



**FACULTY OF ENGINEERING**

**REPORT PROPOSAL**

**EPE 4036 FYP1 PROJECT**

**Project Title: A Servo Controller for Brushed DC Motor**

**Supervisor: Dr. Lo Yew Chiong**

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<b>Name</b>	<b>Bashir Tawfig Bashir Abugharsa</b>
<b>Student ID</b>	<b>1181102921</b>
<b>Major</b>	<b>CE</b>

## **ABSTRACT**

This project entails designing a servo controller for brushed DC motors, focusing on high precision in speed and position control. A key aspect is the inclusion of a Proportional-Integral-Derivative (PID) system to enhance motor operation. The project will demonstrate how to design and implement the circuit, integrating PID control for real-time adjustments, thereby ensuring accuracy and efficiency. This approach aims to provide a comprehensive guide on sophisticated motor control through advanced circuit design and control strategies.

## Table of Contents

<b>ABSTRACT .....</b>	<b>ii</b>
<b>Table of Figures:.....</b>	<b>iv</b>
<b>Table of Tables:.....</b>	<b>v</b>
<b>Chapter 1. Introduction .....</b>	<b>1</b>
<b>1.1 Background Overview .....</b>	<b>1</b>
<b>1.2 Problem Statement.....</b>	<b>2</b>
<b>1.3 Project Scope .....</b>	<b>3</b>
<b>Chapter 2. Objectives.....</b>	<b>4</b>
<b>Chapter 3. Preliminary Literature Review .....</b>	<b>5</b>
<b>3.1 “DC Motor Speed Control Using PWM” Literature Review .....</b>	<b>5</b>
<b>3.2 “Design and Implementation of Fuzzy PID DC Motor Control System Based on STM32” Literature Review.....</b>	<b>7</b>
<b>3.3 “Design of Real-time PID tracking controller using Arduino Mega 2560 for a permanent magnet DC motor under real disturbances” Literature Review.....</b>	<b>9</b>
<b>3.4 “Pulse Width Modulation for DC Motor Control Based on LM32” Literature Review .....</b>	<b>11</b>
<b>3.5 “Working and Analysis of the H-Bridge Motor Driver Circuit Designed for Wheeled Mobile Robot” Literature Review .....</b>	<b>12</b>
<b>Chapter 4. Methodology .....</b>	<b>14</b>
<b>4.1 Brushed DC Motor Driver Circuit: .....</b>	<b>14</b>
<b>4.2 Firmware Development: .....</b>	<b>17</b>
<b>4.3 PID Controller:.....</b>	<b>17</b>
<b>4.4 Flowchart:.....</b>	<b>19</b>
<b>4.5 Project Milestone.....</b>	<b>20</b>
<b>4.6 Project Budget .....</b>	<b>21</b>
<b>References .....</b>	<b>22</b>

## Table of Figures:

Figure 3.1 L293D IC .....	5
Figure 3.2 Block diagram of fuzzy PID DC motor control system .....	7
Figure 3.3 Main circuit of DC motor control system.....	7
Figure 3.4 The PMDC motor control interface designed with MATLAB GUI.....	9
Figure 3.5 Bi-directional rotation using a full-bridge. ....	11
Figure 3.6 Use of high current gain transistor QN2222 for proper.....	12
Figure 3.7 Circuit construction of H – Bridge and testing photos .....	12
Figure 4.1 Brushed DC Motor Driver Circuit.....	14
Figure 4.2 IRF2305 N-channel MOSFET.....	15
Figure 4.3 IR2110 MOSFET Gate Driver.....	15
Figure 4.4 LM317 Voltage Regulator .....	16
Figure 4.5 STM32 Blue Pill Board .....	16
Figure 4.6 STM32CubeIDE User Interface .....	17
Figure 4.7 PID Control Loop Block Diagram [6] .....	18
Figure 4.8 System Flowchart .....	19
Figure 4.9 Project Gantt Chart .....	20

**Table of Tables:**

Table 1 Project Budget .....	21
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## **Chapter 1. Introduction**

### **1.1 Background 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. 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.

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. 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 the performance, cost-efficiency, and minimal complexity, thereby extending the functional envelope of Brushed DC motors.

## **1.2 Problem Statement**

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.

### **1.3 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 speed and 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. The driver circuit's role is pivotal as it acts as the primary mechanism for efficient power management to the motor.

The project will incorporate a Proportional-Integral-Derivative (PID) closed-loop control system. 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. 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 and inconsistencies in power supply. 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.



## **Chapter 2. Objectives**

The objectives of this project are devised to construct a comprehensive solution for the control of Brushed DC motors. By addressing the technical challenges through a systematic approach, the project aims to achieve the following:

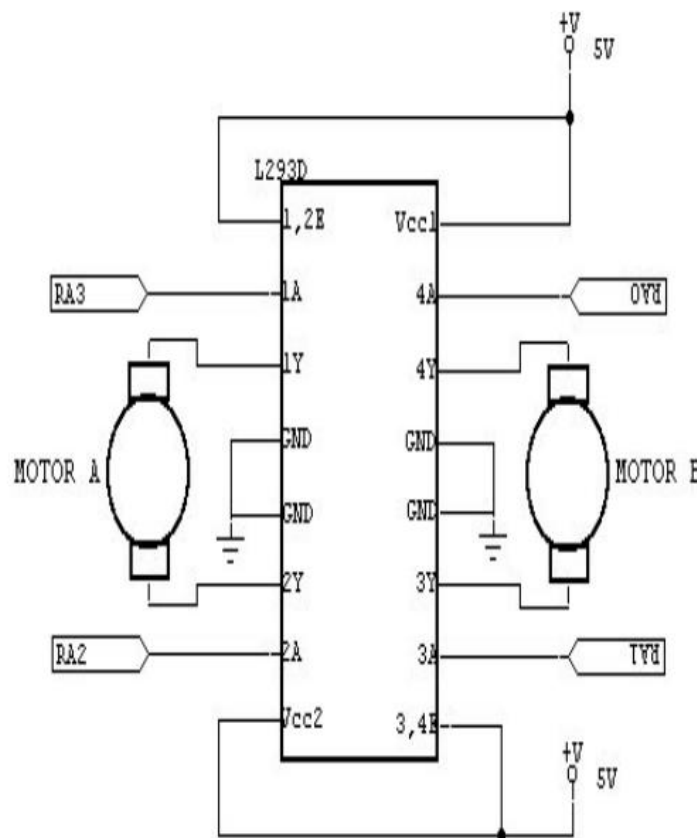
1. To design a driver circuit that ensures efficient power regulation for the motor, minimizing energy waste and enhancing performance.
2. To use a serial communication protocol that enables user interaction with the motor control system, allowing for immediate and precise control modifications.
3. To engineer a closed-loop control system that can accurately manage the speed and position of a Brushed DC motor using feedback from an optical encoder.
4. To implement a PID control system that is capable of real-time adjustments, providing stability and precision in motor responses.
5. To establish a methodology for tuning and calibrating the control system to maintain optimal performance across a range of conditions and applications.

The successful completion of these objectives will lead to the development of a servo controller that not only improves the functionality of Brushed DC motors but also extends their applicability in sophisticated and precision-demanding environments.

## Chapter 3. Preliminary Literature Review

### 3.1 “DC Motor Speed Control Using PWM” Literature Review

The paper [1] presents a detailed method for regulating the speed of a DC motor utilizing Pulse Width Modulation (PWM). This process is achieved using an AT89S52 microcontroller, which interfaces with an L293D IC for driving the motor and a 555 IC combined with an optocoupler for speed sensing. This setup is geared towards providing precise control over small DC motors in a cost-effective manner, ensuring consistent performance even with varying load conditions.



*Figure 3.1 L293D IC*

However, the study is limited by its reliance on L293D IC to drive the DC motor. L293D IC is dual H-bridge motor driver designed to drive small DC motors, which could restrict its wider application across different motor types or more complex operational contexts. Despite this limitation, the research is valuable for its practical

implications in industrial settings. It offers an efficient, reliable, and economically viable solution for controlling the speed of DC motors, highlighting the potential for PWM in motor control applications.

### 3.2 “Design and Implementation of Fuzzy PID DC Motor Control System Based on STM32” Literature Review.

The paper [2] presents an innovative approach to DC motor control, combining fuzzy logic with PID control. Fuzzy logic allows for more adaptable and nuanced control, enhancing the system's robustness. This method is particularly useful for dealing with imprecise or uncertain information, which is common in control systems.

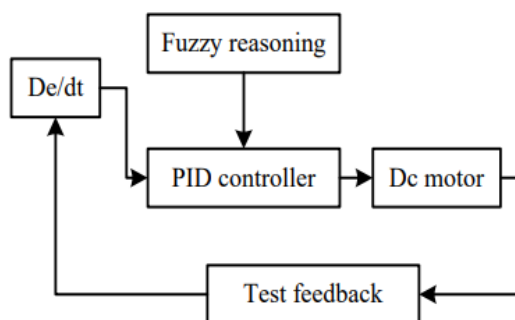
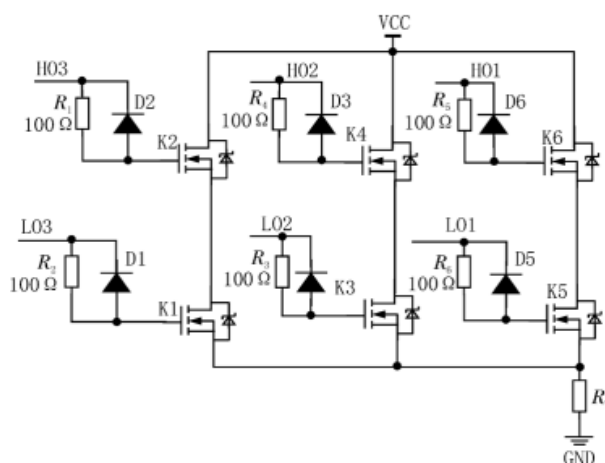


Figure 3.2 Block diagram of fuzzy PID DC motor control system

The system's driving circuit is composed of three IR2110S and a three-phase full-bridge inverter circuit. The IR2110S features undervoltage protection and external overcurrent protection ports. A 120-degree motor is utilized for position detection, with the Hall signal transmitted to the STM32 microcontroller via optical coupling. As the motor rotates, the STM32 generates PWM signals in response to the Hall signal, controlling the MOSFET's operation, thus enabling motor reversing and speed calculation.



*Figure 3.3 Main circuit of DC motor control system*

However, notable weakness of this paper is complexity involved in integrating fuzzy logic with PID control, which can be computationally intensive and affect system efficiency. Additionally, there's a lack of detail on software implementation and algorithm optimization for the STM32 microcontroller, which is crucial for understanding performance and scalability.

### 3.3 “Design of Real-time PID tracking controller using Arduino Mega 2560 for a permanent magnet DC motor under real disturbances” Literature Review

The paper [3] primarily focuses on the application and evaluation of a Proportional-Integral-Derivative (PID) control system for a Permanent Magnet Direct Current (PMDC) motor. The study utilizes the Arduino Mega 2560 microcontroller and MATLAB software for implementing and testing the PID controller. Key aspects include the controller's design, tuning, and real-time response to disturbances, showcasing its adaptability and performance in varying conditions.

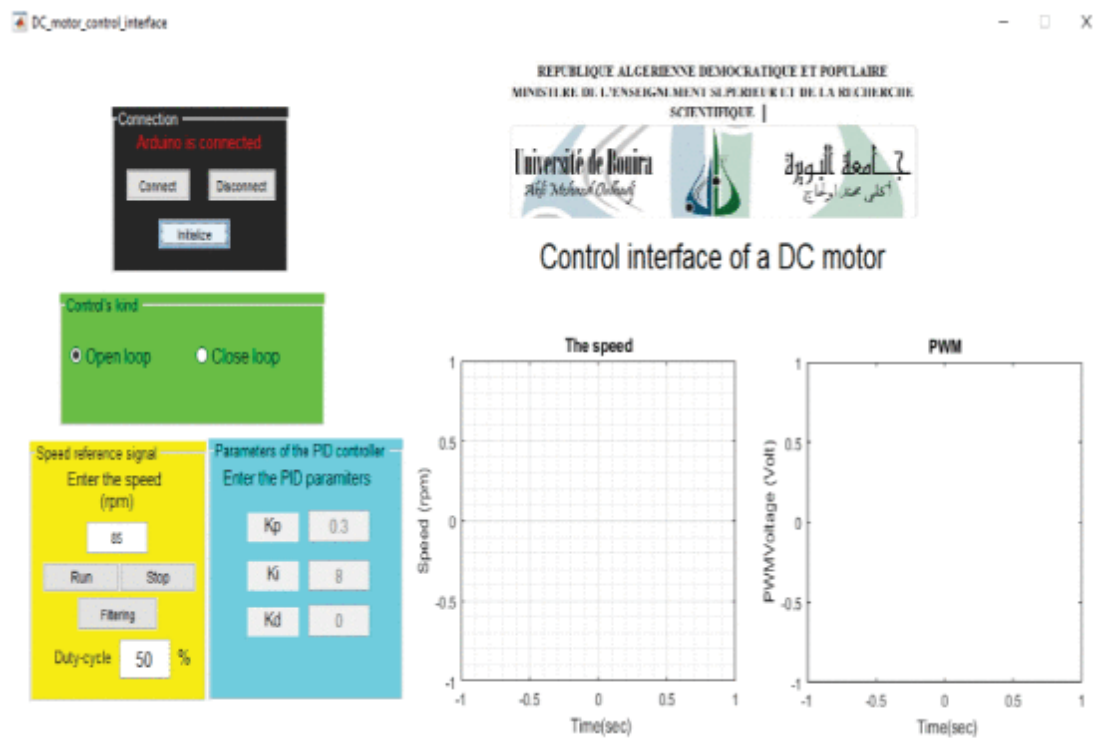


Figure 3.4 The PMDC motor control interface designed with MATLAB GUI

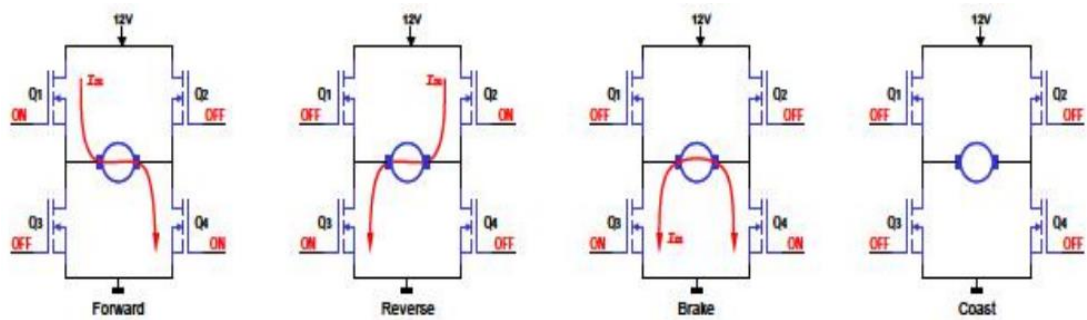
In the study, the use of Arduino Mega 2560 for the PID controller's implementation might present performance limitations. Arduino's hardware constraints, such as processing speed and memory capacity, can impact the controller's ability to handle complex computations or high-speed data processing required for more sophisticated control scenarios. This may limit the controller's responsiveness and precision, particularly in industrial applications where faster and more precise control is crucial.

Additionally, Arduino's scalability and integration with other industrial systems might be limited, potentially affecting its applicability in larger or more complex setups.

### 3.4 “Pulse Width Modulation for DC Motor Control Based on LM324”

#### Literature Review

The paper [4] discusses the development of a PWM-based motor control circuit, integrating an H-bridge for bi-directional control of a DC motor. Using the LM324 operational amplifier, the design aims for cost-effectiveness and efficiency, suitable for small-scale applications. It emphasizes the advantages of PWM in controlling motor speed and direction, ensuring effective control with reduced heat dissipation.



*Figure 3.5 Bi-directional rotation using a full-bridge.*

One potential weakness of this approach is the reliance on the LM324 operational amplifier, which may limit the system's performance in terms of speed and response accuracy, especially in more demanding or high-speed applications. The LM324's characteristics, such as its bandwidth and slew rate, might not be optimal for all DC motor control scenarios, potentially affecting the precision and responsiveness of the PWM control, especially at higher speeds or under varying load conditions.



### 3.5 “Working and Analysis of the H-Bridge Motor Driver Circuit Designed for Wheeled Mobile Robot” Literature Review

The paper [5] discusses the design and implementation of an H-bridge motor driver circuit for controlling wheeled mobile robots (WMRs). The study emphasizes the application of the H-bridge circuit in driving DC geared motors, providing detailed insights into the circuit's construction and functionality. It includes an analysis of different circuit designs for varying load conditions, focusing on enhancing the efficiency and versatility of the motor driver circuit for mobile robotic applications.

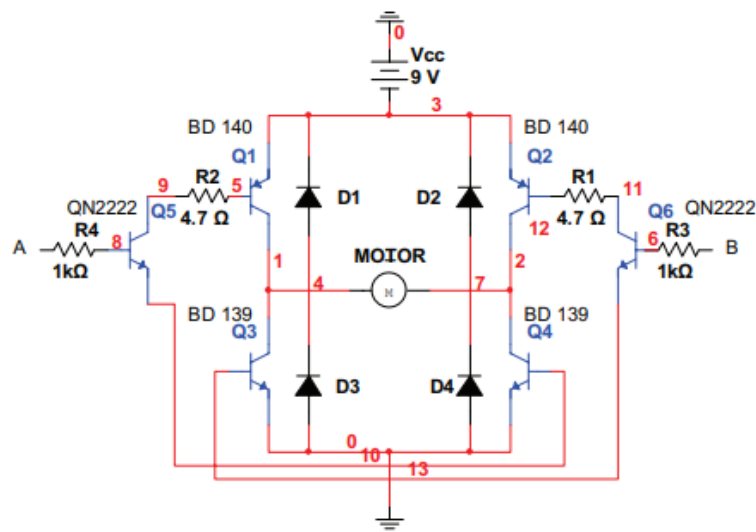


Figure 3.6 Use of high current gain transistor QN2222 for proper

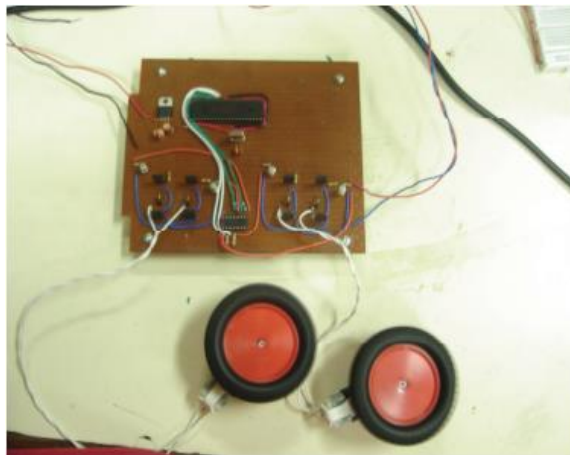


Figure 3.7 Circuit construction of H – Bridge and testing photos

A significant weakness of this design is the use of Bipolar Junction Transistors (BJTs) instead of Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs). BJTs, while cost-effective and straightforward in their operation, may not offer the same level of efficiency as MOSFETs, especially regarding power consumption and heat dissipation. This choice can impact the overall performance and durability of the motor driver circuit, particularly in applications requiring high efficiency and thermal management. The limitations imposed by BJTs could be a critical factor in determining the circuit's suitability for more advanced or demanding robotic applications.

## Chapter 4. Methodology

This chapter will outline the methodology for creating a servo controller for a Brushed DC motor. It will detail the steps from the initial design of the driver circuit to the integration of the PID control system, focusing on the practical implementation and theoretical underpinnings required to achieve precise motor control.

### 4.1 Brushed DC Motor Driver Circuit:

In the circuit, the IR2110 is utilized as a MOSFET gate driver, and IRF3205 N-channel MOSFETs are employed to construct an H-bridge. This H-bridge configuration is essential for the control of both the direction and speed of the motor. PWM signals, necessary for modulating the motor speed, are generated by the STM32F103 microcontroller. The selection of these components underscores the circuit's ability to effectively manage power and precisely control motor operations, accommodating variations in speed and directional shifts.

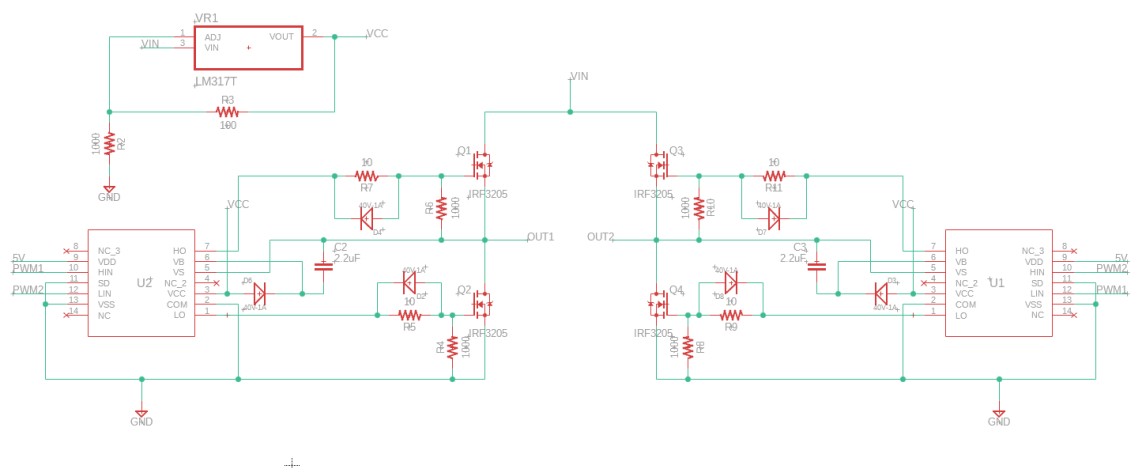


Figure 4.1 Brushed DC Motor Driver Circuit

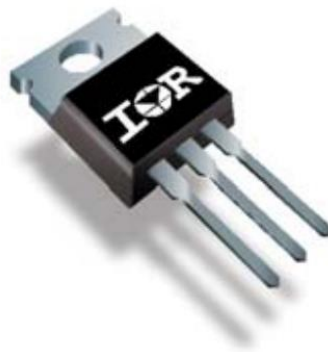
In the circuit design, the two IR2110 MOSFET gate drivers control the H-bridge's sides. The LM317 voltage regulator maintains voltage below 20V, suitable for the IR2110. Bootstrap diodes and capacitors facilitate high side bridge operation. The MOSFETs Q1 and Q4, driven by PWM1, enable forward motor movement, while Q2 and Q3, controlled by PWM2, reverse the direction. These PWM signals are generated

by the microcontroller, with adjustable duty cycles managed via UART serial communication, ensuring precise directional control of the motor.

### **Components:**

#### **IRF3205 N-channel MOSFET:**

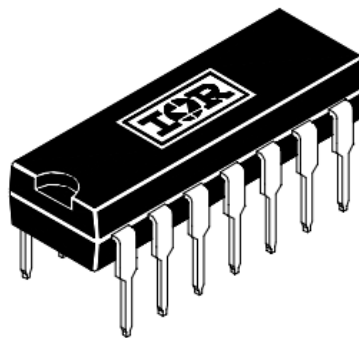
This power MOSFET is known for its high current (110A) and voltage (55V) handling capabilities, making it suitable for heavy-duty applications. Its low on-resistance and fast switching speed are advantageous for efficient power management in motor control circuits.



*Figure 4.2 IRF2305 N-channel MOSFET*

#### **IR2110 MOSFET Gate Driver:**

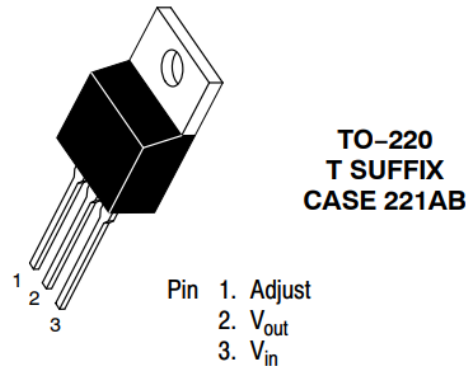
The IR2110 is a high voltage (up to 500V), high-speed driver specifically designed for MOSFETs and IGBTs. It features independent high and low side referenced output channels, crucial for precise and rapid switching in H-bridge configurations.



*Figure 4.3 IR2110 MOSFET Gate Driver*

### LM317 Voltage Regulator:

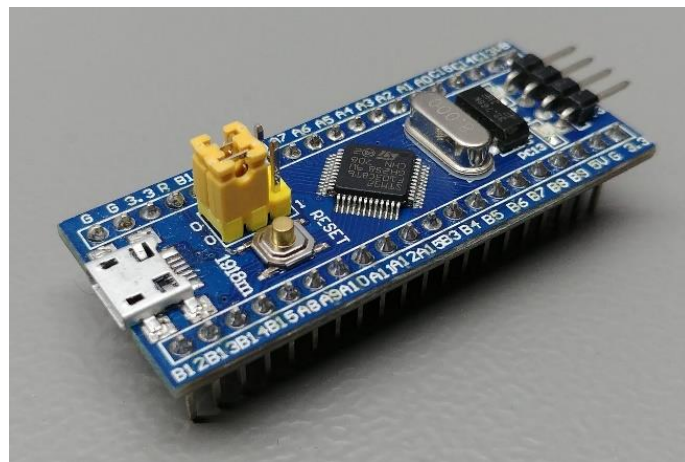
The LM317 will be used in this project as an adjustable voltage regulator to maintain suitable voltage level for the MOSFET gate driver. Its stable output ensures efficient operation of the MOSFETs in the H-bridge circuit, crucial for the motor control system.



*Figure 4.4 LM317 Voltage Regulator*

### STM32f103 Microcontroller (Blue Pill board):

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.



*Figure 4.5 STM32 Blue Pill Board*

## 4.2 Firmware Development:

### STM32CubeIDE and HAL Library:

For the firmware development in this project, STM32CubeIDE, an integrated development environment, will be used. This tool is crucial for programming STM32 microcontrollers, offering initial configuration through STM32CubeMX and the Hardware Abstraction Layer (HAL) Library for simplified hardware interaction. The HAL Library provides user-friendly, high-level APIs, enhancing the development process. The firmware will be developed in C language, leveraging the capabilities of STM32CubeIDE to write, debug, and deploy efficient and reliable code, particularly for the intricate requirements of motor control.

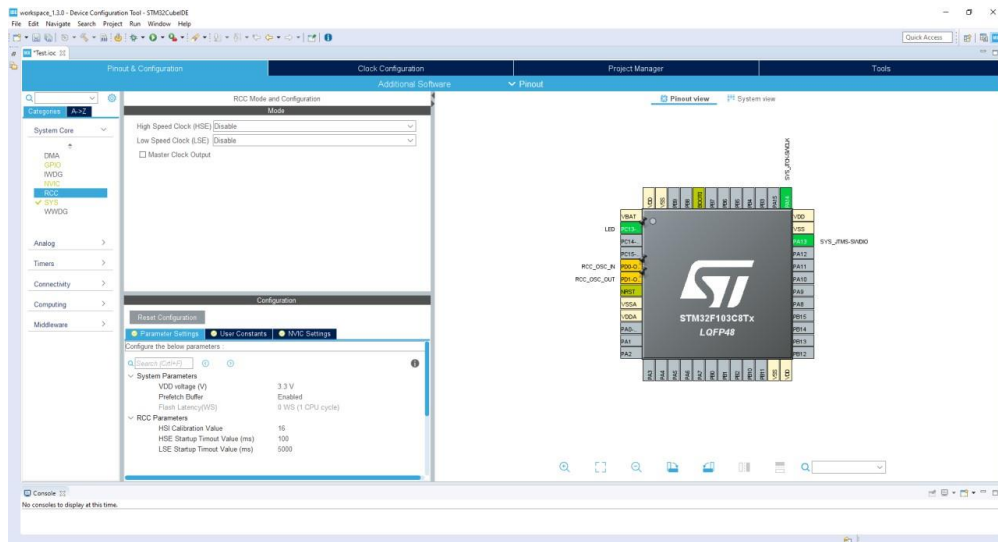


Figure 4.6 STM32CubeIDE User Interface

## 4.3 PID Controller:

In the project, a PID (Proportional-Integral-Derivative) Controller is implemented for precise motor control. The system uses a DC motor equipped with an optical encoder, offering critical feedback for the PID algorithm. This encoder features two phases, A and B, which determine the motor's rotation direction; Phase A leading indicates forward motion (clockwise), while Phase B leading signifies reverse motion (counterclockwise).

To calculate the speed of the motor in the system, the optical encoder's output is utilized. The encoder, with its phases A and B, provides pulses corresponding to the motor's rotation. By counting these pulses within a specific time frame using the STM32 Blue Pill's interrupts, the rotational speed of the motor can be determined. The frequency of pulse generation, correlated with the motor's speed, is measured, and processed to calculate the RPM (Revolutions Per Minute) of the motor. This measurement is integral to the feedback mechanism of the PID controller, enabling accurate control of the motor's speed.

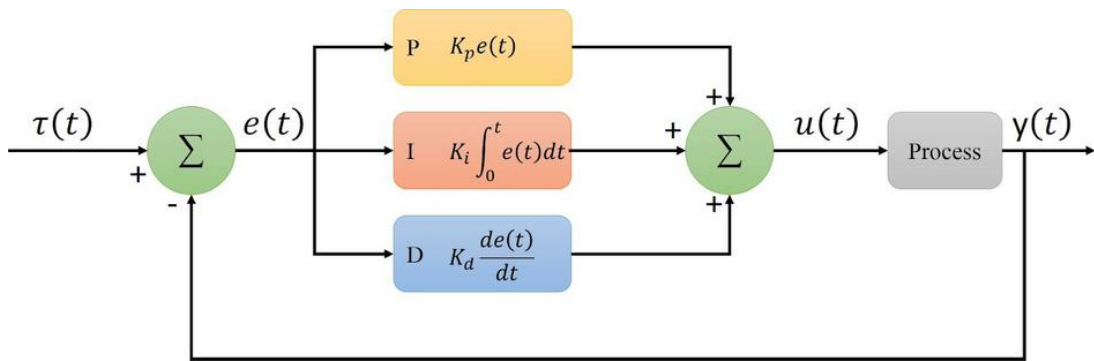
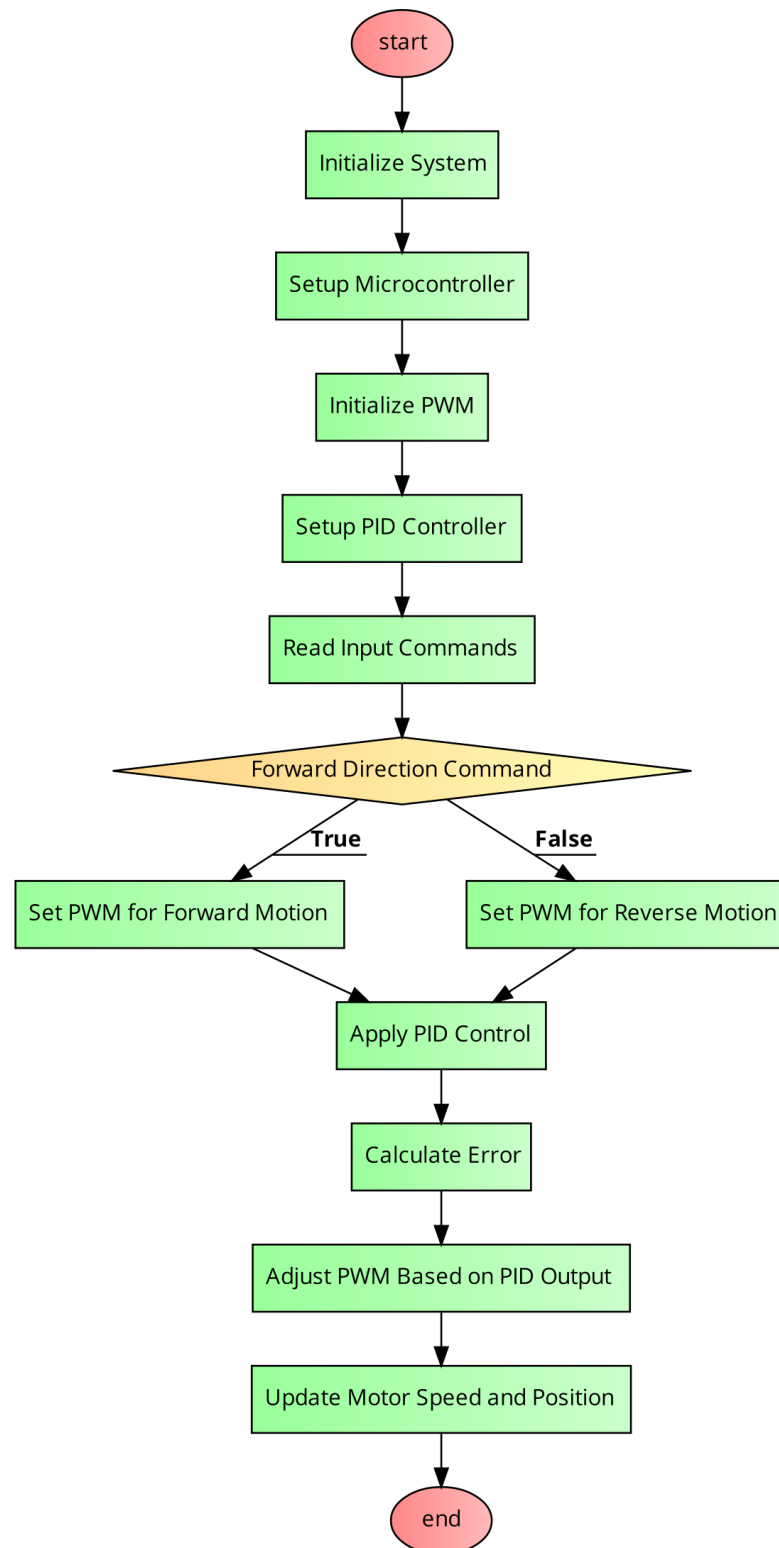


Figure 4.7 PID Control Loop Block Diagram [6]

The STM32 Blue Pill board is employed to capture this motion using interrupts, a crucial aspect of the feedback loop. The PID controller uses this feedback to adjust motor control in real-time. The controller operates on three key parameters:  $K_p$  (Proportional),  $K_i$  (Integral), and  $K_d$  (Derivative). The Proportional component ( $K_p$ ) helps reduce the overall error between the desired and actual motor position or speed. The Integral component ( $K_i$ ) works to eliminate the residual steady-state error by accounting for the accumulated past errors. Lastly, the Derivative component ( $K_d$ ) provides a prediction of future errors based on the current rate of change. This predictive feature helps in smoothing the motor control, especially during rapid changes or disturbances. By fine-tuning these parameters, the PID controller enhances the motor's response, ensuring accurate, stable, and efficient operation.

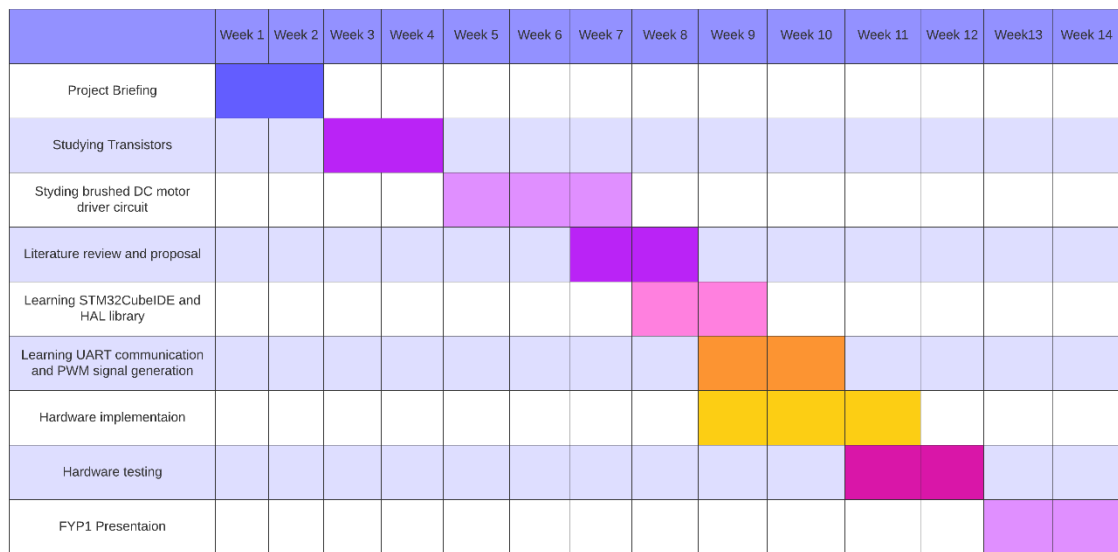
#### 4.4 Flowchart:



*Figure 4.8 System Flowchart*



## 4.5 Project Milestone



*Figure 4.9 Project Gantt Chart*

#### 4.6 Project Budget

Part Name	Quantity	Unit Cost (RM)
LM317 Voltage Regulator	1	1.30
IR2110 MOSFET Gate Driver	2	6.0
IRF3205 Power MOSFET	4	3.50
STM32F103C8T6 Blue Pill Board	1	16.90
Metal Film Resistors	10	0.10
1N5819 Diode	6	0.20
2.2uF 50V Capacitor	2	0.10
<b>Total</b>		46.6

*Table 1 Project Budget*

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