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BRUSHLESS DC MOTOR DRIVE DEVELOPMENT

Bachelor's thesis

Mechanical Engineering and Production Technology

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Mechanical Engineering and Production Technology | Abstract
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Subject Brushless DC Motor Development
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Brushless Direct Current motors are the technology of choice for many high-end and mid-range systems, as they offer constant or variable speed drive, and reliable. This thesis aims to develop an electromechanical system consisting of a simple low-cost laboratory experiment on a Brushless DC motor drive for industrial and educational purposes.

The first chapter represents the fundamental concepts and principles of this type of electric motor and their applications in the industry. In the second chapter, the author selects the suitable electronic components (hardware) and the right software for this experiment, the latest phase is constructing and testing the project.

At the end of the experiment, the author designed a control system consisting of an electric motor with a high speed and high torque level for users at an economical price. As a widely used component in many different areas, the direct current (DC) brushless motor has the prominent advantage of high efficiency, long period, low noise as well as better speed torque.

Keywords Brushless DC motor, electromechanical system, control system

Pages 31 pages and appendices 2 pages

Content

List of abbreviation

BLDC	Brushless Direct Current
PMSM	permanent-magnet synchronous motor
PWM	Pulse-width modulation
FOC	Full Operational Capability
EMF	Electromotive force
VFD	Variable Frequency Drive
ESC	Electronic Speed Controller

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1 Introduction

Brushless direct motors (BLCD) are the technology of choice for many high-range and mid-range systems. This motor has been used and expanded in many industrial applications in the fields of consumer appliances, consumer electronics (fans, drones, power tools), electrical vehicles (EVs), hybrid vehicles, HVAC systems, industrial automation, chemical and medical technologies, aerospace, and automotive industry. Brushless direct current motors, or BLDC motors, are three-phase current synchronous machines: the rotor follows a magnetic rotational field and moves in sync with the alternating current voltage applied to the windings. BLDC has no brushes in the commutator which makes it more reliable than the Brushed DC motor. For this reason, it is needed to use an electronic drive controller, which controls the function of the brushes and converts the direct current fed into the motor into an alternating current. Our objective is to develop the performance of our motor to make it more reliable, good high-speed, high torque, and highly efficient.

BLDC motors find applications in a wide range of industries and products, including:

1. Electric vehicles (EVs) and hybrid vehicles
2. Consumer electronics (fans, drones, power tools)
3. Industrial machinery and automation
4. HVAC systems
5. Aerospace (actuators, drones)
6. Medical devices
7. Robotics

Overall, BLDC motors offer numerous advantages over traditional brushed DC motors, making them a popular choice for various applications that require efficiency, reliability, and precise control.

2 Electric Motors

An electric motor is a device that converts electrical energy into mechanical energy by interacting with electric currents and magnetic fields. It is based on the fundamental concept of electromagnetic induction, which asserts that a current-carrying conductor generates a magnetic field, which interacts with other magnetic fields to induce rotational or linear motion in the mechanical elements of the motor. Electric motors have been used in a wide range of applications, from industrial machinery to household appliances, and they play a significant role in modern technology and automation. Different electric motor technologies, including DC motors, AC motors, and specialised designs, provide varied performance characteristics to satisfy certain requirements .

2.1 Three-Phase AC motor Technology

Three-phase alternating current (AC) motors are electric motors that are powered by a three-phase input voltage and consist of three current-carrying conductors.AC induction motors are widely used in electromechanical applications, which requires a high speed torque level. They are composed of two major parts: the stator and the rotor. When a current is delivered to the stator, the windings generate a magnetic field. The electromagnetic induction generated by the stator field enables the rotor to rotate. Three-phase AC machines can be induction or synchronous. The rotor current in an induction motor is generated by the stator field, whereas the rotor current in a synchronous motor is synchronised with the stator field. The frequency and number of pole pairs in the windings control the motor's speed and torque. This figure represents an example of an AC induction motor (Edwards, 2023).

Figure 1. Example of 3-phase induction motor (Max, 2023).

2.2 DC Motor Technology

A direct current (DC) motor is a type of electrical motor that converts electrical energy into mechanical energy. Direct current is used to generate electrical energy, which is then converted into mechanical rotation. The DC motor is composed of the following main mechanical elements:

• Armature or Rotor: A direct current motor's spinning element is a cylinder of insulated magnetic laminations. The armature is perpendicular to the axis of the magnetic field. The armature is a rotating component that is separated from the field coil by an air gap.

• Field Coil or Stator: A DC motor field coil is a non-moving component on which a magnetic field is produced by windings.

• Commutator and Brushes: A DC motor is a component that delivers electrical current to the armature winding (Magnetic Innovations, n.d.).

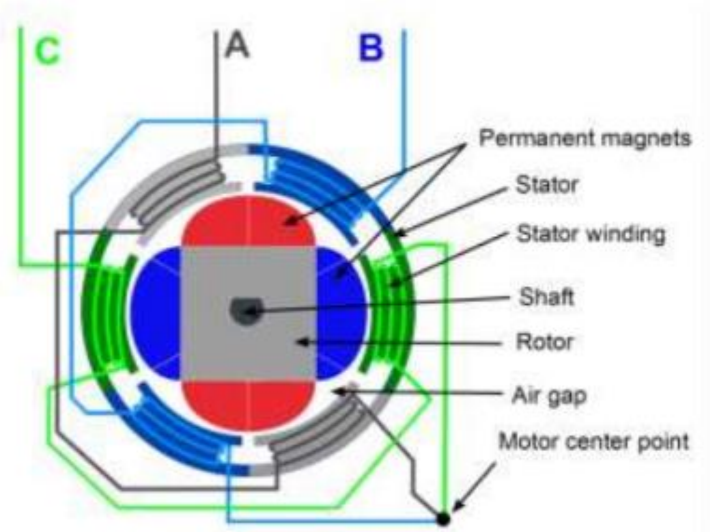
2.3 Brushed DC Motor

A brushed DC electric motor is a type of electric motor that has been designed to be powered by direct current. It is one of the most fundamental forms of DC motors, the brushes transfer current to the motor windings via mechanical commutation. The armature or rotor is an electromagnet, and the number of coils twisted around the motor and their density affect the motor's performance. When an electric current is sent to the armature of a brushed DC motor, the rotor rotates 180 degrees (Max, 2023).

2.4 Brushless DC Motor

The brushless DC (BLDC) motor is an electric machine that uses a traditional 3-phase stator, like an induction motor, and surface-mounted permanent magnets on the rotor. Each phase of the motor might contain more than one pole pair. Figure 2 below shows a two-pole pair motor per phase. The number of pole pairs per phase determines the electrical revolution/mechanical revolution ratio**.** The following Figure explains the BLDC motor component and the number of pole pair.

Figure 2. BLDC motor - cross-section (Freescale Semiconductor,Inc, 2016, p2).



Electrical commutation is used in BLDC motors with a permanent magnet rotor and a stator with a coil sequence. The sensor's rotor position feedback helps in determining when to switch the armature current. In many aspects, BLDC motors outperform brushed DC motors, such as their ability to operate at high speeds, high efficiency, and improved heat dissipation. They are an essential component of current drive technology, being used most often for actuating drives, machine tools, electric propulsion, robotics, computer peripherals, and electrical power production (Freescale Semiconductor,Inc, 2016).

2.5 Drive for the Brushless DC motor

2.5.1 Six-step BLDC control

Brushless DC motors are known as electronically commutated motors. The rotor has no brushes, which means the commutation is done electronically at points. The magnetization and displacement of the permanent magnets on the rotor are selected so that the back EMF (the voltage generated into the stator winding due to rotor movement) has a trapezoidal shape. This enables the use of a rectangular-shaped 3-phase voltage system to generate a rotating field with minimum torque ripples. Figure 3 represent a schematic diagram of 6-step algorithm structure of a BLDC. However, figure 4 illustrates six driving technics of BLDC motor.

Figure 3. 6-step algorithm structure (STM32MCU, 2022).

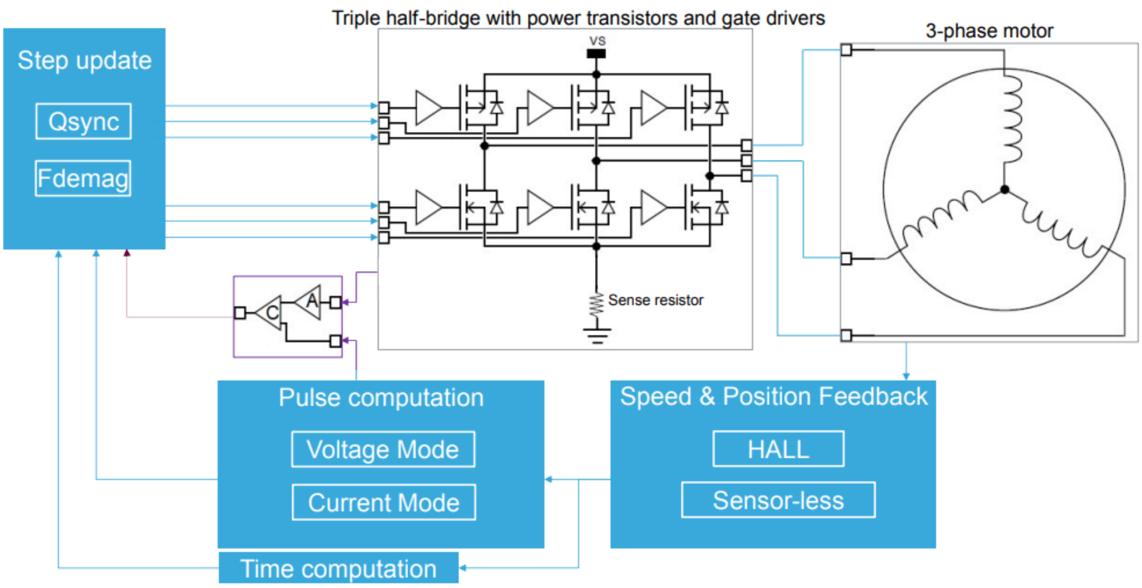
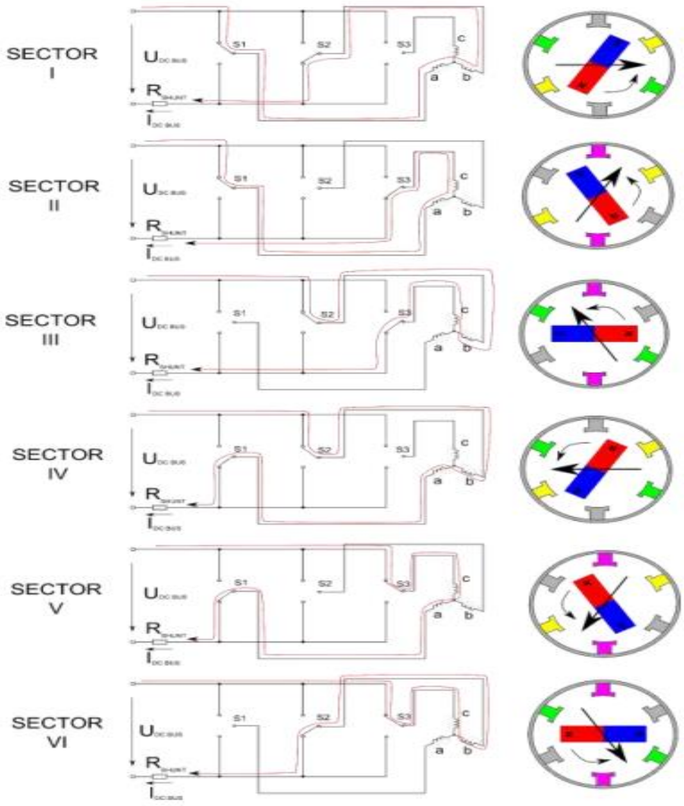


Figure 4. Six-step algorithm technique (Freescale Semiconductor,Inc, 2016, p.4).



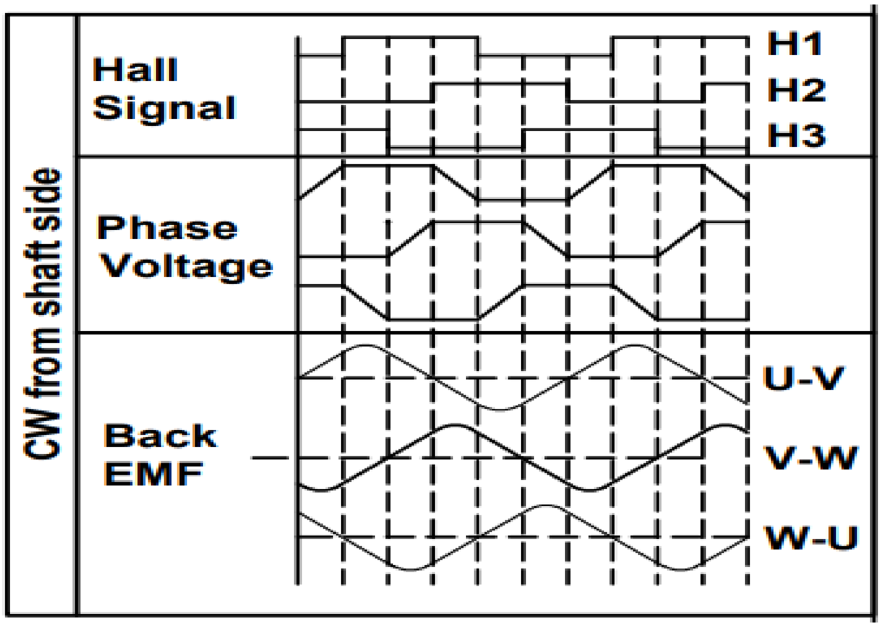
The motor control algorithm structure is mainly composed of speed and positioning feedback components such as a hall sensor for sensored driving mode.

Pulse computation for voltage and current driving mode (VM/CM). Set update this component allows the update of the timer and contributes to the energization of the 3 phases (Freescale Semiconductor,Inc, 2016).

2.5.2 Electronic Commutation Feedback

In Brushless DC motors Hall sensors play a crucial role as a feedback system in this application. The combination of Hall sensors with block commutation is the simplest way to operate a BLDC motor. The rotor position of the motor may be easily defined using Hall sensors. These are then switched by a properly positioned magnet on the rotor at the precise time and the winding must be switched. The figure bellow explains the electronic commutation feedback of DF45M024053-A2 Brushless DC motor.

Figure 5. Hall Signal in parallel with the driving signals DF45M024053-A2 Brushless DC motor (Nanotech, n.d.-b).

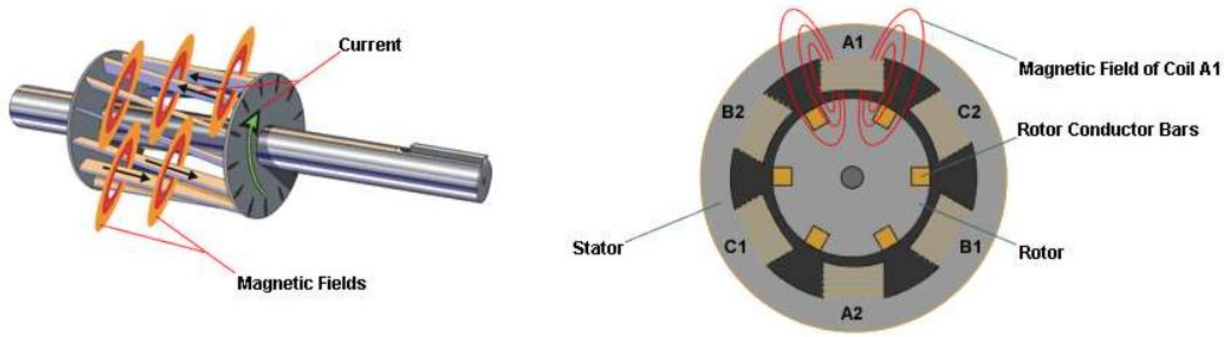


2.6 Induction Motors

Induction motors are a choice for many high-range industrial applications due to their reliability, they are a fundamental type of AC (alternating current) electric motors. There are mainly two types of electric motors. Single-phase induction motors are not controlled, meaning they require an external command to operate. Three-phase induction motors are self-controlled; they are commonly used in industrial settings due to their higher efficiency as well as their power capacity.

Induction motors generate torque and rotation by applying electromagnetic induction, when the stator windings are energised, they form a spinning magnetic field that induces voltage and current conductors. The following figure demonstrate how the magnetic field created in the stator.

Figure 6. The magnetic field created in the stator (Studylib, n.d, p.1).



The motor speed is controlled by the rotational speed of the magnetic field, which is determined by the frequency of the alternating current and the number of poles. The magnetic field produced by the alternating current in the stator induces a motion in the rotor, and the interplay of the electric and magnetic fields produces rotation. VFDs are designed to control Three-phase motors for smoother and more accurate motor control. (Max, 2023).

3 Speed Controllers Technologies

3.1 ESC for BLDC Technology

ESCs are growing more complex as technology advances. More compact, smaller, and more energy-efficient devices are constantly on the rise, without compromising their capacity to manage high power levels. Electronic Speed Controllers (ESCs) are critical components in many electrically driven vehicles, including remote-controlled models such as drones, RC cars, helicopters, and electric motors. Their primary function is to control the speed of the electric motor and to direct the rotation of the motor.

An ESC, or Electronic Speed Controller, regulates the electric motor by sending digital impulses that are converted into changes in speed or even rotation reversal. It generates (AC) alternating three-phase current by using direct current paired with a switch mechanism like (VFD) Variable Frequency Drive to run the motor. This output current can eventually be adjusted by varying the pace at which the circuit's switches open and close.

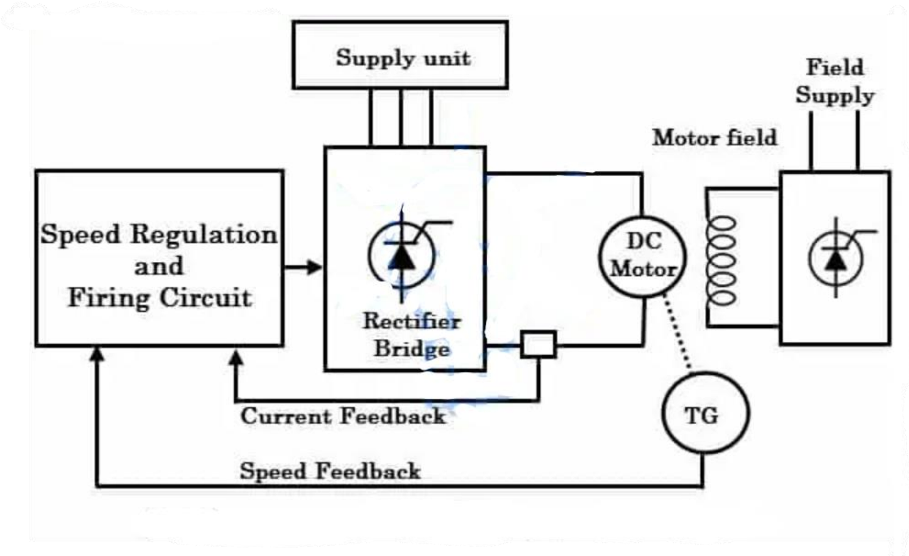
Brushless ESCs require information on the present location of the rotor to activate the motor and set a rotational direction. The ESC controls its position by measuring the induction of the last unpowered electromagnet. The magnetic field created by this induction changes based on the location of the nearest permanent magnet, the closer the electromagnet, the greater the magnetic field is produced (Nagel, 2023).

3.2 DC Motor Drive

DC drive technology is a motor speed controller for DC motors. It transfers the voltage to the motor. DC drive controllers are ideal for low-speed application control such as crane and elevator applications. The DC drive device uses AC power to operate the DC motor.

The DC drive is composed of two main systems, the power system, and the control system, by a rectifier circuit the power system converts AC to DC power. The control system allows the speed control of the motor. Figure 7 is schematic diagram of DC drive (Electrical Technology n.d.)

Figure 7. Main components of DC drive system (Electrical Technology, n.d.).



4 Variable Frequency Drive

Variable Frequency Drive is a motor controller that drives 3-phase AC or BLDC motors. VFDs are systems incorporating a motor that adjusts the speed and torque of the electric motor by adjusting the frequency of the input electricity. I also control the voltage or current variations.

VFDs regulate the motor RPM by adjusting the ratio between the rotor RPMs and the field frequency to provide a measured torque, which is then used to drive the load at the desired speed. (Danfoss, n.d.)

Note that the ESCs and VFDs are both inverter technologies (convert from DC into AC) and also share common qualities; however the ESCs replace the mechanical commutator (Brushes) in this project.

5 Mechanical Components

The electrochemical system consists of a mechanical disc brake system kit, coupling system composed of flange and housing bearings, and for the bench test aluminium profile was used for this case. The following Figure represent the main components of braking system.

Figure 8. Main braking system components.

6 Profiling Technology

An aluminium profile, or an extruded aluminium frame, is a formed component made from aluminium alloys using the extrusion technique. These profiles can be combined and connected using profile connectors.

Profiling systems are widely integrated in industrial automation factories, and conveying systems. These aluminium components are easily maintained due to their design simplicity.

The integration of profiling technology in the electric motor system components demonstrates a dedication to precise engineering, quality, and design accuracy for the project.

To design the bench, different mechanical and sheet metal parts need to be assembled on the aluminium profile to construct a full bench assembly. The parts are purchased from Easy

Systems Ltd, however other parts were manufactured at the university workshop (Profall, n.d.).

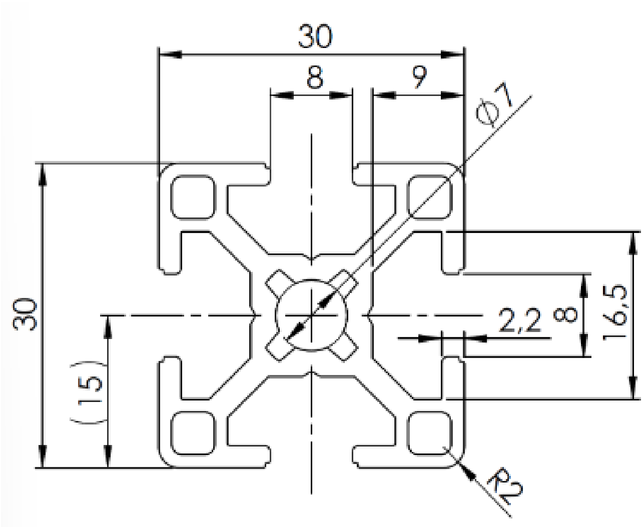
These aluminum profiles offers a range of benefits across the industry due to many factors, such as the assembly flexibility using connectors or flange brackets, time and costs saving during the assembly process. High material properties, aluminium is a light weigh metal, making it flexible for the user during the project assembly.

7 Bench Profile

To design the bench, different mechanical and sheet metal parts need to be manufactured and assembled. The parts are purchased from Easy Systems oy. The bench is used for fixing and gives mor stability to the system. The following figures are a mechanical drawing of the aluminium profiles used in the project.

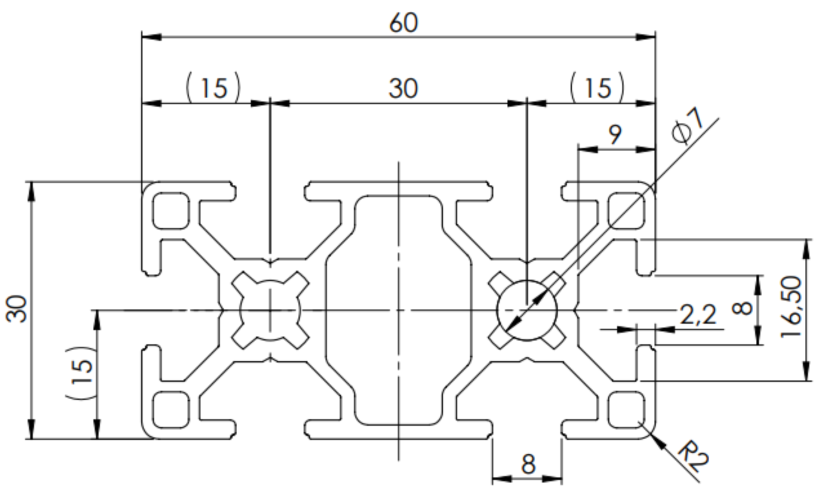
- BSB 30 x 30 aluminium profile:

Figure 9**.** Front view of BSB 30 x 30 aluminium profile (Easy Systems, n.d.-a).



- BSB 30 x 60 aluminium profile:

Figure 10. Front view of BSB 30 x 60 aluminium profile (Easy Systems, n.d.-b).



8 Coupling Technology

Coupling technology is an integrative device of several technical components and systems. Moreover, it is used to improve the functionality, performance, and compatibility of the system. Couplings can be rigid or flexible depending on the required alignment precision and the torque.

In the current system, the flexible coupling of 4mm to 8mm holes which links two rotating shafts. This device allows the power transmission of the motor and the system through the axle. This figure is a 4 mm to 8 mm coupling, this device allows the energy transfer from the motor directly to the system.

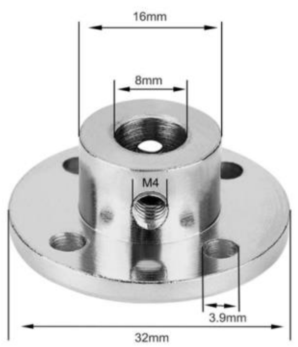
Figure 11. Motor Coupling 4mm to 8 mm connection (Amazon. n.d.-a).

The coupling system is supported with 8 mm flange and 8 mm housing bearings.

A coupling system consisting of a flange and bearings constructs a structural arrangement used to connect two mechanical elements while allowing for controlled motion transmission. The flange is a rigid and flat joining contact that enables the connection of various components.

Bearings are important in this setting because they provide support and allow for smooth rotational movement within the coupling system. This figure is an example of 8 mm flange used in the system assembly.

Figure 12. 8 mm flange (Amazon. n.d-b).



Because of its robust form, the flange is typically provided with bolt holes to provide a secure attachment to the attached components with the system. This architecture allows an accurate alignment, which is crucial for maintaining the integrity and efficiency of the system. The following figure is 8 mm bearing it allows the rotation of the brakes.

Figure 13. 8 mm bearing (Amazon. n.d.-c).

Bearings strategically placed within or around the flange help.

9 Kits Solutions

9.1 STEVAL-SPIN3204

The STEVAL-SPIN3204 3-phase BLDC controller with triple half-bridge gate driver serves as the foundation for the STEVAL-SPIN3204 three-phase brushless DC motor driver board. An adaptable evaluation platform allows switching between external quadrature encoder motor position feedback and sensorless position feedback according to the task . The following figure and table demonstrate the STEVAL-SPIN3204 board and its and connectors (STlife.augmented, STEVAL-SPIN3204, n.d.).

Figure 14. STEVAL-SPIN3204 evaluation board (STlife.augmented, n.d.-c, p.1).

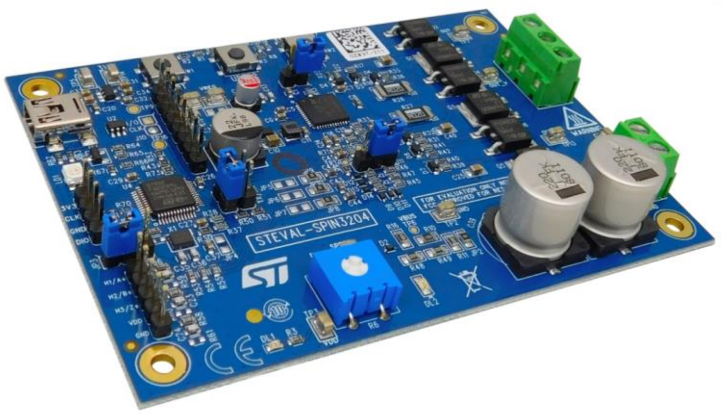


Table 1. Connectors and test points description (STlife.augmented, n.d.-c, p.12).

Name	Pin	Label	Description
J1	1		PB8 GPIO
	2		PB9 GPIO
	3		PC14 GPIO
	4		PC15 GPIO
	5		PB1 GPIO
	6		PA5 GPIO
	7		PA3 GPIO
	8		Ground
J2	1	8-45 V	Motor supply voltage (VM)
	2	GND	Motor supply ground
J3	1 - 2 - 3	U, V, W	Motor phase connections
J4	1	HALL1/A+	Hall effect sensor 1 signal Quadrature encoder A signal
	2	HALL2/B+	Hall effect sensor 2 signal Quadrature encoder B signal
	3	HALL3/Z+	Hall effect sensor 3 signal Quadrature encoder index/zero signal
	4	VDD	Hall sensors/encoder supply
	5	GND	Ground

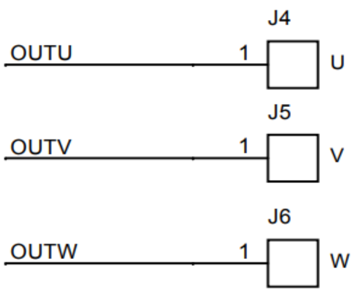
9.2 STEVAL-PTOOL1V1

STEVAL-PTOOL 1V1 tiny 70 mm x 30 mm reference design board is intended for low-voltage power tools, it is controlled by 3-phase brushless motors, with a motor voltage range of 7 - 45 V supported by 2S to 6S power supplies The following figures are an example of STEVAL-PTOOL1V1 board with description of connection points (STlife.augmented, 2023).

Figure 15.STEVAL-PTOOL1V1 reference design (STlife.augmented, 2023.-d, p1).

We can make a direct connection by soldering the three ports U V W with the right BLDC motor ports.

Figure 16. Motor connection Schematic diagram (STlife.augmented, 2023.-d, p.9).

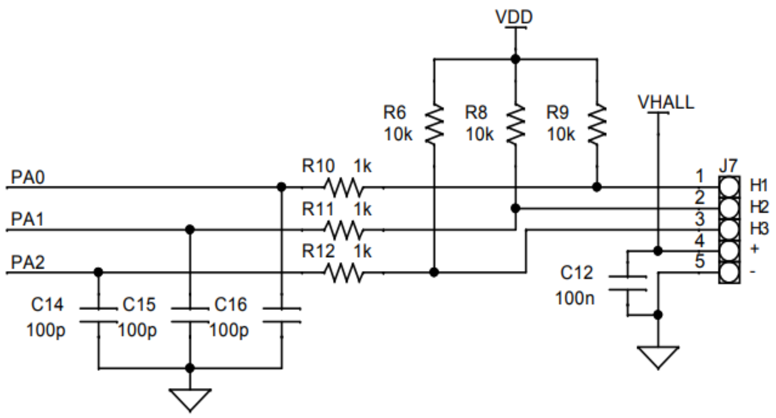


The STEVAL-PTOOL1V1 Support The hall effect sensor and encoder connector can be connected through the Jumper 7 Connector . Table 2 and figure 17 are a table and schematic diagram of a hall sensor connection through J7.

Table 2. J7 pinout (STlife.augmented, 2023, p.5).

Pin	Encoder	Hall effect sensor
1	A+	Hall 1
2	B+	Hall 2
3	Z	Hall 3
4	Encoder power supply	Sensor power supply

Figure 17. Hall Sensor and Encoder Schematic Diagram (STlife.augmented, 2023, p.9).



9.3 ST-LINK/V2 Debugger

ST-LINK/V2 debugger allows the user to program and debug both STM32 & STM8 microcontrollers. The debugger has been used to program STEVAL-SPIN3204 since the latter does not contain a USB port to upload the code directly.

The debugger device incorporates the high-performance Arm®(a) Cortex®-M3 core.

ST-LINK/V2 provides two ports for both STM32&STM8:

• an STM32 connector for the JTAG/SWD and SWV interface .

• an STM8 connector for the SWIM interface The ST-LINK/V2-ISOL provides one connector for the STM8 SWIM, STM32 JTAG/SWD, and SWV interfaces.

The following figures represent the debugger device with its pin connections.

Figure 18. ST-LINK/V2 device STM32MCU (STlife.augmented, 2023.-e, p.8).

A = STM32 JTAG and SWD target connector

B = STM8 SWIM target connector

D = Communication activity LED

The SWIM connector will be connected directly to STEVAL-SPIN3204 after debugging the program (STlife.augmented, 2023.-e).

Figure 19. Target SWIM connector (STlife.augmented, 2023.-e, p.11).

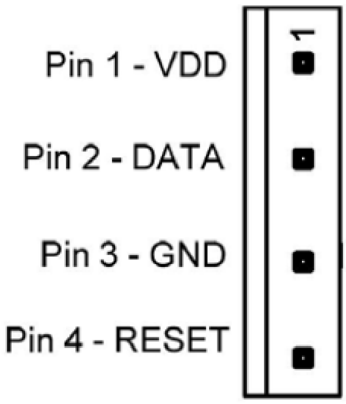


Table 3. Signal names function SWIM connector (STlife.augmented, 2023, p.11).

Pin no.	Name	Function	Target connection
1	VDD	Target VCC(1)	MCU VCC
2	DATA	SWIM	MCU SWIM pin
3	GND	GROUND	GND
4	RESET	RESET	MCU RESET pin

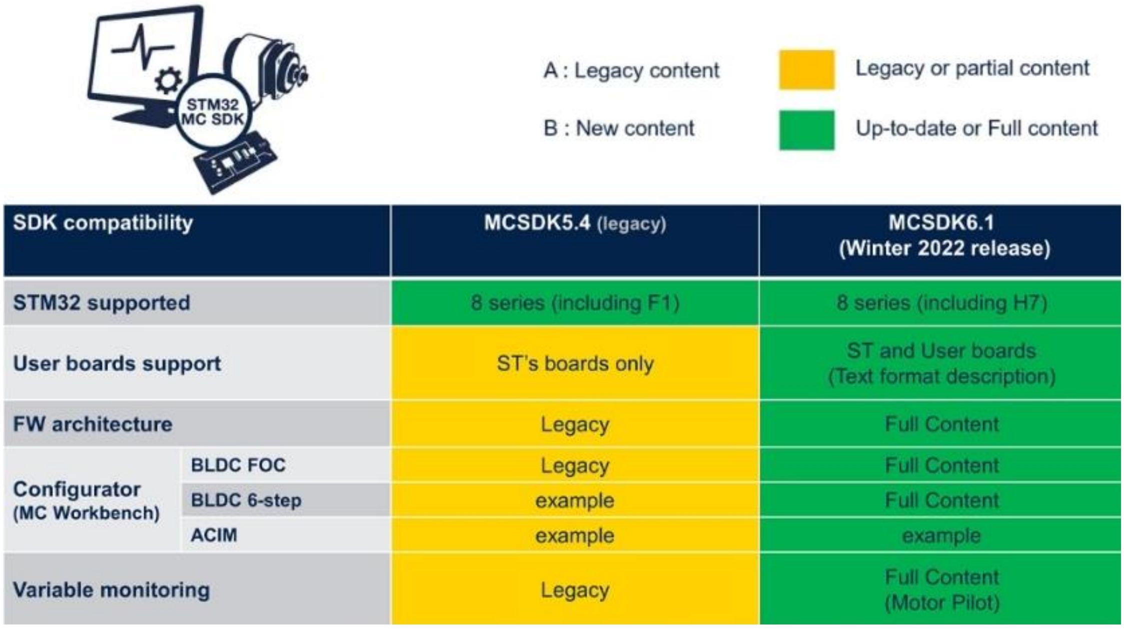
10 Software Requirement

STM32 MC SDK firmware contains features that support software development for STM 32 motor applications. The firmware contains library parameters for the used motor and can be easily configured in the graphical user interface (GUI). Real-time communication through STM32 Motor Control Workbench PC software, where the user can generate and functionalize the library project through the GUI according to the application`s needs.

C Embedded template is a programming tool for microcontroller developers, the program starts by setting the ESC parameters as target speed**.** Using these values, it then calculates a PWM duty cycle using the ESC. Figure 20 is table of the X-Cube-MCSDK software properties (STMicroelectronics, X-CUBE-MCSDK, n.d.).

Figure 20. STM32 motor Control development Software X-Cube-MCSDK

(STMicroelectronics-X-CUBE-MCSDK, n.d).



SDK compatibility		MCSDK5.4 (legacy)	MCSDK6.1 (Winter 2022 release)
STM32 supported		8 series (including F1)	8 series (including H7)
User boards support		ST's boards only	ST and User boards (Text format description)
FW architecture		Legacy	Full Content
Configurator (MC Workbench)	BLDC FOC	Legacy	Full Content
	BLDC 6-step	example	Full Content
	ACIM	example	example
Variable monitoring		Legacy	Full Content (Motor Pilot)

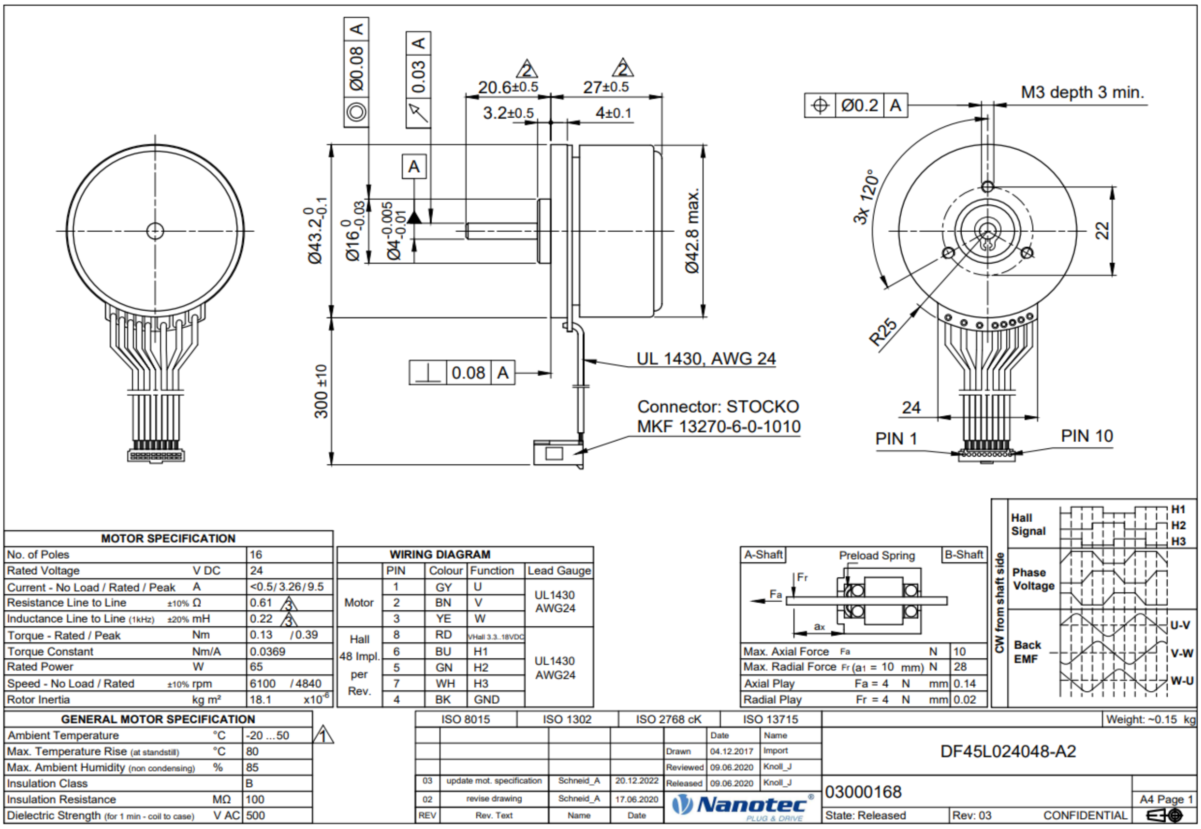
11 Project Implementation

There are several components required for the project to be completed. The chosen hardware for this project is composed of a sensored BLDC motor (DF45M024053-A2) from Nanotech, and B-G431B-ESC1 electronic speed controller. It is designed to perfectly drive a single 3-phase brushless motor (BLDC/PMSM) which makes it the convenient unit for our application. These figures represent the DF45M024053-A2 Brushless DC motor used in the project and its mechanical drawing.

Figure 21. DF45M024053-A2 Brushless DC motor (Nanotec, n.d.-a).

BLDC motor (DF45M024053-A2) is a three-phase flat brushless DC motor designed and developed by Nanotec company, with a 16-pole external rotor for quiet operation and extended life. The motor magnets allow an acceleration and speed up to 14,000 rpm.

Figure 22. DF45M024053-A2 Brushless DC motor (Nanotec, n.d.-b).



The B-G431B-ESC1 Discovery kit is based on the STM32G431CB microcontroller family, it is perfectly designed to operate a single 3-phase brushless motor (BLDC/PMSM), it performs well for both sensorless FOC and 6-step control algorithm with speed regulation, as well as an active brake function algorithm. The motor's output peak current is 40 A.

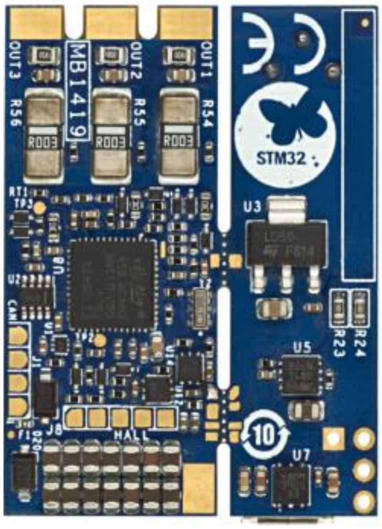
The unit itself is compatible with both hall and encoder motor sensors. In addition, the selected microcontroller has many communication bus interfaces (UART, CAN, and PWM channels). It also features a main power board, a daughterboard with embedded ST-LINK/V2-1, and a 5 V Battery Eliminator Circuit (BEC), and the main power board provides overcurrent, overvoltage, and overcurrent protection circuits. The following figures are B-G431B-ESC1 Microcontroller Unit (Nanotec, n.d.-b; STlife.augmented, 2021.-a).

Figure 23. Microcontroller Unit Serie B-G431B-ESC1 Discovery kit front view

(STlife.augmented, 2021.-a, p.1).

Figure 24. Microcontroller Unit Serie B-G431B-ESC1 Discovery kit back view

(STlife.augmented, 2021.-a, p.1).



Note that in parallel with these components, Oscilloscope was used to measure the motor speed settings.

This chapter explains how the mechanical components were implemented during the project with the motor and the microcontroller.

- **Hardware:**

the hardware system is divided into four main components, for the system can be developed:

1. Microcontroller Unit Serie B-G431B-ESC1
2. BLDC motor
3. Bicycle framing system
4. Motor bench

- **Development board:**

The STM32G431CB microcontroller, the L6387 driver, and STL180N6F7 power MOSFETs are all present in the B-G431B-ESC1 Discovery kit. It is intended to operate a single 3-phase brushless motor (BLDC/PMSM), making it the ideal Unit for our application; it performs well for both sensorless FOC and 6-step control with speed control, as well as an active brake function algorithm. The motor's output maximum current is 40 A.

The unit is compatible with both hall and encoder motor sensors. In addition, the selected microcontroller has many communication bus interfaces (UART, CAN, and PWM channels). It also consists of a main power board, a daughterboard with integrated ST-LINK/V2-1 and a 5 V Battery Eliminator Circuit (BEC), and the main power board contains an overcurrent and overvoltage protection circuit.

- The board is divided into two main boards:

The lower half is primarily focused on the digital part. It is based on the STM32G431CB microcontroller, which supports sensorless and sensored FOC control as well as 6-step control in an LQFP 48-pin package. The following figures explain the difference between the daughter board and main bord, however figure 29 is input and output modules of the board (STlife.augmented, 2021).

Figure 25. Top view of the daughterboard (STlife.augmented, 2021, p.11).

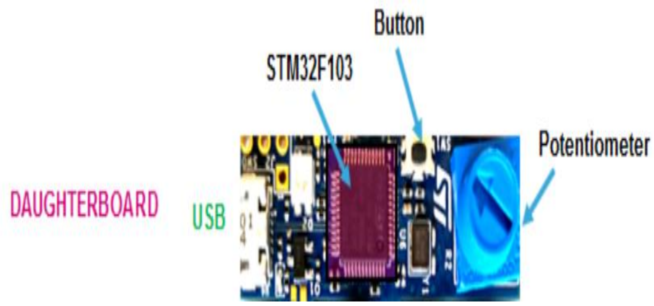


Figure 26. Bottom view of the daughterboard (STlife.augmented, 2021, p.12).

The main board covers the power section, which is made up of power MOSFETs, gate drivers, and DC to DC converter.

Figure 27. Top view of the main board (STlife.augmented, 2021, p.11).

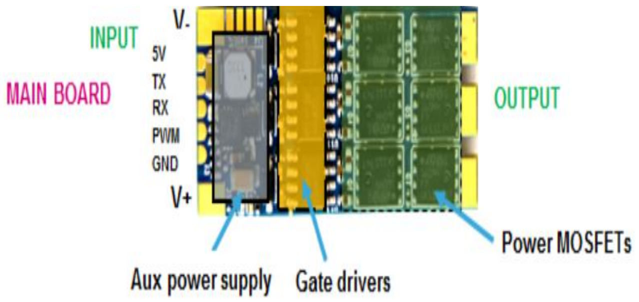
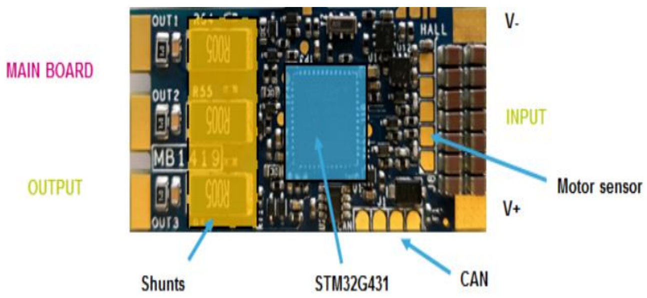


Figure 28. Bottom view of the main board (STlife.augmented, 2021, p.12).



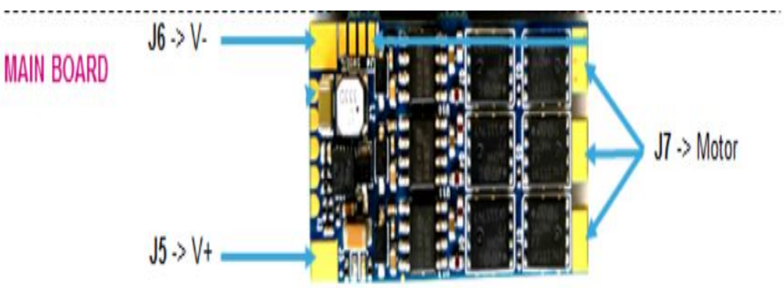
The microcontroller can be connected to the motor by soldering the ports in Jumper (J7)

Main I/O Terminal: Function

J5/J6 : LiPo battery power input (3S-6S)

J7 3-phase : motor connector

Figure 29. Input and output modules (STlife.augmented, 2021, p.14).



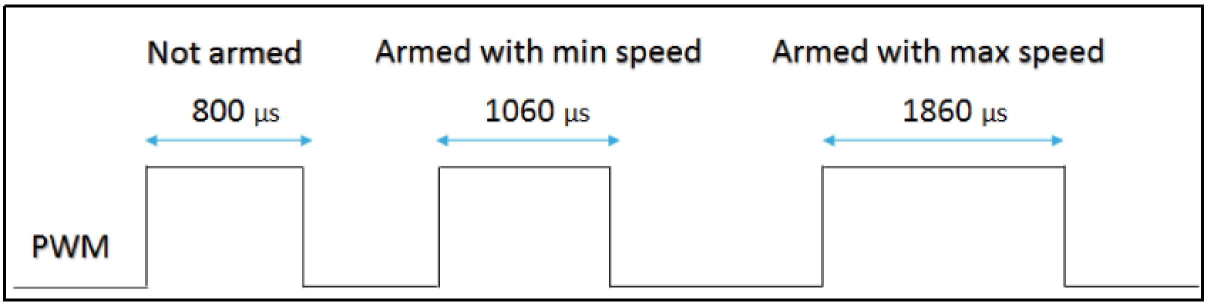
12 Pulse Width Modulation

Pulse width modulation is control Technique, it generates analogue signal from digital components such as microcontrollers. The pulse produced take a form of square waves as it shows in figures 31 & 32. The frequency of a PWM signal is the change between high and low voltages. Frequency is given in Hertz. However, the duty cycle is the amount of time the signal remains at high voltage. It is calculated as a percentage of the period.

Pulse width modulation is commonly utilised in a sinusoidal brushless motor controller circuit. The PWM approach enables motors to deliver maximum torque even while running at low speeds. It allows for more effective and efficient operation of commutation by controlling the current injected into the windings on the rotors. This is used in closed-loop controllers that accept feedback from an output signal and alter the duty cycle to control the input power.

The following figure present pulse width modulation of traditional drone.

Figure 30. PWM input signal for motor speed regulation in traditional drone (STlife.augmented, 2021.-a, p.21).



The Pulse width modulation depends on one task to another. However, it should always be high to minimise power loss.

Note that before completing the connection, it must be ensured that the voltage is high enough to support the load.

• Solder the three motor wires U, V, and W at J7 .

• Connect the PWM input and GND to the J3 connection (pins 4 and 5).

• The PWM input signal will have a voltage range of 3.3 V to 5 V.

• Connect the main board to the power source (minimum 12v - maximum 24v) and turn it on.

• We generate a duty cycle value between 1060 s and 1860 s on the J3 connection (PWM signal at 490 Hz), and the motor rotation will progressively rise from minimal to maximum speed (STlife.augmented, n.d.-a.).

13 Results

The study set out to assess the efficiency of the brushless DC motor for both educational and industrial purposes, many factors affect the improvement and the performance of the motor, starting from choosing the right microelectronic. In this phase, it was challenging to select the right board which will communicate effectively with the motor. However, the author concluded that the ESC microcontroller is convenient for developing our product.

The second challenge is to program the board to operate with the motor, in this case, two main software has been used to set the program for the system, first programming the microcontroller to start operate using c embedded software, second platform is STM32 MC SDK firmware, which contains features that support software development for STM 32 motor applications. The firmware contains library parameters for the used motor and can be easily configured in the graphical user interface to fit the project needs.

The initial tests were carried out to assess how the Electronic speed controller will operate with the BLDC, in APPENDIX 1 illustrate the first operation code, also the BLDC speed Setting and the field period.

The operation results of the system with two PWM were selected and captured by the oscilloscope.The following figures 31 & 32 are a result of the motor speed settings captured by the oscilloscope. However, Figures 33 & 34 are a 3D model prototype of the system.

Test 1 Results: (No Load application)

Figure 31. BLDC Speed Setting 1200us field period 4ms.

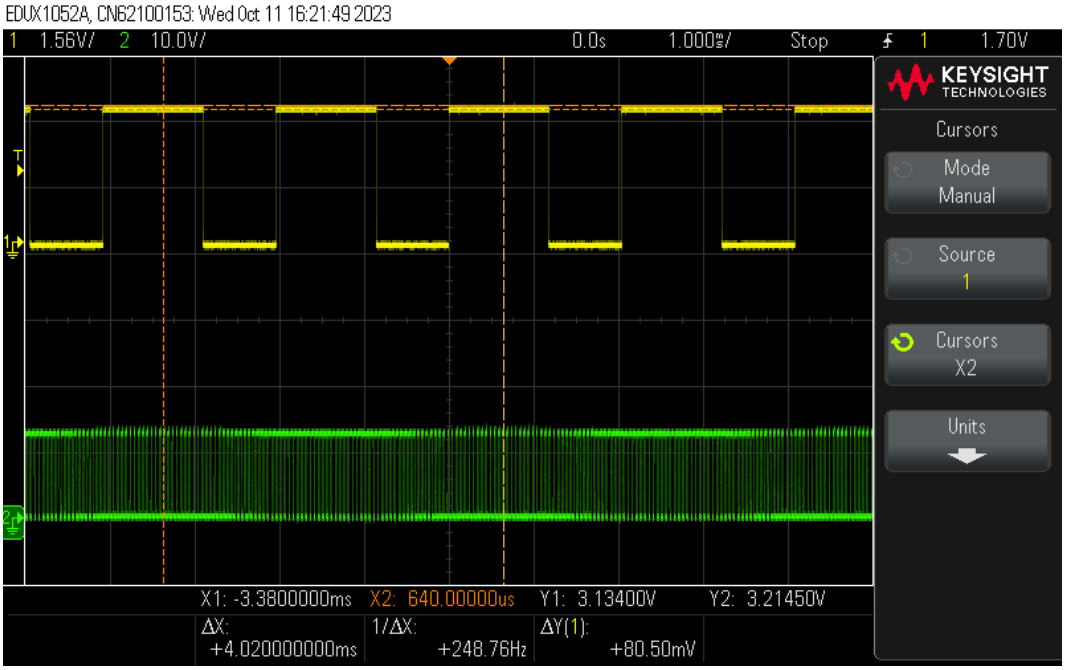
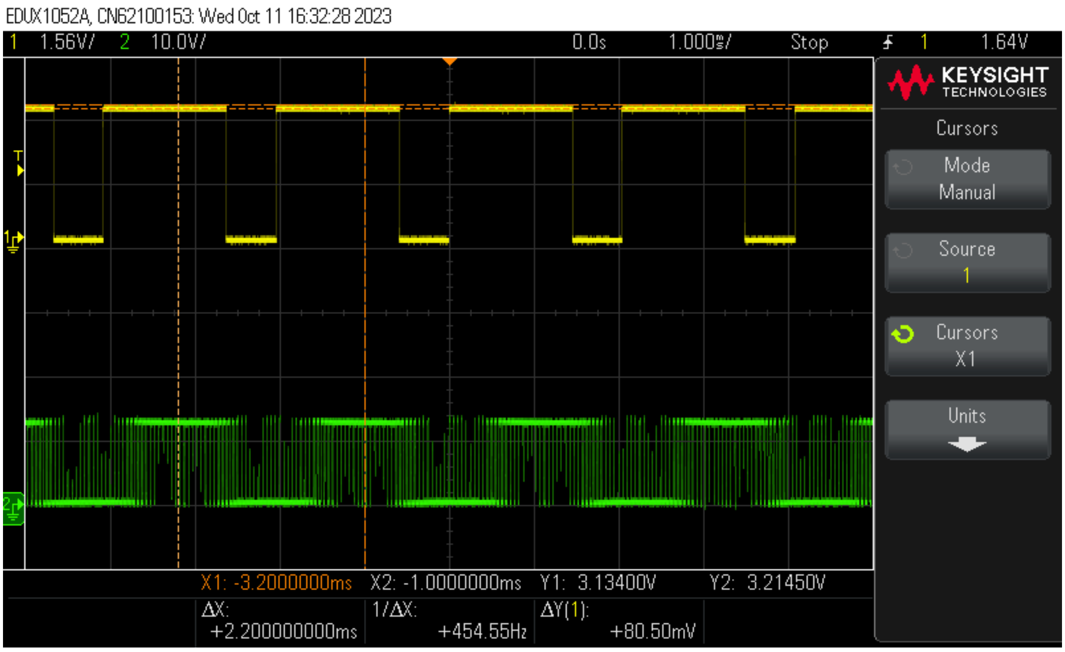


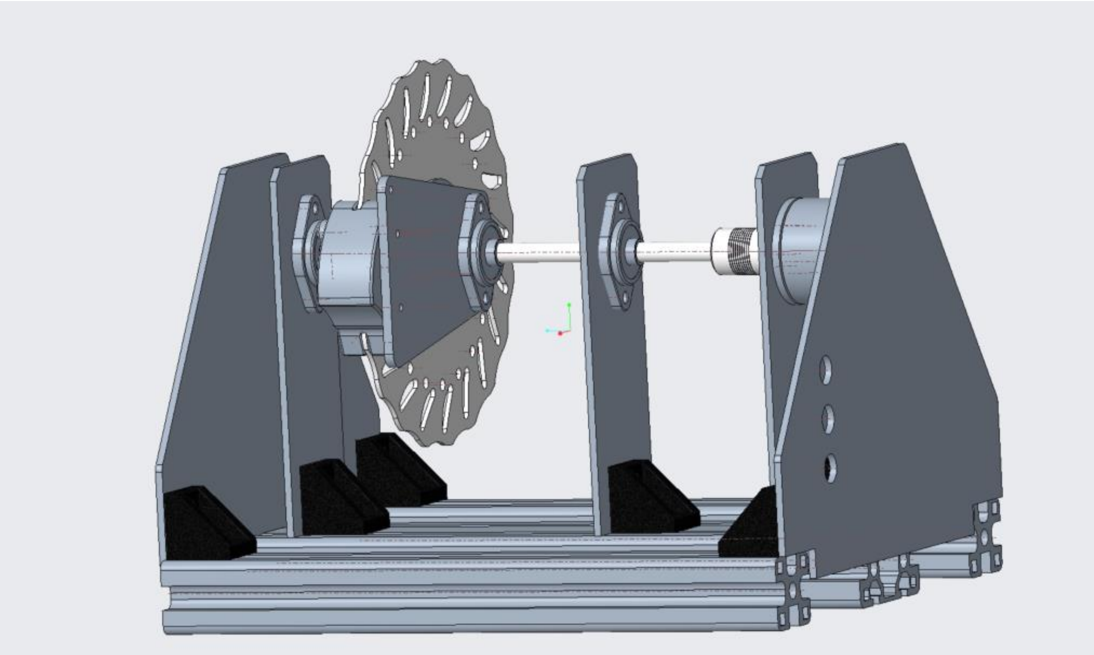
Figure 32. BLDC speed setting 1450 us field period 2.2 ms.



Test 1 results demonstrate the results of the motor speed setting with no load action.

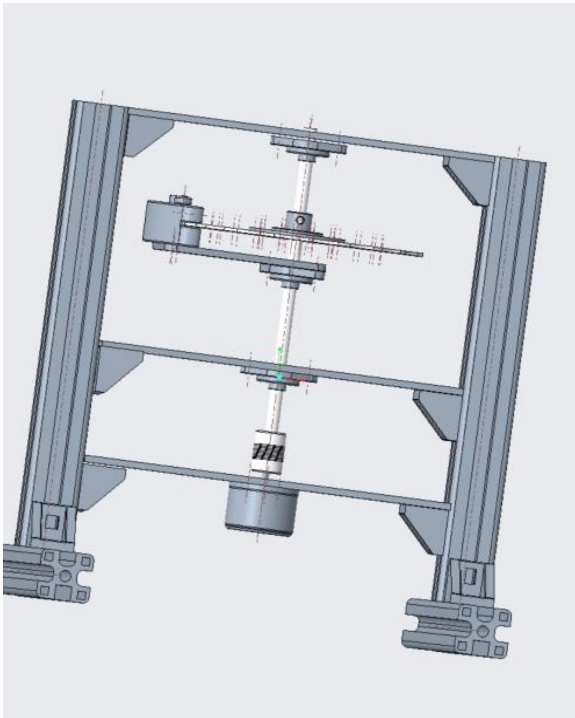
- Design Solution for Vertical assembly.

Figure 33. Vertical assembly of the system.



- Horizontal design solution.

Figure 34. Front view of the horizontal assembly.



14 Summary

BLDC is also known as EC motor can affect many sectors especially energy efficiency technologies in HVAC (heating, cooling, and ventilation) systems allows energy saving in buildings services and factories, these motors has been used in low power range applications only. Thanks to VFD or ESC technology, the BLDC motor can integrate effectively in smart control technologies and systems allowing features such as speed, low noise, load sensing, and smart communication with the network.

Developing a Brushless DC (BLDC) motor drive is essential due to the various advantages it brings over standard brushed DC motors, including maintenance-free operation, compact design, and accurate control of speed and direction. BLDC motors are critical in applications requiring high reliability, longevity, and energy savings. They are adaptabtable to various speeds, and interaction with smart systems and IoT platforms make them suitable for businesses that are looking for advanced motor solutions that are environmentally conscious and meet changing technological needs.

The process of writing and implementing this thesis gave the author valuable knowledge and insights in the field of microelectronics and how to integrate electric motors in different systems.The thesis process seemed somewhat challenging for the author and he was concerned about completing the thesis at the right time. However, this thesis project will continue the development process under the guidance of the supervisor.

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Appendices

Appendix 1

First code for the ESC

```
/*
Controlling an Electronic Speed Control unit for brushless
DC motors. The control signal is the traditional servo signal
used in RC model airplanes and nowadays used in drone ESCs.
Period = 22.5 ms
Minimum speed = 1 ms
Full speed = 2 ms
That is roughly the original definition for analog control from 1970's.
In the ST Microelectronics B-G431B-ESC from StMicroelectronics:
period = 1/490 Hz = 2040.816 us
Minimum speed = 1060 us
Maximum speed = 1860 us
*/
#include "mbed.h"
// main() runs in its own thread in the OS
int main()
{
  AnalogIn pot1(A2);
  PwmOut   servoSignal(D9);
  float   speed;
  float   pulseWidth_us;
  servoSignal.period_us(2041);  //  22500 for original and 2041 for the ST Microelectronics

  while (true) {
    speed = pot1.read();  // returning a value from 0.0. to 1.0
    pulseWidth_us = 1000 + 1000 * speed; // returning value from 1000 us to 2000 us
    servoSignal.pulsewidth_us((int)pulseWidth_us);
    ThisThread::sleep_for(200ms);    }}
```

Appendix 2

Hardware system