DEVELOPMENT OF ELECTRONIC SPEED CONTROL (ESC) CIRCUIT OF BRUSHLESS DC MOTOR FOR DRONE APPLICATIONS

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DECLARATION

I declare that this thesis entitled "DEVELOPMENT OF ELECTRONIC SPEED CONTROL (ESC) CIRCUIT OF BRUSHLESS DC MOTOR FOR DRONE APPLICATIONS is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "DEVELOPMENT OF ELECTRONIC SPEED CONTROL (ESC) CIRCUIT OF BRUSHLESS DC MOTOR FOR DRONE APPLICATION" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

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Date : 6 JULAI 2021

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DEDICATIONS

This research work is dedicated to my beloved parents and family, who have been my source of inspiration and motivation. They never stop encouraged and counseled me to always strive for excellence in my studies. They were my strength when I thought for giving up, who always gave me spiritual, emotional, and financial support.

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ABSTRACT

Over the past few years, the significant of drone applications had drastically increased in many sector of industries such as agriculture, aerial photography and entertainment. Nowadays, there are many types of drone in markets which generally classified based on its aerial platform. Basic construction of drones would need several essential part to make it operates such as motor, ESC circuit, frame, remote control (transmitter and receiver), battery, power distribution board and flight controller. This thesis project presents the development of electronic speed control (ESC) circuit for sensored BLDC motor for drone applications. It also presents the design of proposed ESC for clockwise and counterclockwise rotation which its performance analysis also will be presented in this project. Theoritically, the operations of BLDC motor would need an ESC circuit to receive the signals about the informations of position rotor from sensors. This project proposes the development of ESC circuit for BLDC motor using hall effect sensors instead of using conventional approach of back EMF approach. The usage of hall effect sensors will easier the development of ESC circuit due to avoide difficulties in microcontroller programming and more realible at low speeds. To validate the accuracy of proposed model, the performance of proposed ESC circuit which using sensors approach was analyzed based on simulation using Simulink MATLAB software and performed experiment analysis based on existing design of ESC circuit. Then, the performance was evaluated based on varying the experiment parameter to observe the changes of output results. Finally, the experiment investigations also done on proposed ESC circuit to study the relation between duty ratio of PWM and speed of BLDC motor. The simulation and experimental results verified that the proposed ESC circuit using hall effect sensor approach can be for drone applications. Furthermore, it also verifed that the proposed ESC circuit design can perfromed clockwise and counterclockwise rotation for BLDC motor. Lastly, the result verified that the speed of BLDC motor can be verified when the duty ratio of PWM signal varied since it was proportianal to each other.

ABSTRAK

Sepanjang beberapa tahun yang lalu, kepentingan terhadap pengaplikasian drone telah meningkat dalam banyak sektor industri seperti pertanian, fotografi udara dan hiburan. Pada masa kini, terdapat banyak jenis drone di pasaran yang mana jenis terebut dikelaskan secara umum melalui platoform udara. Pembinaan asas drone memerlukan bebearapa komponen wajib untuk memasitikan drone berfungsi seperti motor, pengawal kelajuan elektronic, bingkai, alat kawalan jauh (pemancar dan penerima), bateri, papan agihan kuasa dan pengawal penerbangan. Projek tesis ini memaparkan pembangunan litar pengawal kelajuan elektronik untuk BLDC motor yang mempunyai sensor bagi aplikasi drone. Ianya juga memaparkan reka bentuk litar pengawal kelajuan elektronik yang dicadangkan bagi putaran mengikut dan melawan arah jam yang mana analisis prestasinya juga akan dipaparkan dalam projek ini. Berdasarkan teori, motor BLDC memerlukan litar pengawal kelajuan elektronik untuk menerima maklumat tentang kedudukan rotor daripada sensor. Projek ini mencadangkan pembangunan litar pengawal kelajuan elektronik menggunakan sensor hall effect bukannya menggunakan pendekatan konvensional iaitu pendekatan balikan-EMF. Penggunaan sensor hall effect akan memudahkan pembangunan pengawal kelajuan elektronik kerana dapat mengelakkan kesukaran pengaturcaraan miktrokontroller dan lebih sesuai pada kelajuan rendah. Bagi mengesahkan ketepatan model yang dicadangkan, prestasi litar pengawal kelajuan elektronik dinilai berdasarkan simulasi mengunakan perisian Simulink MATLAB. Kemudian, prestasi litar juga dianalisis berdasarkan pemerhatian terhadap hasil eksperiment apabila parameter eksperimen diubah. Akhirnya, penyiasatan eksperimen telah dilakukan bertujuan untuk mempelajari hubunagan diantara *duty ratio* signal PWM dan kelajuan BLDC motor. Hasil simulasi dan eksperimen menunjukkan bahawa litar pengawal kelajuan elektronik yang dicadangkan yang menggunakan sensor hall effect boleh digunakan dalam aplikasi drone. Selain itu, dapat juga ditunjukkan bahawa litar pengawal kelajuan elektronik yang dicadangkan boleh membuatkan BLDC motor berputar mengikur dan melawan arah jam. Akhir sekali, hasil projek juga menunjukkan bahawa kelajuan motor BLDC boleh diubah apabila *duty ratio* signal PWM berubah yang mana ianya berkadar langsung antara satu sama lain.

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LIST OF SYMBOLS AND ABBREVIATIONS

ω_m	-	Angular speed of rotor
Ke	-	Back EMF constant
$F(\theta_e)$	-	Back EMF references function of rotor
BLDC	-	Brushless Direct-Current (DC)
Te	-	Electrical torque produced by BLDC
$Tabc$	-	Electrical torque produced by each phases
EMF	-	Electromotive Force
ESC	-	Electronic Speed Controller
FPV	-	First Person View
L	-	Inductance of each phases of BLDC
J	-	Inertia of the motor
LiPo	-	Lithium Polymer
Tl	-	Load torque applied to BLDC
θ_m	-	Mechanical angle of rotor
M	-	Mutual inductance
P	-	Number of poles used
$Eabc$	-	Phase back-EMF
$iabc$	-	Phase current
$Vabc$	-	Phase voltages applied from inverter to BLDC
PDB	-	Power Distribution board
PCB	-	Printed Circuit Board
PWM	-	Pulse Width Modulation
R	-	Resistance of each phases of BLDC
RPM	-	Revolution Per Minute
β	-	Static fraction
Kt	-	Torque constant
UAV	-	Unmanned Aerial Vehicle
VTOL	-	Vertical Take-Off and Landing

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CHAPTER 1

INTRODUCTION

1.1 Motivation

In recent years, drone application has been grown exponentially which is not only used as an individual hobby, but it is also used in many areas such as aerial photography, shipping and delivery, rescue operations, building safety inspection and supplying essentials for disaster management. There are two types of motor that typically used in drones which are brushed and brushless motor. Brushed motor usually used in small sized of drones due to less power produced. Brushless motor is more widely used in market due to the higher efficiency, less maintenance and last longer. Brushless motor is a motor that commutated electronically which needs an electronic circuit to control the sequence of current flow to the three-phase motor winding in order to make the rotor spin. Typical brushless motor uses hall effect sensor which will send the signal about the position of rotor to the electronic circuit so that the electronic circuit will decide the correct phase current to flow and magnetize the winding. The sequence of megnetizing the windings is very important to maintain the rotation of the motor. In order to have a perfect rotation, the electronic speed control (ESC) circuit must be designed perfectly so that it can rotate without any disturbance.

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The project will develop electronic speed controller (ESC) which consists of the electronic circuit that will control the sequence of current flow to the phase winding with the information of the hall effect sensor signals.

1.2 Problem Statement

Electronic Speed Control (ESC) circuit is an important component in a drone. The construction of ESC for a sensored BLDC and sensorless BLDC are different due to the presence of back EMF circuit. Back EMF circuit is a circuit to detect the position of motor using back EMF approach which in other words, this circuit was implemented in ESC for a sensorless BLDC motor operation. The problems that can be found in ESC with back EMF approach are difficulties in microcontroller programming and difficulties in determine the rotor position at low speeds. In designing the ESC with back EMF approach, the programming of microcontroller is one of the hardest part because it need to consider all situations happened and provide the solution. This programming part will take a lot of time in order to design a perfect ESC which will detect the information signal from back EMF waveform. Some microcontrollers would have its own voltage rating which back EMF voltage should be not exceeed this value to prevent damage on microcontrollers. As the back EMF voltage produce is proportional to the speed of BLDC motor, hence the back EMF voltage will be low when the speed of BLDC motor is low. This will bring the problem for the ESC to detect the rotor position because the back EMF voltage is to low while starting the motor. Hall effect sensor implementation will increase the complexity motor construction due to the addition component in the BLDC. Hence, it indirectly will increase the construction cost of a drone but this can be avoided by implementing perfect design of motor construction. Finally, In motor selection, the usage of BLDC was more suitable to be implemented instead of brushed motor for drone applications due to the limitations of brushed motor which it has low efficiency and it cannot operate at very high speed due to the presense of commutator and brushed that will produce spark at high speed.

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1.3 Objectives

The major findings of the research are summarized as follow:

i. To design and develop electronic speed control (ESC) circuit for sensored BLDC motor for drone applications.

ii. To design the electronic speed control (ESC) circuit for clockwise and counterclockwise rotation of BLDC motor.

iii. To analyze performance of the proposed electronic speed controller (ESC) for controlling the speed.

1.4 Scope

The simulation results presented in the thesis are based on the design and development of electronic speed controller in MATLAB software. For MATLAB simulation, the subsystem of BLDC motor must be designed carefully to make it suitable for analysis. As the research focused on the hall effect sensor method, the designed ESC must be suitable with the BLDC which has hall effect sensor. The analysis of the developed electronic speed controller is done by analyze the speed produced by the BLDC motor which using hall effect sensor to sense its rotor position. The analysis also done by varying the PWM generated to change the duty cycle of switching frequencies which will increase the speed of rotor when the duty cycle increase. Lastly, the project analyse the results obtained from the experiment in terms of motor speed, output power and the PWM signal waveform produced for each upper swithces of three phase inverter.o

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CHAPTER 2

LITERATURE REVIEW

2.1 Types of Drones

Drones is also known as Unmanned Aerial Vehicle (UAV) which an aircraft without the presence of human pilot aboard. Drones can be classified based on the usage of drones itself such as Drones for Photography, Drones for Surveillance etc. but the best to classify the drones are based on the type of aerial platform such as Multi Rotor Drones, Fixed Wing Drones, Single Rotor Helicopter and Fixed Wing Hybrid VTOL.

2.1.1 Multi Rotor Drones

Multi rotor drones are the type of drone which consists of the multi motor which mostly of the motors are small which are necessary for their stability. Usually, these drones consist minimum of four motors to keep them flying. Nowadays, popular examples for the multi rotor drones that widely used is Phantom Drone made by the Chinese company DJI (Da-Jiang Innovations) [1]. Multi rotor drones are the most used type of drones which used by the professionals and hobbyists alike. This is because the multi rotors drones have lot of advantages such as less noise which suitable for applications like aerial photography and aerial video surveillance. These multi rotor drones does not need a landing strip and can hover in the air [1] which shows that the drones are flexible.

Multi rotor can be further classified based on the number of motors used by the drones. For example, figure 2.1 shows the DJI Phantom 1, a quadcopter which consists of four rotors. Other types of multi rotor drones are Tricopter (3 rotors), Hexacopter (6 rotors) and Octocopter (8 rotors).

Figure 2.2.1: DJI Phantom 1

2.1.2 Fixed Wing Drones

Fixed wing drones are the types of drones that have fixed or static wings which combine with forward airspeed to generate lift [1]. This type of drones frequently used by the construction, mining, environmental industries and agricultural. The simple construction of this drone makes the manufacture cost low and less maintenance.

Fixed wing drones have its own advantages such as longer flight time which this type of drones have longer flight time compare to multi rotor drone. Excellent stability also one of the advantages which due to the airframe design. Lastly, the advantage of this drone is it can cover large area up to 10 km^2 in shorter time. Figure 2.2 shows the example of Fixed wing drones.

This type of drone can further classify based on their type of wing such as straight wing, swept wing and Delta wing. Straight wings consist of rectangular, tapered and rounded while swept wings consists of slightly, moderately, and highly. Next, delta wing consists of two which are simple and complex.

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Figure 2.2.2 :Fixed wing drones

2.1.3 Single Rotor Helicopter

Single rotor helicopter built up with very same design and structure with actual helicopter. This type of drones consists of one big sized rotor and small rotor for the tail of drone to control its heading.

Single rotor helicopter has advantage such as it can has higher flying times, and the rotors can be powered up using gas engines. It shows that this drone type has higher efficiency than multi rotor drones, but it has complexity machine and operational risks due to the larger sized rotor blades. The bigger blades are very dangerous if the drone is mishandled, and the accident might cause fatal injuries. Figure 2.3 shows the example of single rotor helicopter.

Figure 2.2.3 :Single rotor helicopter

2.1.4 Fixed Wing Hybrid VTOL

Fixed wing hybrid VTOL is a combination drone of fixed wing drone and multi rotor drones. This drone consists of advantages from the multi rotor drones and fixed wing drones. Some of its advantages such as it can take off vertically, has higher cruise velocity and high performance due to the ability to change the flight mode to hover mode [2].

This type of drone usually used for civil applications such as tracking and monitoring in agent of agricultural, emergency and disaster situations. It also used in mapping for land registry, wildlife monitoring, traffic monitoring and geology researchers [2]. The design of fixed wing hybrid VTOL which built up with camera, hyper spectral image, and air data sensors able it for use in many applications. Figure 2.4 shows the example of fixed wing hybrid VTOL.


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Figure 2.2.4: Fixed wing hybrid VTOL (UKRSpecSystems PD-1)

2.2 Essential parts of Drone

In drone’s construction, there are two essential systems which are movement system and control system [3]. Movement system consists of frame, propellers and engine (motor) and power of drone (batteries) while control system consists of electronic speed control (ESC) and flight controller [3].

2.2.1 Frame

Frame is the backbone for a drone which will hold all others essential parts of drone so its material should be maximum lightweight and high durability. The frame mostly classified based on the number of arms which each arm has one rotor installed[3]. The types of arms consist of:

1. Bicopters – two rotors
2. Tricopters – three rotors
3. Quadcopters – four rotors (Mostly used)
4. Hexacopters – six rotors
5. Octocopters – eight rotors

Figure 2.5 shows the examples of possible frame construction [3]. The quadcopters is widely used because its enough to hold of weight without increasing the cost of production since by adding the arms will need to expense more in adding the rotor and ESC.

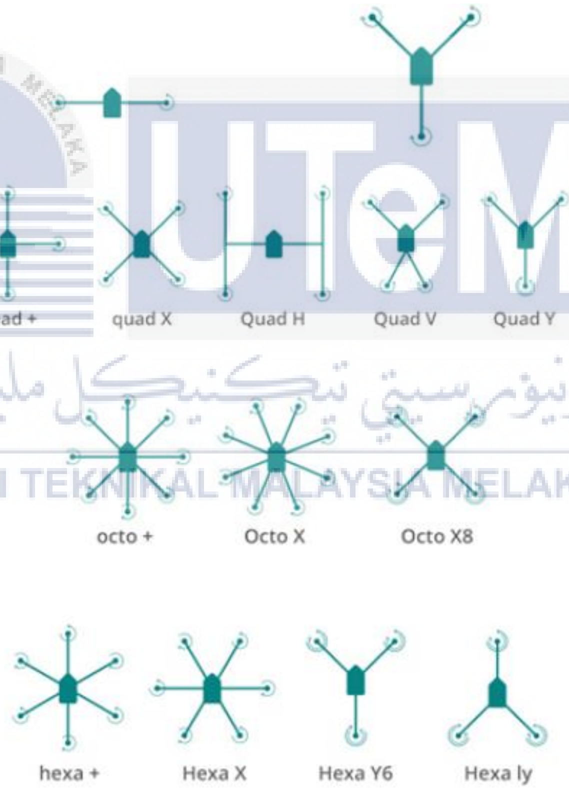

Figure 2.2.5: Possible frame construction with its propellers

2.2.2 Batteries

Batteries are the same type of two set or more voltaic cells that provide a current to all essential parts of drone. There are many types of batteries and accumulators that currently used as power supply to the drone such as lead-acid, nickel-iron, nickel-zinc, lithium-ion and lithium-polymer (LiPo) but the most popular used nowadays is LiPo. Lipo commonly sold in 1S to 6S which S stand for number of cells so the more number of cell grouped togther, the more overall voltage.

There are many advantages of lithium-polymer such as its cells can resist to mechanical damage and it can work at high loads-up depending on the cell type [4]. Next, lithium polymer battery has cells that enclosed with thin aluminium pouches which this will give more advantages in term of weight. It will minimise consumption of power due to the lighter weight and able it provides longer time of a drone in the air [4].

Lithium polymer also provide safety due to the use of solid polymer that increase the resistance of cells in case of short-circuit which it can prevent the electrolyte leakage. LiPo also can be design in wide range of sizes, shapes and power levels [5]. Its flexibility in design makes LiPo as one of the battery types that commonly used in electronic devices. Figure 2.6 shows the example of designed lithium polymer battery for drone applications. The battry model is 35024 by Venom Group brand which has capacity of 2200mAh with 3S equivalent to 11.1V output voltage.

Figure 2.2.6: Lithium polymer batteries (Lipo)