all the individual conclusions can be included here. Notes: You may write your abstract in one or two paragraphs. It is important to note that abstract is written in a case by case basis. However, a typical format can be useful as a guide or reference for you to write the abstract of your project report.

The following items CANNOT be included in the abstract: 1. Issues related to personal, e.g. learned a lot of things from this project. 2. First and second person pronouns (I, we, you, me, my, etc.). 3. Outline of chapters in your project report. 4. Any issues that are not produced from your project (except comparison cases with another person’s work). 5. Reference index or reference number.

TABLE OF CONTENTS

[CHAPTER 1 INTRODUCTION 1](#_Toc169033098)

[1.1 Overview 1](#_Toc169033099)

[1.2 Problem Statements 2](#_Toc169033100)

[1.3 Project Scope 3](#_Toc169033101)

[1.4 Report Outline 3](#_Toc169033102)

[CHAPTER 2 LITERATURE REVIEW 4](#_Toc169033103)

[2.1 Brushed DC Motor Driver Circuit Design 4](#_Toc169033104)

[2.2 PID Controller Design 4](#_Toc169033105)

[2.3 Comparison with Literature Review 4](#_Toc169033106)

[CHAPTER 3 DETAILS OF THE DESIGN 5](#_Toc169033107)

[3.1 Writing Style 5](#_Toc169033108)

[3.2 Figures and Tables 5](#_Toc169033109)

[3.3 Equations 7](#_Toc169033110)

[CHAPTER 4 DATA PRESENTATION AND DISCUSSION OF FINDINGS 8](#_Toc169033111)

[4.1 Data Presentation 8](#_Toc169033112)

[4.2 Discussion of Findings 9](#_Toc169033113)

[CHAPTER 5 CONCLUSIONS 10](#_Toc169033114)

[5.1 Summary and Conclusions 10](#_Toc169033115)

[5.2 Areas of Future Research 10](#_Toc169033116)

LIST OF FIGURES

[Figure ‎2.1 H-Bridge DC Motor Control Circuit [7] 7](#_Toc169454302)

[Figure ‎2.2 Motor Driver L293D [8] 8](#_Toc169454303)

[Figure ‎2.3 Bi-directional rotation using a full bridge [9] 8](#_Toc169454304)

[Figure ‎2.4 H- Bridge motor driver circuit using BJTs [10] 9](#_Toc169454305)

[Figure ‎2.5 Block diagram for the DC motor model [11] 10](#_Toc169454306)

[Figure ‎2.6 Block diagram for DC motor position control [12] 11](#_Toc169454307)

[Figure ‎3.1 IRF3205 N-channel MOSFET [15] 14](#_Toc169454308)

[Figure ‎3.2 IR2110 MOSFET gate driver [16] 15](#_Toc169454309)

[Figure ‎3.3 LM7812 12V voltage regulator IC [17] 16](#_Toc169454310)

[Figure ‎3.4 LM7805 5V voltage regulator [18] 17](#_Toc169454311)

[Figure ‎3.5 1N5819 Schottky Diode [19] 18](#_Toc169454312)

[Figure ‎3.6 STM32f103 microcontroller [21] 19](#_Toc169454313)

[Figure ‎3.7 12V 5A AC/DC Adapter 20](#_Toc169454314)

[Figure ‎3.8 Basic H-bridge circuit [] 21](#_Toc169454315)

LIST OF TABLES

[Table ‎3.1 IRF3205 N-channel MOSFET specifications [15] 14](#_Toc169454316)

[Table ‎3.2 IR2110 MOSFET gate driver specifications [16] 15](#_Toc169454317)

[Table ‎3.3 LM7812 12V voltage regulator specification [17] 16](#_Toc169454318)

[Table ‎3.4 LM7805 5V voltage regulator specification [18] 18](#_Toc169454319)

[Table ‎3.5 1N5819 Schottky diode specification [19] 19](#_Toc169454320)

LIST OF ABBREVIATIONS

FYP Final Year Project

DC Direct Current

AC Alternating Current

PID Proportional-Integral-Derivative

PWM Pulse Width Modulation

MOSFET Metal Oxide Semiconductor Field Effect Transistor

BJT Bipolar Junction Transistor

# INTRODUCTION

## Overview

The advent of electric motors has been pivotal in the evolution of various mechanical systems, and among the spectrum of motors utilized, the Brushed DC motor is known for its straightforward architecture and control [1]. This type of motor is ubiquitous across multiple sectors due to its operational simplicity and cost-effectiveness, making it a preferred choice for mass-produced goods. Brushed DC motors are characterized by their direct compatibility with DC power sources, a feature that has solidified their position in applications where easy power access is a prerequisite. However, with the advent of more sophisticated technological demands, there is a pressing need for precision in motor operations. Precision, a non-negotiable quality in contemporary applications such as automated precision machining, unmanned aerial vehicles, and sophisticated navigational systems, requires an advanced degree of control that surpasses the capabilities of conventional open-loop controllers [2].

Considering these requirements, the domain of servo controllers has gained popularity, offering the potential for refined control and enhanced operational efficiency of Brushed DC motors. These controllers employ feedback mechanisms, principally through encoders, to furnish a continuous stream of data regarding motor position and velocity, facilitating an immediate corrective response via closed-loop control systems. The implementation of such feedback loops is fundamental to the servo control methodology, enabling the system to counteract any deviations from predefined motor performance criteria. Nonetheless, the task of engineering a servo controller that is both precise and efficient is fraught with challenges [3]. It necessitates meticulous signal processing, effective power management, and a resilient design that can withstand the exigencies of operation. As the application spectrum of Brushed DC motors broadens to more demanding tasks, the controller technology must concurrently advance, incorporating sophisticated control algorithms. This project aims to forge a controller that focuses on performance, cost-efficiency, and minimal complexity, thereby extending the functional envelope of Brushed DC motors.

## Problem Statements

The inherent mechanical properties of Brushed DC motors limit their capacity for precision control when relying solely on conventional driver circuits. These standard circuits lack the sophistication to finely tune the motor’s speed and positioning, which is a critical deficiency for applications that necessitate exact movements and strict adherence to motion profiles. The driver circuit alone is not equipped to account for the dynamic variables that impact motor performance, such as external loads and power supply irregularities. To achieve the high level of precision required in advanced technological applications, it is essential to go beyond the basic control that driver circuits offer.

The necessity for precise motor control becomes evident in applications like automated precision machining, unmanned aerial vehicles, and sophisticated navigational systems, where even minor deviations can lead to significant errors or failures. Conventional open-loop control systems are insufficient in these scenarios as they cannot provide real-time feedback and correction, resulting in inaccuracies and inefficiencies.

Moreover, as the complexity and demand for higher performance in technological systems increase, there is a pressing need for a robust control solution that can dynamically adjust to varying conditions and maintain optimal motor performance. This challenge is further compounded by the need for a cost-effective and minimally complex solution that can be easily implemented and maintained.

Thus, the primary problem addressed by this project is the development of a servo controller for Brushed DC motors that can provide precise and efficient control. This involves designing a system that integrates feedback mechanisms and advanced control algorithms to ensure accurate motor operation despite external disturbances and variations in operating conditions. By addressing these challenges, the project aims to enhance the functionality and applicability of Brushed DC motors in high-precision and demanding environments.

## Project Objectives

TODO:

## Project Scope

The objective of this project is to engineer a servo controller tailored for Brushed DC motors, with a focus on significantly enhancing their precision in terms of positioning control. A critical part of the project involves designing and building a driver circuit. This circuit will be controlled by a Pulse Width Modulation (PWM) signal originating from a microcontroller [4]. The driver circuit's role is pivotal as it acts as the primary mechanism for controlling the motor.

The project will incorporate a Proportional-Integral-Derivative (PID) closed-loop control system [5]. This system will be integrated seamlessly with the driver circuit and microcontroller, establishing the PID controller as the core unit responsible for continuously monitoring and fine-tuning the motor's output. An optical encoder will be used in the feedback loop to provide real-time data on the motor's position and velocity. Through this dynamic regulation, the system will be able to maintain strict adherence to the predefined motion profiles, effectively handling external influences such as variations in load. This comprehensive approach aims to elevate the performance of Brushed DC motors to meet the demanding precision standards of modern applications, ensuring they operate efficiently and accurately under a wide array of conditions.

## Report Outline

TODO: This section serves to inform readers about the organisation of the report, e.g. what are presented and where and how they are presented.

# LITERATURE REVIEW

This chapter provides a comprehensive overview of the existing literature related to the development and implementation of servo controllers for Brushed DC motors. It outlines the various works that have been conducted in this area, emphasizing different methodologies used to enhance motor control precision and efficiency. More specifically, it highlights the approaches that integrate advanced control techniques, including Pulse Width Modulation (PWM) and Proportional-Integral-Derivative (PID) controllers, in motor control systems.

Particular attention is given to the design and application of H-bridge circuits and their role in controlling the speed and direction of Brushed DC motors. The review also delves into the integration of feedback mechanisms, such as optical encoders, which provide real-time data essential for closed-loop control systems. These feedback systems are crucial for maintaining strict adherence to predefined motion profiles, ensuring accurate and efficient motor performance.

This chapter critically evaluates the contributions of various methodologies, comparing their strengths and weaknesses in relation to the overall research context. The investigated research domains include real-time control techniques and the implementation of microcontrollers, specifically STM32, in embedded motor control applications. The adaptation of these advanced control systems to handle external influences, such as load variations, is also discussed.

The findings of this review will offer an in-depth analysis of the current state of research in the field of Brushed DC motor control. Additionally, it will highlight novel strategies and advancements in control algorithms and feedback mechanisms that contribute to the enhanced precision and efficiency of servo controllers for Brushed DC motors.

## Brushed DC Motor Driver Circuit Design

The design of driver circuits for Brushed DC motors is crucial in achieving precise control of motor speed and direction. Various methods and components are utilized to enhance the performance and efficiency of these driver circuits. This section reviews the key methodologies and components, focusing on the use of Pulse Width Modulation (PWM) and H-bridge circuits.

The H-bridge configuration is a fundamental circuit for driving DC motors, allowing them to operate in both forward and reverse directions. An H-bridge consists of four switching elements, typically transistors or MOSFETs, arranged in a configuration that can control the direction of the current flow through the motor, thus controlling its rotation direction [6].

Research has shown that designing an H-bridge DC motor driver using a microcontroller that generates high-frequency PWM signals can effectively control motor speed and direction. One study [7] implemented an H-bridge driver circuit utilizing NPN and PNP MOSFETs driven by TLP250 MOSFET drivers. The use of PWM signals allowed for efficient control of motor speed by adjusting the duty cycle, which directly influenced the motor terminal voltage.

A diagram of a circuit board

Description automatically generated

Figure ‎2.1 H-Bridge DC Motor Control Circuit [7]

The design included a current sensor to monitor the motor current, protecting the motor from high current conditions such as short circuits or overloading. This integration ensured the longevity and reliability of the motor and the driver circuit [7].

Another research [8] explores the use of Pulse Width Modulation (PWM) for controlling DC motor speed, employing an AT89S52 microcontroller and L293D IC. This method excels in providing precise control over small DC motors in a cost-effective manner. However, the reliance on L293D IC limits its applicability to small motors, posing a challenge for more complex operational contexts.

A diagram of a motor

Description automatically generated

Figure ‎2.2 Motor Driver L293D [8]

Other research [9] implements a PWM-based motor control circuit using an LM324 operational amplifier and four MOSFET to form the H-Bridge circuit. This design is lauded for its efficiency and suitability for small scale applications. Nonetheless, the LM324’s limitations in bandwidth and response accuracy may hinder performance in high-speed applications.

A diagram of a circuit

Description automatically generated

Figure ‎2.3 Bi-directional rotation using a full bridge [9]

Another research [10] discussed the design of wheeled mobile robots that use H-bridge motor driver circuit, stands out for its detailed analysis of circuit designs under varying load conditions. The use of BJTs in this design provides a cost-effective solution, but it falls short in terms of efficiency and power management compared to MOSFETs, which could affect its performance in more demanding robotic applications.

A diagram of a motor

Description automatically generated

Figure ‎2.4 H- Bridge motor driver circuit using BJTs [10]

### Efficiency and Reliability

The efficiency of an H-bridge driver circuit is significantly enhanced by using PWM control. Traditional methods, such as using a variable resistor, result in considerable power loss due to heat dissipation. PWM, on the other hand, minimizes these losses by rapidly switching the supply voltage, reducing the time the transistors spend in the transition states where power loss is highest.

In their implementation, researchers emphasized the cost-effectiveness and reliability of their design, noting that it allowed for precise speed control without the need for expensive components. The use of microcontrollers for generating PWM signals further enhanced flexibility and control accuracy, making the design suitable for various industrial applications.

## PID Control in DC Motor Position Systems

The proportional-integral-derivative (PID) controller is a widely used control algorithm in industrial applications due to its simplicity and effectiveness in handling a variety of control problems [10]. For brushed DC motors, PID controllers are particularly valuable in achieving precise speed and position control, which is critical in applications requiring exact movements and strict adherence to motion profiles.

In one study [11], a PID controller was applied to control the angular position of a DC motor connected to a valve of a hydraulic pump. The system was implemented using an ATmega16 microcontroller, and the PID parameters were carefully tuned to optimize performance. The experimental results demonstrated that the PID controller effectively suppressed oscillations caused by system and sensor nonlinearities, maintaining precise control of the motor's position.

A diagram of a block diagram

Description automatically generated

Figure ‎2.5 Block diagram for the DC motor model [11]

Another research [12] focused on controlling the angular position of a DC geared motor using a PID controller with friction compensation. The study utilized an Arduino microcontroller and an L298N dual H-bridge motor driver to execute PWM signals. The PID controller successfully minimized errors and oscillations, achieving a high level of precision in the motor's position control. The inclusion of friction compensation further improved the system's performance, making it suitable for applications like robotic arm position control.

A diagram of a computer component

Description automatically generated

Figure ‎2.6 Block diagram for DC motor position control [12]

Implementing a PID controller for DC motors involves several challenges, including tuning the PID parameters and handling system nonlinearities. The process of tuning involves setting the proportional gain (Kp), integral gain (Ki), and derivative gain (Kd) to achieve the desired control performance. Incorrect tuning can lead to issues like overshoot, oscillations, and steady-state errors.

A study [13] on DC motor speed control using PWM highlighted the importance of precise tuning of PID parameters. The researchers used an Arduino microcontroller to generate PWM signals and control the motor speed. They emphasized the need for iterative tuning and testing to find the optimal PID settings that balance responsiveness and stability.

Another study [14] investigated the application of PID controllers for DC motor angular position control, highlighting the advantages of PID controllers in terms of stability and precision. The study utilized a genetic algorithm for tuning the PID parameters, achieving superior performance compared to the Ziegler-Nichols method. This approach provided a more refined tuning process, reducing the error between the actual and desired responses, and enhancing the system's robustness against disturbances

The primary advantage of PID controllers lies in their ability to provide stable and accurate control with relatively simple implementation. They are capable of handling a wide range of operating conditions and can be easily adjusted to meet specific performance requirements. The use of PID controllers in brushed DC motor systems enhances their applicability in high-precision environments, such as automated machinery, robotics, and navigation systems.

# DETAILS OF THE DESIGN

This chapter provides a comprehensive overview of the methodology employed in the creation of a servo controller for a Brushed DC motor. It covers the entire design process, from the initial development of the H-bridge driver circuit to the integration of the PID control system. Emphasis is placed on both the practical implementation and the theoretical foundations necessary to achieve precise motor control.

The design and construction of the H-bridge driver circuit are detailed with schematics and component descriptions, addressing the selection of components and the challenges encountered. The integration of the PID control system is then explored, highlighting the principles of Proportional-Integral-Derivative control and the tuning methods used to optimize performance. Additionally, the chapter discusses the feedback mechanism involving an optical encoder, which provides real-time data on the motor's position and velocity, crucial for maintaining accurate control and responding to changes in load and other external factors. By detailing each step from concept to implementation, this chapter aims to provide a clear understanding of the design and execution involved in developing a robust servo control system for Brushed DC motors.

## Main Components:

In designing the Brushed DC motor driver circuit, several key components are essential for achieving precise control over the motor's speed and direction. This section provides an overview of the main components used in the circuit. By understanding the function and role of each component, we can better appreciate how they are integrated to create an efficient and reliable motor control system. The primary components discussed include the H-bridge circuit, MOSFETs, the microcontroller, and the PWM signals.

### IRF3205 N-channel MOSFET:

This power MOSFET is known for its high current (110A) and voltage (55V) handling capabilities, making it suitable for heavy-duty applications. Its low on-resistance and fast switching speed are advantageous for efficient power management in motor control circuits [15].

A close-up of a chip

Description automatically generated

Figure ‎3.1 IRF3205 N-channel MOSFET [15]

Table ‎3.1 IRF3205 N-channel MOSFET specifications [15]

|  |  |
| --- | --- |
| **Specification** | **IRF3205** |
| **ID (@25°C) max** | 110 A |
| **Mounting** | THT |
| **Operating Temperature min max** | -55 °C / 175 °C |
| **Ptot max** | 150 W |
| **Package** | TO-220 |
| **Polarity** | N |
| **QG (typ @10V)** | 97.3 nC |
| **Qgd** | 36 nC |
| **RDS (on) (@10V) max** | 8 mΩ |
| **RthJC max** | 1 K/W |
| **Tj max** | 175 °C |
| **VDS max** | 55 V |
| **VGS(th) min max** | 3 V / 2 V / 4 V |
| **VGS max** | 20 V |

### IR2110 MOSFET Gate Driver:

The IR2110 is a high voltage (up to 500V), high-speed driver specifically designed for MOSFETs and IGBTs. It features independent high and low side referenced output channels, crucial for precise and rapid switching in H-bridge configurations [16].

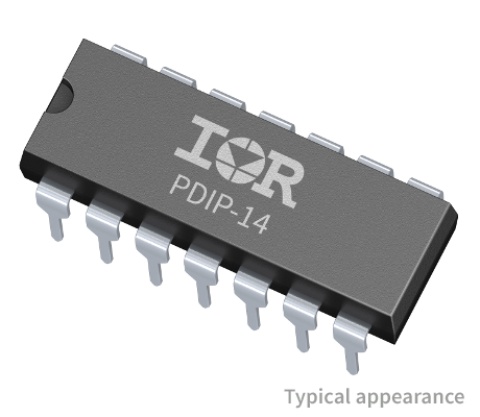


Figure ‎3.2 IR2110 MOSFET gate driver [16]

Table ‎3.2 IR2110 MOSFET gate driver specifications [16]

|  |  |
| --- | --- |
| **Specification** | **IR2110** |
| **Channels** | 2 |
| **Configuration** | High-side and low-side |
| **Input Vcc min max** | 10 V / 20 V |
| **Isolation Type** | Functional levelshift |
| **Output Current (Source)** | 2.5 A |
| **Output Current (Sink)** | 2.5 A |
| **Qualification** | Industrial |
| **Turn Off Propagation Delay** | 94 ns |
| **Turn On Propagation Delay** | 120 ns |
| **VBS UVLO (On)** | 8.6 V |
| **VBS UVLO (Off)** | 8.2 V |
| **VCC UVLO (On)** | 8.5 V |
| **VCC UVLO (Off)** | 8.2 V |
| **Voltage Class** | 500 V |

### LM7812 12V Voltage Regulator

The LM7812 is a three-terminal positive voltage regulator IC that provides a stable 12V output from a higher voltage input, typically ranging from 14.5V to 35V. It is widely used in electronic circuits to ensure a consistent voltage supply, protecting components from voltage fluctuations. The LM7812 is capable of delivering up to 1.5A of output current and features internal thermal overload protection, short-circuit protection, and safe area protection. This makes it a reliable choice for a variety of applications requiring a regulated 12V power supply [17].

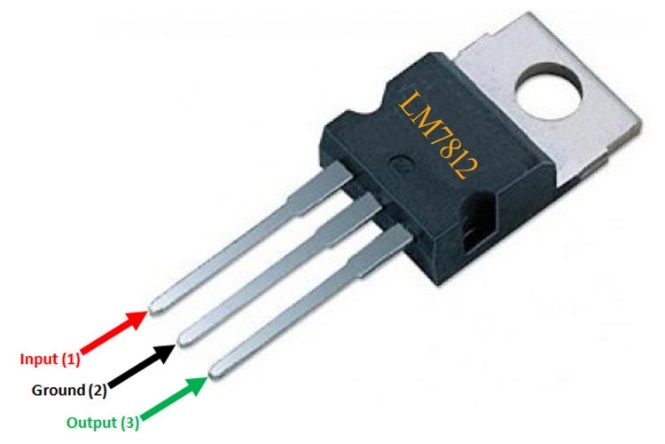


Figure ‎3.3 LM7812 12V voltage regulator IC [17]

Table ‎3.3 LM7812 12V voltage regulator specification [17]

|  |  |
| --- | --- |
| **Specification** | **LM7812** |
| **Output Voltage** | 12V |
| **Input Voltage Range** | 14.5V to 35V |
| **Output Current (max)** | 1.5A |
| **Dropout Voltage (typ)** | 2V |
| **Line Regulation** | 3mV |
| **Load Regulation** | 15mV |
| **Quiescent Current (typ)** | 8mA |
| **Operating Temperature Range** | 0°C to 125°C |
| **Thermal Overload Protection** | Yes |
| **Short-Circuit Protection** | Yes |
| **Package Types** | TO-220, TO-3, D2PAK |

### LM7805 5V Voltage Regulator

The LM7805 is a three-terminal positive voltage regulator IC that provides a fixed 5V output from a higher voltage input, typically ranging from 7V to 35V. It is commonly used in a variety of electronic devices to ensure a stable and consistent 5V power supply. The LM7805 can deliver up to 1.5A of output current and includes features such as internal thermal overload protection, short-circuit protection, and safe area protection. These features make the LM7805 a reliable and widely used component for powering low-voltage digital circuits and other applications requiring a regulated 5V supply [18].

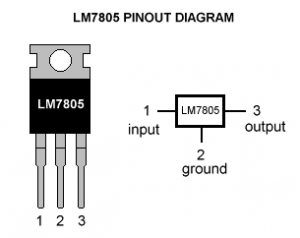


Figure ‎3.4 LM7805 5V voltage regulator [18]

Table ‎3.4 LM7805 5V voltage regulator specification [18]

|  |  |
| --- | --- |
| **Specification** | **LM7805** |
| **Output Voltage** | 5V |
| **Input Voltage Range** | 7V to 35V |
| **Output Current (max)** | 1.5A |
| **Dropout Voltage (typ)** | 2V |
| **Line Regulation** | 3mV |
| **Load Regulation** | 15mV |
| **Quiescent Current (typ)** | 8mA |
| **Operating Temperature Range** | 0°C to 125°C |
| **Thermal Overload Protection** | Yes |
| **Short-Circuit Protection** | Yes |
| **Package Types** | TO-220, TO-3, D2PAK |

### 1N5819 Schottky Diode

The 1N5819 is a Schottky diode known for its low forward voltage drop and fast switching speed. It is widely used in power supply circuits and other applications where efficiency and performance are crucial. The 1N5819 can handle a maximum reverse voltage of 40V and a forward current of up to 1A. Its low forward voltage drop, typically around 0.2V to 0.45V, makes it ideal for use in low-voltage, high-efficiency applications. Additionally, the fast recovery time of the 1N5819 enhances its performance in high-speed switching applications [19].

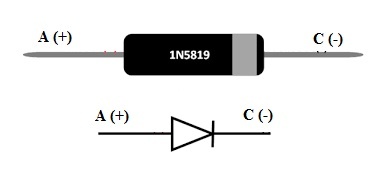


Figure ‎3.5 1N5819 Schottky Diode [19]

Table ‎3.5 1N5819 Schottky diode specification [19]

|  |  |
| --- | --- |
| **Specification** | **1N5819** |
| **Maximum Reverse Voltage (VR)** | 40V |
| **Forward Current (IF)** | 1A |
| **Forward Voltage Drop (VF)** | 0.2V to 0.45V |
| **Reverse Current (IR)** | 1mA at 40V |
| **Operating Temperature Range** | -65°C to 125°C |
| **Package Type** | DO-41 |

### STM32f103 Microcontroller

This microcontroller board offers robust features like a 72 MHz ARM Cortex-M3 processor, 20KB SRAM, and 64KB Flash memory. It's capable of complex tasks like generating accurate PWM signals, essential for intricate motor control applications like speed and directional adjustments [20].

A blue circuit board with many small objects

Description automatically generated with medium confidence

Figure ‎3.6 STM32f103 microcontroller [21]

### 12V 5A AC/DC Adapter

The AC to DC Power Adapter converts an input of 100-240V AC to a stable 12V DC output, capable of delivering up to 5A of current. This adapter is well-suited for powering motor driver circuits, providing the necessary DC voltage to operate components such as the H-bridge and control electronics. The adapter's standard DC barrel connector ensures compatibility with common motor driver setups. Additionally, it includes built-in safety features such as overvoltage, overcurrent, and short-circuit protection, ensuring reliable and safe operation of the motor driver circuit. Its compact design facilitates easy integration into various setups, making it a practical choice for powering Brushed DC motor control systems.



Figure ‎3.7 12V 5A AC/DC Adapter

### MD36NP2724V Brushed DC Motor

This Brushed DC Motor, available on AliExpress, operates at 24V and is equipped with an optical encoder that provides 500 pulses per revolution. The motor features a gear ratio of 3249:121, allowing for precise control of its speed and position. The inclusion of the optical encoder enhances its performance in applications requiring accurate feedback and fine-tuned control. This makes it ideal for integration into systems where precise motor control is essential, such as in servo mechanisms and automated machinery [22].

A close-up of a small electric motor

Description automatically generated

Figure ‎3.8 MD36NP2724V brushed DC motor [22]

## Hardware Tools

This section outlines the various hardware tools utilized in the design and implementation of the servo controller for the Brushed DC motor. These tools are essential for developing, testing, and refining the motor control system. By providing detailed descriptions of each hardware tool, we aim to give a comprehensive understanding of their roles and importance in the project. The hardware tools discussed include the microcontroller, development boards, power supplies, oscilloscopes, and other essential equipment used throughout the design and testing phases.

### Hantek2000 Oscilloscope / Multimeter

The Hantek2000 Handheld Oscilloscope is a versatile and portable diagnostic tool designed for capturing and analyzing electrical signals in various applications. It features a compact design with a user-friendly interface, making it ideal for fieldwork and on-the-go troubleshooting. The oscilloscope provides real-time waveform viewing with high resolution and accuracy, capable of measuring a wide range of signal frequencies and amplitudes. It includes multiple measurement modes, such as single-shot and continuous sampling, as well as built-in functions for signal analysis. The Hantek2000 is equipped with a rechargeable battery, ensuring extended operational time without the need for constant power sources, and its robust design ensures durability in various working environments [23].

A black device with a screen

Description automatically generated

Figure ‎3.9 Hantek2000 Handheld Oscilloscope [23]

### ST-LINK/V2 Debugger and Programmer

The ST-LINK/V2 is an in-circuit debugger and programmer for the STM8 and STM32 microcontroller families. It provides a straightforward interface for programming and debugging these microcontrollers, making it an essential tool for development and troubleshooting. The ST-LINK/V2 supports JTAG/SWD and SWIM communication protocols, ensuring compatibility with a wide range of STMicroelectronics devices. It connects to a host computer via USB, offering a reliable and high-speed connection for firmware uploads and debugging sessions. The programmer is compact and portable, equipped with multiple connectors for easy integration into various development environments. Its robust design and comprehensive support make it a valuable tool for both professional and hobbyist embedded systems developers [24].



Figure ‎3.10 ST-LINK/V2 in-circuit debugger/programmer [24]

### USB to TTL Module (CP2102)

The USB to TTL Module (CP2102) is a compact and efficient adapter that facilitates communication between a computer's USB port and TTL (Transistor-Transistor Logic) serial devices. Based on the CP2102 chipset, this module provides reliable and fast data transfer rates, making it ideal for a wide range of applications, including microcontroller programming, debugging, and serial communication with other TTL devices. It features easy-to-use pin headers for direct connection to the target device and supports various baud rates to accommodate different communication needs. The module is widely compatible with major operating systems, including Windows, MacOS, and Linux, ensuring seamless integration into diverse development environments. Its small form factor and robust performance make it an essential tool for embedded systems developers and hobbyists alike [25].



Figure ‎3.11 3.2.3 USB to TTL Module (CP2102) [25]

## Software Tools

This section outlines the various software tools utilized in the development and implementation of the servo controller for the Brushed DC motor. These tools play a crucial role in programming, debugging, simulation, and overall project management. By providing detailed descriptions of each software tool, we aim to give a comprehensive understanding of their roles and importance in the project. The software tools discussed include integrated development environments (IDEs), debugging tools, and other essential software used throughout the design and testing phases.

### STM32CubeIDE

STM32CubeIDE is an integrated development environment (IDE) developed by STMicroelectronics specifically for STM32 microcontrollers. It combines the capabilities of the STM32CubeMX graphical configurator with the Eclipse-based development environment, providing a comprehensive tool for configuring, coding, debugging, and optimizing STM32 applications. STM32CubeIDE supports C/C++ programming languages and offers advanced debugging features, including support for SWD, JTAG, and ST-LINK interfaces. The IDE integrates seamlessly with STM32CubeMX, allowing users to generate initialization code and set up peripheral configurations easily. With its extensive libraries and middleware, STM32CubeIDE simplifies the development process, making it an essential tool for embedded systems developers working with STM32 microcontrollers [26].

A computer screen shot of a computer

Description automatically generated

Figure ‎3.12 STM32CubeIDE user interface

### Arduino IDE 2

The Arduino Integrated Development Environment (IDE) is a versatile software tool used primarily for programming Arduino microcontrollers. It provides a user-friendly interface for writing, compiling, and uploading code to Arduino boards. In this project, the Arduino IDE was utilized specifically for its serial monitor and serial plotter features. These tools facilitate real-time data visualization and debugging by allowing users to monitor and plot serial data transmitted from the microcontroller. The serial monitor displays text data sent from the microcontroller, while the serial plotter provides graphical representation of numerical data, making it easier to analyze the system's performance and troubleshoot issues [27].

A screenshot of a computer

Description automatically generated

Figure ‎3.13 Arduino IDE 2 user interface

### Autodesk Fusion 360

Fusion 360 is a comprehensive 3D CAD, CAM, and CAE tool developed by Autodesk. It integrates various design and engineering capabilities into a single platform, making it a powerful tool for product development. In this project, Fusion 360 was used specifically for schematic design. The software's robust schematic capture and PCB design tools facilitated the creation of detailed and accurate circuit schematics, ensuring a reliable foundation for the hardware implementation of the servo controller. Fusion 360's intuitive interface and extensive library of electronic components made it an essential tool for designing and documenting the electrical aspects of the project [28].

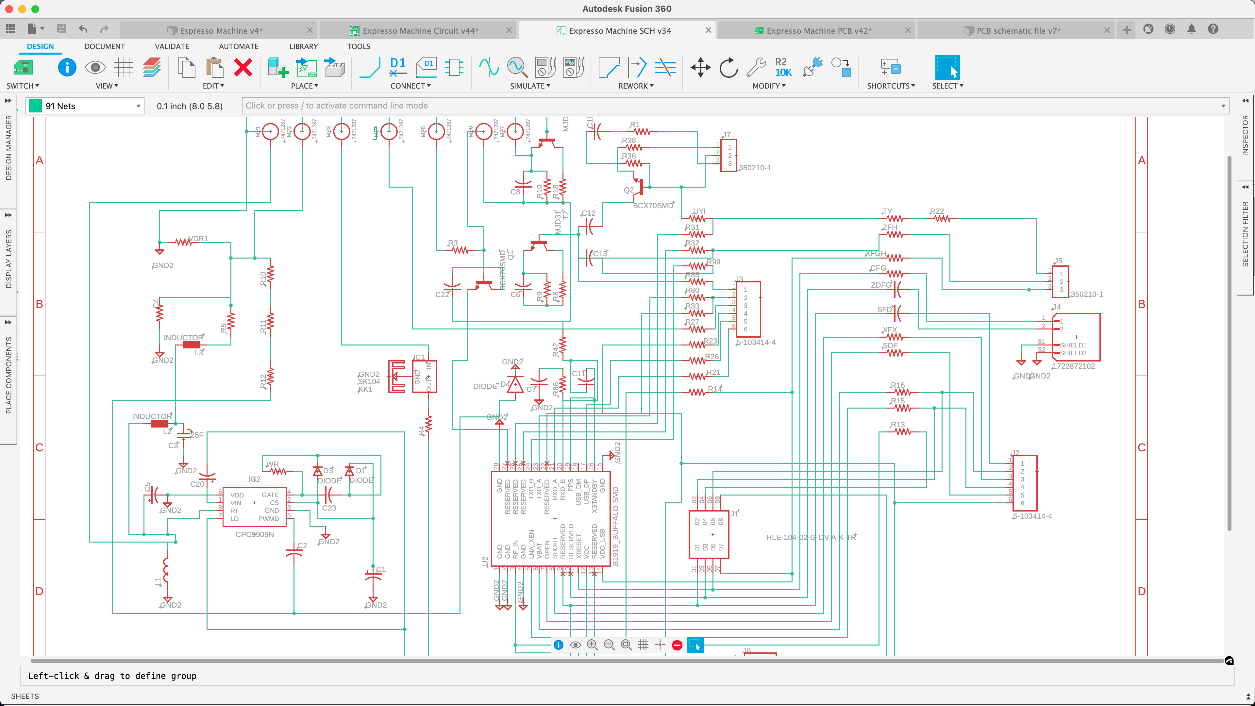


Figure ‎3.14 Autodesk Fusion 360 user interface

## Brushed DC Motor Driver Circuit Design

The Brushed DC motor driver circuit is designed using an H-bridge configuration to control the speed and direction of the motor. The H-bridge circuit allows for the bidirectional control of the motor by changing the polarity of the voltage applied to it. The speed of the motor is controlled using Pulse Width Modulation (PWM) signals generated from a microcontroller.

The H-bridge circuit consists of four MOSFETs arranged in a configuration that enables the motor to be driven in both forward and reverse directions. By switching the appropriate pairs of MOSFETs, the polarity of the voltage applied to the motor is reversed, allowing for the control of the motor's rotational direction [6]. The PWM signals, which control the switching of the MOSFETs, are generated by the microcontroller. The duty cycle of these PWM signals determines the average voltage applied to the motor, thus controlling its speed.

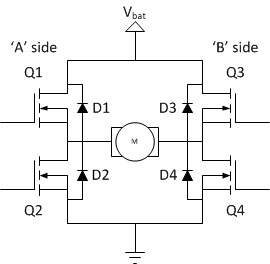


Figure ‎3.15 Basic H-bridge circuit []

### Driver Circuit Schematic Design

# DATA PRESENTATION AND DISCUSSION OF FINDINGS

The results/data presentation and discussion sections can be both the most interesting as well as the most challenging sections to write. You may choose to write these sections separately, or combine them into a single chapter, depending on your preferences.

## Discussion of Findings

This section has several purposes. Among others it should interpret and explain your results, answer your research questions or problem statement, justify your approach and critically evaluate your study. The discussion section therefore needs to review your findings in the context of the literature and the existing knowledge about the subject.

You also need to demonstrate that you understand the limitations of your research and the implications of your findings for policy and practice. This section should be written in the present tense. The discussion section needs to follow from your results and relate back to your literature review. Make sure that everything you discuss is covered in the results section. However leave the conclusions for the conclusion chapter.

# CONCLUSIONS

## Summary and Conclusions

This chapter describes briefly and concisely the overall achievement of the project in terms of what have been done, what are the features, what are the functions, etc..

Notes: You may write your conclusion in several paragraphs. Note that conclusions are written in a case by case basis. Hence, this typical format is used as a guide or reference for you to write conclusions. First and second person pronouns (I, we, you, me, my, etc.) should be minimized or avoided.

Conclusion CANNOT include the following items: 1. Issues related to personal, e.g. learned a lot of things from this project. 2. Any issues or works that are not produced from your project (except comparison cases with another person’s work). 3. Any issues that are not discussed in discussion chapter.

Individual conclusions: These individual conclusions are made based on the chapter ‘discussion of findings’. Each discussion in the discussion chapter is concluded here without further discussion. In some cases, a conclusion can be made based on several discussions. Conclusions are made in terms of advantages, disadvantages, limitations, dependencies, affecting factors, problems, etc. All the conclusions should be in justified or confirmed (either good or bad) manner and should not look like discussion.

Overall conclusion: In some cases, an overall conclusion can be made based on the individual conclusions which can be combined into one.

## Areas of Future Research

This section describes some of the issues, which remain to be tackled in the future.

REFERENCES

1. D. Steefo, "A comprehensive guide on DC motor applications," Medium, Jan. 15, 2023. [Online]. Available: <https://medium.com/@dm.steefo/a-comprehensive-guide-on-dc-motor-applications-ecbbf417a5f8#:~:text=DC%20motors%20have%20many%20advantages,appliances%20to%20large%20industrial%20machinery>. [Accessed: Jun. 15, 2024].
2. "Introduction to Servo Motors," Fuji Electric, [Online]. Available: https://www.fujielectric.com/about/column/detail/servo\_01.html#01. [Accessed: Jun. 15, 2024].
3. "Servo Motors: Advantages," RealPars, [Online]. Available: https://www.realpars.com/blog/servo-motors-advantages. [Accessed: Jun. 15, 2024].
4. J. Upadhyay, "What is a PWM Signal?," CircuitBread. [Online]. Available: https://www.circuitbread.com/ee-faq/what-is-a-pwm-signal. [Accessed: Jun. 15, 2024].
5. T. Mortenson, "PID Controller Explained," RealPars, Dec. 14, 2022. [Online]. Available: https://www.realpars.com/blog/pid-controller. [Accessed: Jun. 15, 2024].
6. J. Shah, "How does an H-Bridge work?," CircuitBread. [Online]. Available: https://www.circuitbread.com/ee-faq/how-does-an-h-bridge-work. [Accessed: Jun. 15, 2024].
7. T. Özer, S. Kıvrak, and Y. Oğuz, "H Bridge DC Motor Driver Design and Implementation with Using dsPIC30f4011," International Journal of Innovative Research in Science, Engineering and Technology, vol. 6, Special Issue 10, May 2017. [Online]. Available: https://www.researchgate.net/publication/317225711\_H\_Bridge\_DC\_Motor\_Driver\_Design\_and\_Implementation\_with\_Using\_dsPIC30f4011. [Accessed: Jun. 15, 2024].
8. K. Priyanka and A. Mariyammal, "DC Motor Speed Control Using PWM," International Journal of Innovative Science and Research Technology, vol. 3, no. 2, Feb. 2018. [Online]. Available: https://www.researchgate.net/publication/338116979\_DC\_Motor\_Speed\_Control\_Using\_PWM. [Accessed: Jun. 15, 2024].
9. J. A.-K. Mohammed, "Pulse Width Modulation for DC Motor Control Based on LM324," Engineering and Technology Journal, vol. 31, Part (A), no. 10, pp. 1882-1896, Mar. 2013. [Online]. Available: https://www.researchgate.net/publication/338389782\_Pulse\_Width\_Modulation\_for\_DC\_Motor\_Control\_Based\_on\_LM324. [Accessed: Jun. 15, 2024].
10. U. Waseem, "PID Loops: A Comprehensive Guide to Understanding and Implementation," Wevolver, Dec. 12, 2022. [Online]. Available: https://www.wevolver.com/article/pid-loops-a-comprehensive-guide-to-understanding-and-implementation. [Accessed: Jun. 15, 2024]
11. Khaled Sailan and K.-D. Kuhnert, "DC Motor Angular Position Control Using PID Controller for the Purpose of Controlling the Hydraulic Pump," International Conference on Control, Engineering & Information Technology (CEIT'13), 2013.
12. M. M. Maung, M. M. Latt, and C. M. Nwe, "DC Motor Angular Position Control Using PID Controller with Friction Compensation," International Journal of Scientific and Research Publications, vol. 8, no. 11, Nov. 2018.
13. M. Saad, A. Amhed, and M. Al Sharqawi, "Real Time DC Motor Position Control Using PID Controller in LabVIEW," Journal of Robotics and Control (JRC), vol. 2, no. 5, Sep. 2021. [Online]. Available: https://www.researchgate.net/publication/348151106\_Real\_Time\_DC\_Motor\_Position\_Control\_Using\_PID\_Controller\_in\_LabVIEW. [Accessed: Jun. 15, 2024].
14. R. Awar, Y. K. Al Ali, and Y. Al Jrab, "Speed and Position Control of a DC Motor," American University of Beirut, Beirut, Lebanon, 2021. [Online]. Available: https://www.researchgate.net/publication/348151106\_Real\_Time\_DC\_Motor\_Position\_Control\_Using\_PID\_Controller\_in\_LabVIEW. [Accessed: Jun. 15, 2024].
15. Infineon Technologies, "IRF3205," Infineon, [Online]. Available: https://www.infineon.com/cms/en/product/power/mosfet/n-channel/irf3205/. [Accessed: Jun. 11, 2024].
16. Infineon Technologies, "IR2110," Infineon, [Online]. Available: https://www.infineon.com/cms/en/product/power/gate-driver-ics/ir2110/. [Accessed: Jun. 11, 2024].
17. Components101, "LM7812 Voltage Regulator IC," [Online]. Available: https://components101.com/ics/lm7812-voltage-regulator-ic-pinout-datasheet-circuit-specifications. [Accessed: Jun. 11, 2024].
18. "7805 IC Voltage Regulator," Electronics For You, [Online]. Available: https://www.electronicsforu.com/technology-trends/learn-electronics/7805-ic-voltage-regulator. [Accessed: Jun. 11, 2024].
19. "1N5819 Schottky Diode," ElProCus, [Online]. Available: https://www.elprocus.com/1n5819-schottky-diode/. [Accessed: Jun. 11, 2024].
20. STMicroelectronics, "STM32F103 Microcontrollers," [Online]. Available: https://www.st.com/en/microcontrollers-microprocessors/stm32f103.html. [Accessed: Jun. 11, 2024].
21. J. Benas, "Power Management and RTC Alarms in STM32F103," Medium, Oct. 10, 2020. [Online]. Available: https://medium.com/@jobenas\_25464/power-management-and-rtc-alarms-in-stm32f103-d144a214cc40. [Accessed: Jun. 11, 2024].
22. "24V Brushed DC Motor with Optical Encoder," AliExpress, [Online]. Available: https://vi.aliexpress.com/i/1005001798024541.html. [Accessed: Jun. 11, 2024].
23. "Hantek2000 Handheld Oscilloscope," Hantek, [Online]. Available: https://hantek.com/products/detail/13174. [Accessed: Jun. 11, 2024].
24. "ST-LINK/V2 In-circuit debugger/programmer for STM8 and STM32," STMicroelectronics, [Online]. Available: https://www.st.com/en/development-tools/st-link-v2.html. [Accessed: Jun. 11, 2024].
25. "CP2102 USB to UART Bridge VCP Drivers," Silicon Labs, [Online]. Available: https://www.silabs.com/interface/usb-bridges/classic/device.cp2102?tab=specs. [Accessed: Jun. 11, 2024].
26. "STM32CubeIDE," STMicroelectronics, [Online]. Available: https://www.st.com/en/development-tools/stm32cubeide.html. [Accessed: Jun. 11, 2024].
27. "Arduino IDE," Arduino Documentation, [Online]. Available: https://docs.arduino.cc/software/ide/. [Accessed: Jun. 11, 2024].
28. "Fusion 360," Autodesk, [Online]. Available: https://www.autodesk.com/asean/products/fusion-360/overview?term=1-YEAR&tab=subscription. [Accessed: Jun. 11, 2024].
29. A. Tantos, "H-bridges: The Basics," Modular Circuits, May 20, 2010. [Online]. Available: https://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridges-the-basics/. [Accessed: Jun. 11, 2024].

APPENDIX A

This section contains lengthy materials which are not suitable to be put inside the main text, for example; raw data, equipment and computer programs. Times New Roman typeface with font size 10 shall be used.