

**BLACK-BOX MODELLING FOR BRUSHLESS
DC MOTOR AND CONTROL STRATEGY FOR
QUADCOPTER APPLICATIONS**

BY

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BACHELOR DEGREE OF ENGINEERING (HONOURS)**

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DECLARATION

This thesis is the result of my investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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ABSTRAK

Penggunaan motor arus terus tanpa berus dalam aplikasi quad copter menimbulkan permintaan baru. Quad copter drone biasanya menggunakan motor arus terus tanpa berus kerana prestasi tinggi, kecekapan tinggi dan jumlah kecil. Fungsi motor arus terus tanpa sikat dalam quad copter adalah untuk kedudukan dan halaju drone itu sendiri. Pasti motor arus terus tanpa berus memberikan lebih banyak kecekapan dan keberkesanan berbanding dengan motor berus. Untuk menganalisis tindak balas motor arus terus tanpa berus dan strategi kawalan untuk aplikasi quad copter, pemodelan kotak hitam diciptakan. Kotak hitam atau dikenali sebagai model eksperimental adalah kaedah untuk pengembangan pangkalan data proses model. Oleh kerana simulasi fizikal memerlukan banyak kali, pemodelan kotak hitam adalah cara biasa untuk mendapatkan input dan output proses tingkah laku secara keseluruhan. Biasanya, model binaan digunakan untuk pengiraan nilai proses berpotensi atau dalam aplikasi untuk pengurusan proses. Aspek penting dalam pemodelan kotak hitam iaitu analisis sistem, pengkondisian data, analisis pemboleh ubah utama, reka bentuk struktur model, pengenalan model dan penilaian model. Perisian yang digunakan adalah MATLAB dan Simulink. Perisian MATLAB dan Simulink digunakan untuk menunjukkan dan mengukur prestasi konsep yang berkesan. Perisian ini membantu dalam merancang dan mengenal pasti sistem quad copter. Lazimnya, persembahan model yang berbeza-beza memberikan hasil model yang berbeza. Pasti, model fungsi pemindahan linear memberikan hasil terbaik untuk simulasi.

ABSTRACT

The uses of brushless DC motor in quad copter application gives rise to a new demand. Quad copter drone usually uses brushless DC motor due to high performance, high efficiency and small volume. The function of brushless DC motor in quad copter is for positioning and velocity of the drone itself. Surely brushless DC motor gives more efficiency and effectiveness compared to brush motor. In order to analyse the responses of the brushless DC motor and control strategy for quad copter applications, black box modelling is invent. Black box or known as experimental modelling is a method for the development of process database of the models. Since physical simulation cost so much times, black box modelling is a common way to gain the overall behaviour process input and output. Typically, the built model used for estimation of potential process values or in application for process management. Important aspects in black box modelling which is system analysis, data conditioning, key variable analysis, model structure design, model identification and model evaluation. Software that been used is MATLAB and Simulink. The MATLAB and Simulink software used to demonstrate and measure the effective performance of the concept. The software helps in designing and identification of the system of the quad copter. Usually, the performances of different linearity of the models give different results of the models. Surely, linear transfer function models gives the best result for the simulation.

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LIST OF SYMBOLS

K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
F_c	Centripetal force
m	Mass
v	Velocity
r	Radius path of motion
a_c	Centripetal acceleration
R	Length of shaft
w	Angular rate

LIST OF ABBREVIATIONS

AC	Alternative Current
ADC	Analog Digital Converter
BLDC	Brushless Direct Current
CPU	Central Processing Unit
DAT	Data
DC	Direct Current
ESC	Electronic Speed Controller
GND	Ground
I/O	Input / Output
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
PID	Proportional Integral Derivative
QOV	Quiscent Output Voltage
RPM	Revolutions per Minute
SI	System Identification
VCC	Input Voltage Supply

CHAPTER 1

INTRODUCTION

1.1 General overview

In a control design system, we need to understand the behavior of the system itself. Back in the 1945s where is black box modelling known as the English language. Earlier, Wilhelm Cauer developed black-box modeling for computing, mathematics, science, and technology functions. For detail, a black box program is a program that users do not know the system's physical behaviour and inner workings. By using the black-box modelling approach, the researcher can expect the inner working of the system. In 1961s, Norbert Wiener described a black box as an unexplained device that needs a system identification process. Besides that, it is also can reduce time consumption. A lot of developers consume so much time in the identification of black box programs. With this method, time consumption is reduced. The development of black-box models has high accuracy compared to the physics-based models (Chen, Su, and Li 2020).

Generally, there are three types of modeling approaches which is black-box, white-box, and grey-box. Black-box modeling is when there is no physical insight that accessible or utilised. The chosen model structure belongs to families that have good flexibility in terms of performance and quality. The system is stable and perfect to work on and has been successful in the past. Researchers used several black-box modeling methodologies for some experiments, such as motor experiments, dynamic or static systems. White-box is mathematical modeling that using some equation to describe the physical properties of the system. The equation will give the overall description of the system from input to output. This is when a model is completely known and understood that could be constructed with prior information and from the given data. Grey-box is a parameter estimation method. This method can be used where the structure and system

properties are well known, without exact physical parameters. The grey-box process relies on the experimental data to estimate the parameters of the system. This is when some physical knowledge is provided, but only some of the data and information need to be revealed and establish from the experiment itself. Grey-box modeling got two cases that can be consider. First one is physical modeling, which means that a model structure with several parameters must be evaluated from the data. This could be a state-space model with a specific order and structure. Next is semi-physical modeling. Certain non-linear combinations of collected data signals are suggested using physical behavior. These new signals are subjected to black-box modeling.

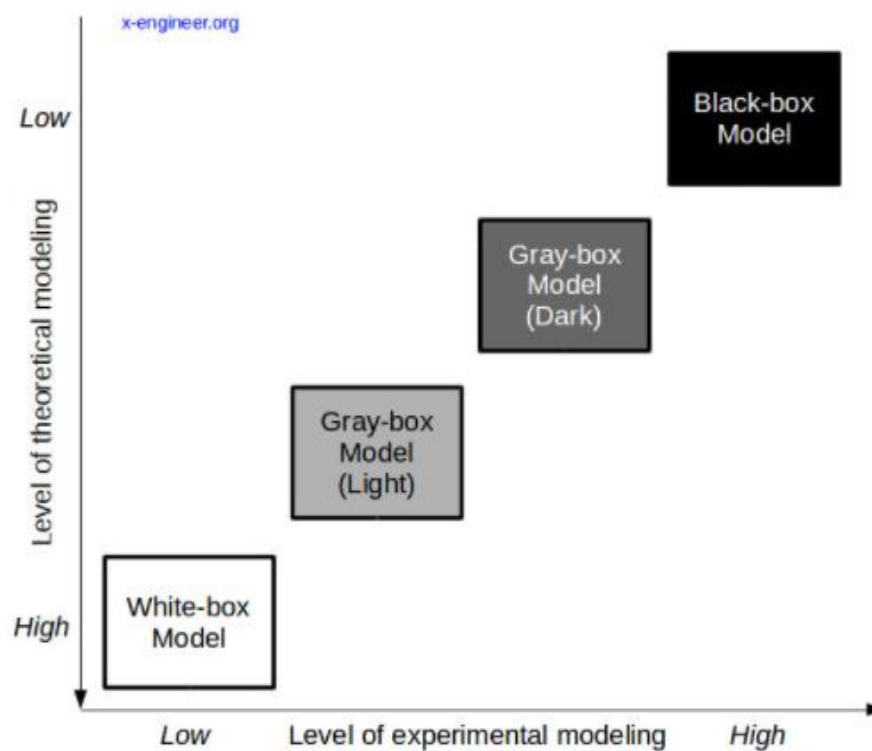


Figure 1.1 Methods of mathematical modeling

Over the years, the uses of black-box modeling have gone in and out of style. It depends on the market, whether up or down. Investors using black-box modeling as their

method conceal their real risk under the guise of proprietary technology. Proprietary technology is any combination of processes, tools, or systems that are related to each other. It has an opacity or black implementation. A transistor, an algorithm, or even the human brain may be defined as a black box.

Black-box modeling got several testing techniques. One reliable technique is Boundary Value Analysis (BVA). Boundary Value Analysis is the most widely used black-box testing approach for locating the error in the boundaries of input value rather than the center. Next is Equivalence Class Partitioning. This method is used to decrease the number of available inputs to small inputs. The goal of this technique is to minimise the number of possible inputs to a manageable quantity. It is done by separating inputs into classes and getting value from each class to test an application thoroughly and eliminate the redundancy of inputs. The third one is Decision Table Based Testing, and the most rigorous strategy is preferably used when the number of combinations of measures is taken under different situations. Cause-Effect Graphing Technique takes solely takes the expected outward behavior of the system only. It helps special test cases that tie causes to effect to build test cases. In the above phrase, discrete input condition resulting in internal system changes, but the effect means the output condition brought about by a combination of causes. The last technique is error guessing. This technique's success is entirely contingent upon the tester's experience. There are no such tools or approaches. However, test cases can be written as one reads the document or as one encounters an undocumented mistake while testing.

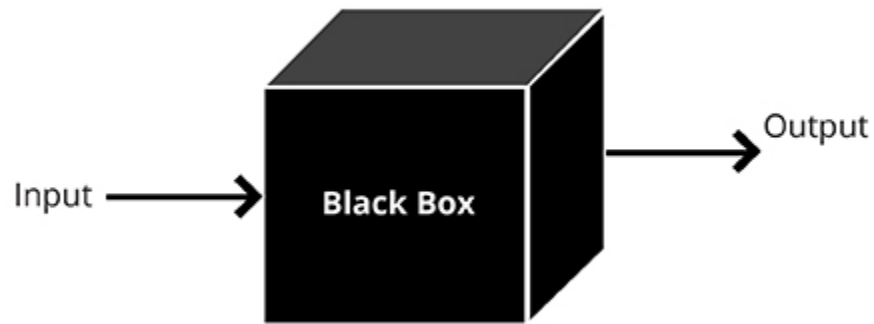


Figure 1.2 Black-box testing approach

(Rongala 2015)

A control system is a combination of multiple parts connected to itself or any other system as a unit to direct or control a specified output is referred to as a control system. Controlling is the act of regulating or supervising. Then, a control system is used to modify the system's behaviour and direct the operation of a physical system to achieve the intended and desired purpose (Antsaklis and Gao n.d.). Control system is essential in every industry sector like in space technology, transportation, and machine control. Components of the control system are divide by two, where are the controlled system and the controller. A controlled system is a control portion of the system is known as a plant. A controller is the internal and external elements of the system. For the control system, some aspects need to be considered in the system such as input, output, and disturbances. Some excitation signals must be delivered to each system in order to provide a specific result. This signal is normally transmitted via an external source. The signal from external that for desired operation also known as input. The whole system response after the input is applied is known as output. But sometimes, even though the system provides the required input, the desired output is not generated. The signal that causes the desired output to variate is hence known as disturbances. Disturbances have

two types where is depending on their origin. If the system perturbation itself is generated, it is known as the internal perturbation. If the disturbances are generated from outside of the system and create a negative impact on the output of the system, it is called external disturbances.

Control system is classified into two types which are open-loop system and closed-loop system. An open-loop system is a non-feedback system. The input applied to the system is not dependent on the system output. A closed-loop system is a feedback system because the output only success when no longer feedback to the input and it is meet the desired output. The input applied depends on the output system.

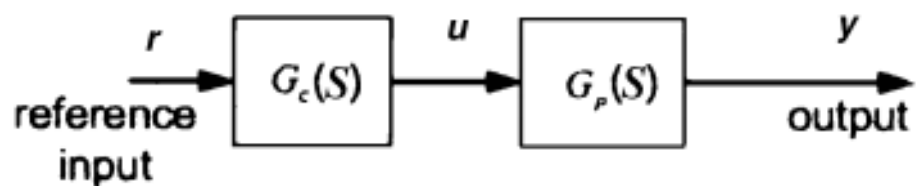


Figure 1.3 Open-Loop system

(Antsaklis and Gao n.d.)

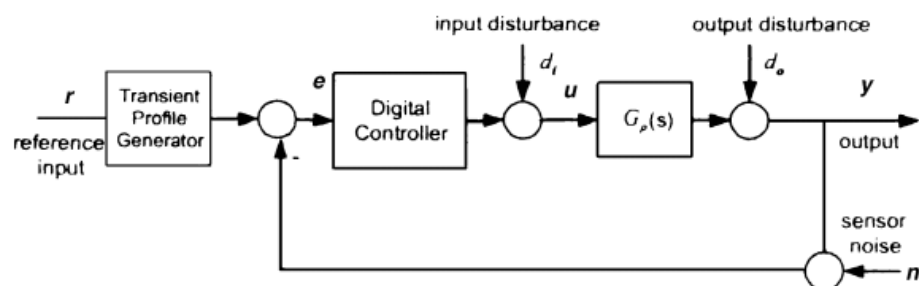


Figure 1.4 Closed-Loop system

(Antsaklis and Gao n.d.)

1.2 Problem Statement

The challenge of this project is to implement the extracted data of the BLDC motor to the quadcopter application. The single-arm propeller represents the quadcopter application in one axis rotation. Firstly, in practise, for a variety of purposes such as control and system design, we are frequently happy with a mathematical model that accurately describes the input and output dynamics, without questioning the true meaning of the model's parameters. Real-world systems are frequently too complex to represent using physical rules that regulate the operation of several small components and their interconnections.(Xie and Ljung 2002). In that condition, plant mathematical derivation system is often difficult to obtain when dealing with combine component or setup. Second, Real-world systems are frequently too complex to represent using physical rules that regulate the operation of several small components and their interconnections.(Xie and Ljung 2002). Derived mathematical model often does not provide the accuracy in real time data due to some disturbances, environmental condition and product variance. The basic concerns of system identification are whether it is possible to model the input-output dynamics of a system using only its input-output data (black box modelling) and how to do so.

1.2.1 Objective 1

Conduct an experiment and extract the experimental data as the input and output from the BLDC motor propeller setup

1.2.2 Objective 2

Analyse and evaluate the accuracy of transfer function based on the experimental data.

1.2.3 Objective 3

Implement the transfer function in single-arm propeller system.

1.3 Thesis Outline

This thesis report contains five chapters overall. The first chapter explained the introduction of this project, the problem statement, and the objectives of the object.

Chapter 2 discusses the literature review for this project. All the equipment used in this project is studied and explained in the literature review. The physical properties of equipment such as battery, motor, load cells, current sensor, and tachometer are reviewed. For software like Arduino Uno, MATLAB, system identification and Simulink are studied in more detail.

Chapter 3 covers the methodology of this project. The flow of work from the beginning to the end of this project from designing, wiring, coding, simulation and analysing done in this part.

Chapter 4 discuss the result of the experiment and simulation that been done in the methodology part. The result of the coding of Arduino Uno, transfer function in

system identification, and the response of the applied transfer function is explained in this chapter.

Chapter 5 is the last chapter that presents the conclusion of this project and works throughout this project.

1.4 Importance of Study

This final year project was carried out to give some experience and benefit in the Aerospace Engineering field. This study will be able to estimate the response of the BLDC motor without knowing the physical behavior of the motor. Black-box modelling gives some idea on how to extract and implement the function of the motor. System Identification is the most important step to estimate the transfer function for the BLDC motor. The estimated transfer function compared with experimental data to obtain the best-fit percentage. PID tuning also helps to stimulate the better response of the BLDC motor transfer function. Without knowing any physical behavior of the system, an estimated response based on the desired input can be achieved. Fast result and reliable method in estimating the response.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

Black-box modelling is mathematical modelling that uses for System Identification without knowing the physical insight. Brushless DC motor (BLDC) physical insight carry out by using black-box modelling approaches. As we know, the motor is widely used in drone application. The speed input of the motor controls the thrust of the drone. The thrust of the drone depends on the speed and voltage input in the system, generally parameter determination for brushless DC motor modelling based on the drone power performance.

2.1.1 Brushless DC Motor (BLDC)

For this project, the motor that been used is a brushless DC motor. Generally, we have two types of DC motors where is brushless DC motor and brushed DC motor. Brushless DC motors are increasingly gaining popularity over brushed DC motor. This motor requires less maintenance and has a longer lifespan due to the absence of wearable brushes. It also has flat speed-torque characteristics, increased efficiency, and improved thermal handling stators windings allow effective heat dissipation and a better dynamic reaction with lower rotor inertia. (Cham and Samad 2014). It also has a complex controller design and more expensive. The permanent magnets are on the rotor in the brushless DC motor (BLDC), and the electromagnets are on the stator. Brushless DC motor revolves 360-degrees while brushed DC motor spins 180-degrees when the electric current runs the armature. The brushless DC motor gives 90% efficiency from

the statistics, while the brushed DC motor gives 80% efficiency. The model used in this project is XA2212 brushless motor 1400kV.

2.1.2 Motor Driver

The motor driver used in this project is ESC. ESC stands for the electronic speed controller. As a result, we can see how critical this electronic control technique is for various electrical machinery. It won't perform for as long as we don't have an excellent way to control our speed. As a result, the electronic speed control method is utilized to control the rotational speed of both machine and motors such as drones, motors and any vehicles. ESC is utilized to control the speed of the BLDC motor in this project and its function as a dynamic brake. Commonly it is used on a radio-controlled model such as BLDC motor by providing a small voltage source for the BLDC motor. Different type of speed controls are required for BLDC motor since the speed of the motor can be change by altering or varying the voltage of the armature. This type of motor requires a variety of operating rules, such as adjusting the timing of pulse for current supplied to adjust the motor speed. The model that used for this project is 30A RC Brushless Motor Electronic Speed Controller 30A UBEC.

2.1.3 Current sensor

Current sensor ACS712 used to monitor digital current throughout the motor. The current sensor ACS712 operates on the hall effect concept and works on the circuit's simple complexity.(Ratnawati and Sunardi 2020). The use of the ACS712 current sensor with Arduino Uno would continuously determine the power consumption and prevent the theft of electricity. (Lubis et al. 2017). ACS712 current sensor used in the

design of prototype electrical protection repeatedly monitors the amount of current use and output data to the display such as LCD and serial monitor of Arduino Uno as read by the sensor. This sensor is capable of detecting both Direct Current (DC) and alternating current (AC). This current sensor provides a cost-effective and accurate solution for measuring AC and DC in industrial, automotive, commercial and communications applications.

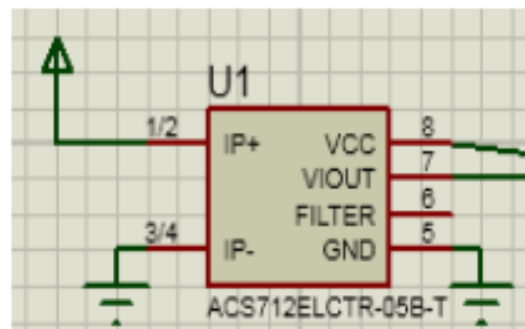


Figure 2.1 ACS712 Current Sensor Installation Circuit

(Lubis et al. 2017)

2.1.4 Load Cell

Load cells are transducers that generate an electrical signal when a force applied to the load cell. Load cells are frequently used in laboratory instruments to measure static and dynamic forces. (Lubis et al. 2017). A load cell compression is essentially a block to sustain a load at one point to measure the compression force given by the machine. A compression load cell often positioned under the object to be measure. Due to the stiffness of the standard load cell striking surface, and usually, it is alloy compared to the test material, the load cell deformation frequently is ignored when simulating the

impact collision. There are two types of load cells where is resistive load cells and capacitive load cells.

Resistive load cells operate on the piezoelectric principle. When the sensor is subject to a load, force or stress and the resistance changes. When an input voltage is a supply, a change in resistance results in a change in output voltage. Capacitive load cells operate on the principle of capacitance change, which refers to a system's capacity to store a specific amount of charge when a voltage is applied. Capacitance is related to the overlap between the plates and the dielectric between them in conventional parallel plate capacitors and inversely proportional to the spacing between the plates. The pair to the load cell is the module amplifier (HX711). Module amplifier usually uses an analogue-to-digital converter (ADC) for the load cell from analogue to digital readings. It also has high precision 24-bit that able for weighing scales and industrial control applications. Module amplifier especially for receiving signals from the load cell and send the signals to the microcontroller.



Figure 2.2 Sensor load cell

(WAHYUDI, RAHMAN, and NAWAWI 2018)



Figure 2.3 Module Amplifier HX711

(WAHYUDI et al. 2018)

2.1.5 Tachometer

A tachometer is an excellent instrument for determining the rotational motion of machines. Tachometers display revolutions per minute (RPM), which indicates how frequently a spinning component completes one complete turn. Automotive, aerospace and industrial industries all rely on RPM data [source]. Therefore, tachometers are critical for evaluating fuel consumption and motor speed correlations, the safety of moving parts, and even wind speed indications. However, while some tachometers use lasers, they depend on colour and may even be incorrect under certain lighting situations. (Hrisko 2018). A mechanical tachometer's core functioning mechanism is a moveable magnet powered by the spinning input shaft that interacts intimately with an eddy current sensor to generate the reading. (Palanisamy et al. 2021). The sensor's revolving magnet compels the indicator needle to display the proportional reading on the specified output method concerning the engine speed. At the same time, a countering spring operates against the sensor's force to bring it to a stable stopping position. Compared to a digital tachometer, the conventional got many disadvantages, including the possibility of mechanical failure and ageing parts that may cause mistakes.

2.1.6 Power Source

There are several sources of power sources, and there two common types that used in electronics. They are classified into two types which AC and DC types. DC has two subtypes where is DC voltage and DC current. The same goes for AC has AC voltage and AC current. The power source used in this project is a battery where is DC voltage. LiPo battery used in this project. LiPo or lithium-ion polymer battery was mainly available as chargeable batteries with small capacities. They use a polymer electrolyte instead of a liquid electrolyte, and it has high conductivity gel polymers from these electrolytes, which improves ion mobility. Lithium-Ion batteries offer an extremely high energy density, and it is ideal for cyclic applications. Lithium-polymer batteries offer the consumer-driven, market-driven benefits of being lightweight and having a high mechanical strength. Consumers of portable electronic applications demand fast charging, longer battery duration, and greater battery charge and energy efficiency. However, battery life may be extended via the use of numerous hardware and software solutions.(Amanor-Boadu, Guiseppi-Elie, and Sánchez-Sinencio 2018).

2.2 Microcontroller

A microcontroller is a small integrated circuit that regulates the functioning of a certain function in an embedded system. In simple, it is as a controller to a system that needed to insert the program and code into the microcontroller. The term ‘micro’ is because the controller is small and functioning the same and the controller. A typical microcontroller contains a CPU, memory, and input-output (I/O) peripherals on a single chip.(Rouse, Shea, and Lutkevich 2019). Microcontrollers are widely used in industries such as aerospace, communications, transportation and mobiles. Microcontroller interpreting the received data from I/O peripherals that accomplished by a central

processor. The microcontroller stores temporary data in its data memory, which accessed by the processor, which employs instruction stored in its programme memory to understand and apply the incoming data. Then they communicate and performs the required action via its I/O peripherals. There are two types of microcontrollers such as embedded and external memory microcontrollers. There are some core elements in the microcontroller. Most importantly is the processor (CPU). The CPU is the device's brain. It interprets and reacts to a variety of instructions that regulate how the microcontroller operates. Memory is also important for storing data received by the processor and utilised to respond based on the programmed code. It has two types which program memory and data memory. Program memory is non-volatile memory, which means it retains data indefinitely without requiring a power source. Data memory is volatile, which means that the data it stores is only retained while the device is power on. The microcontroller used in this project is Arduino Uno. Arduino Uno is one of a series that contains a microcontroller based on ATmega28. (Siahaan et al. 2018). Arduino uses C++ code with some extra functionality and features. The code will be written in Arduino IDE, where the workspace for Arduino code.



Figure 2.4 Arduino Uno
(Siahaan et al. 2018).

2.3 Software

2.3.1 System Identification

The term "System Identification" refers to the process of developing mathematical models of a dynamic system using measurable data. The primary problem in developing the optimal controllers for linear or non-linear systems is mathematical modelling. Conventional and intelligent identification recommended for resolving this issue. (Piltan, Haghghi, and Sulaiman 2017). The goal is to determine the mathematical model for a system based on the experiment.

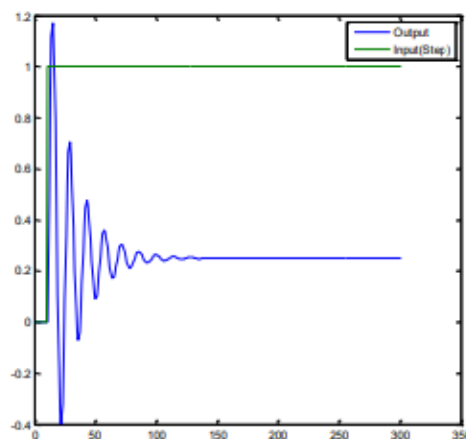


Figure 2.5 Step Function System Identification

System Identification (SI) got several steps, including the measurement of the system in time or frequency domain, selecting a candidate model structure, selecting and applying a method for estimating values of the adjustable parameters in the model structure. The validation and evaluation of the estimated model to determine whether it is appropriate for the application's needs. (Esteves, Perdicoulis, and Dos Santos 2015). Several functions can be simulated from system identification, such as transfer function, state-space model, polynomials and non-linear system.

2.3.2 Simulink

Simulink is a graphical interface for modelling and simulating dynamic systems. Designed block diagrams in which the blocks represent the individual components of a system. A block used to represent a physical component, a small system, or a function. A block is complete defined by its input/output relationship. Simulink block diagrams used to solve models that contain a collection of ordinary differential equations. The function that gains from system identification is usually needed for simulation in the block diagram.

Additionally, Simulink also provides a solution for mathematical models and eases the system variables' visualization. The main advantages of Simulink are the ability to model a non-linear system where a transfer function is unable to do. Simulink also can take on the beginning conditions. When constructing a transfer function, initial conditions assumed to be zero.

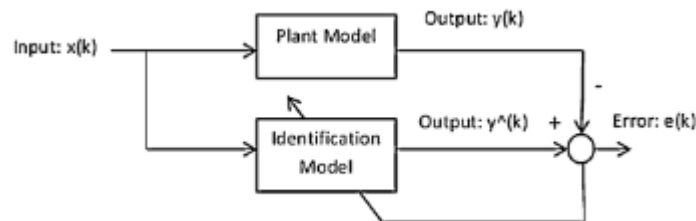


Figure 2.6 General system identification block diagram

(Tutunji 2016)

2.4 PID Controller

A proportional-integral-derivative (PID) controller is a frequently used feedback loop component in control systems. The controller compares a measured value from a process or other apparatus to a setpoint value as a reference. The discrepancy (or "error" signal) is then utilized to change a process input to restore the process is measured value to its desired set point. There are three gain blocks in PID controller, which is K_p , K_i and K_d . Proportional gain K_p act as a large proportional control can improve response time and decrease steady-state error, it can cause the system to oscillate. (Gu, Zhang, and Gao 2009). Derivative gain of K_d reduces the rate of change of the controller output, which is most visible around the set point of the controller. Thus, derivative control is utilized to mitigate the size of the integral component's overshoot and to improve the combined controller-process stability. (Gu et al. 2009). Integral control gain K_i is favourable for diminishing the steady state error but it will lengthen the transient response. (Gu et al. 2009).

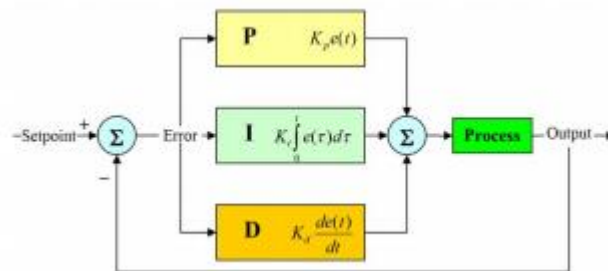
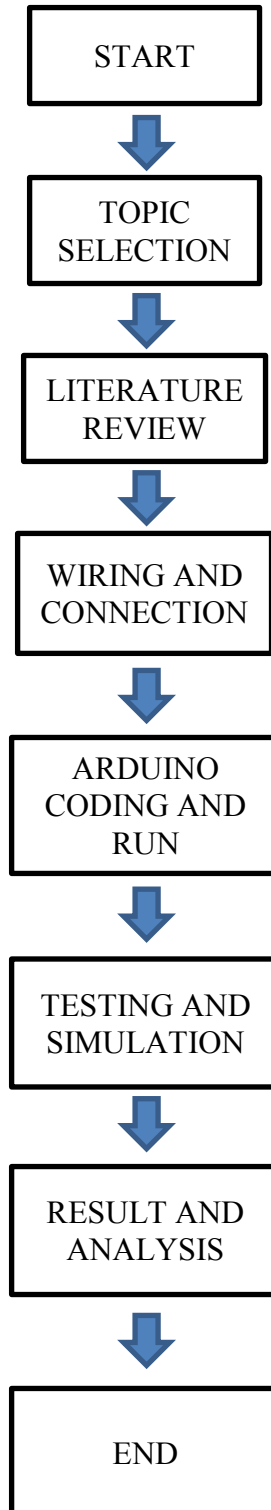


Figure 2.7 Gain Block Diagram of PID Controller

(Mohammadbagheri and Yaghoobi 2011)

CHAPTER 3
METHODOLOGY

3.1 Flow chart of work








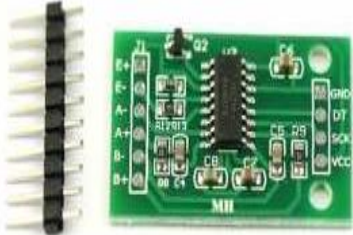
Based on the flowchart above, the first tasking is about topic selection. The supervisor gives the topic. The topic given is black-box modelling for brushless DC motor and control strategy for quadcopter applications. After the topic given, research and literature review need to be done to understand and familiarise the hardware and software used for this project. The theory about control system is for the closed-loop system is important to illustrate some ideas to further research in this project. The next step is wiring and connection of the hardware. All the hardware such as a microcontroller, load cell, BLDC motor, ESC, current sensor and battery need to connect to run the experiment. Before running the experiment, the coding C++ for Arduino Uno needs to be programme to give commands to the BLDC motor. After getting the result for the experiment about the BLDC motor, the data will be transfer to MATLAB with four sets of data. All four sets of data are inserted in system identification (SI) in MATLAB. The data is processed, and the result of a function obtained and will be used in Simulink. The Simulink used to simulate with graphical with method block diagram. After that, the response from the simulation of the block diagram and analyse of the result.

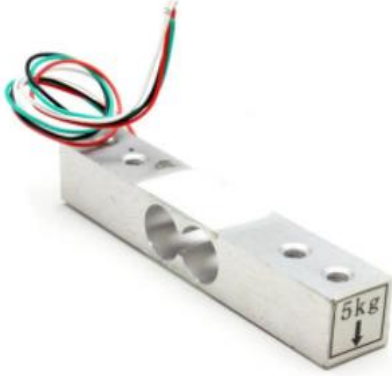

3.2 Hardware Setup

Before every hardware is connected and tested as a whole platform, each hardware test separately, especially for ESC and BLDC propeller motor. Both need to calibrate, and their wiring connection are examined to ensure that both motors rotate in the same direction. There are several hardware implements in this project to obtain the result from the experiment.

Table 3.1 Hardware Specification

Hardware	Specification and Properties	Values
<p>Microcontroller (Microchip ATmega328P)</p> 	Model	Arduino Uno R3
	Input Voltage	7 to 20 Volts
	Operating Voltage	5 volts
	Flash Memory SRAM EEPROM	32 KB 2 KB 1 KB
	Clock Speed	16 MHz
	Weight	25 g
	Digital I/O Pins	14 (6 provide PWM output)
	<p>Electronic Speed Controller (ESC)</p> 	Model
Power		5v and 30A
Battery		LiPO = 2 cells NiCd = 5-12 cells
Programmable		Programming Card
Advantages		Overheat protection Battery protection
<p>Current sensor</p> 	Model	ACS712ELCTR-30A-T
	Measuring	AC and DC
	Sensor type	Hall effect
	Sensitivity	66 mV/A
	Supply Voltage	5V
	Supply Current	13mA
	Accuracy	1.5%

Hardware	Specification and Properties	Values
Brushless DC Motor (Microchip ATmega328P) 	Model	Emax XA2212 1400kV
	Input Voltage	8 to 12 Volts
	Current	11.9-20.6 volts
	Thrust	520-940 g
	Poles	14
	Weight	47 g
	Shaft size	3.17 mm
RPM sensor (Tachometer) 	Model	A3144 Hall Effect Sensor
	Operating Voltage	4.5V to 28V
	Output Current	25mA
	Operating Temperature	-40 °C to 80 °C
	Detection	Both poles of magnet
	Digital Output	Hall-effect Sensor
Load Cell Amplifier 	Model	HX711
	Operating Voltage	2.7V-5V
	Operating Current	< 1.5mA
	Sample Rate	10 Hz

Hardware	Specification and Properties	Values
Load Cell (Microchip ATmega328P) 	Model	YZA-133
	Voltage	8 to 12 Volts
	Load	5 kg
	Thrust	520-940 g
	Insulation resistance	2000 MΩ
	Weight	28 g
	Output Impedance	1000 ± 10% Ω
Power Source (DC LiPo Battery) 	Model	Nano
	Operating Voltage	11.1V
	Capacity	5200mAH
	Discharge Rate	30C
	Dimension	145mm x 45mm x 28mm
	Fully-charge Voltage	12.6VD

3.3 Hardware connection and circuit

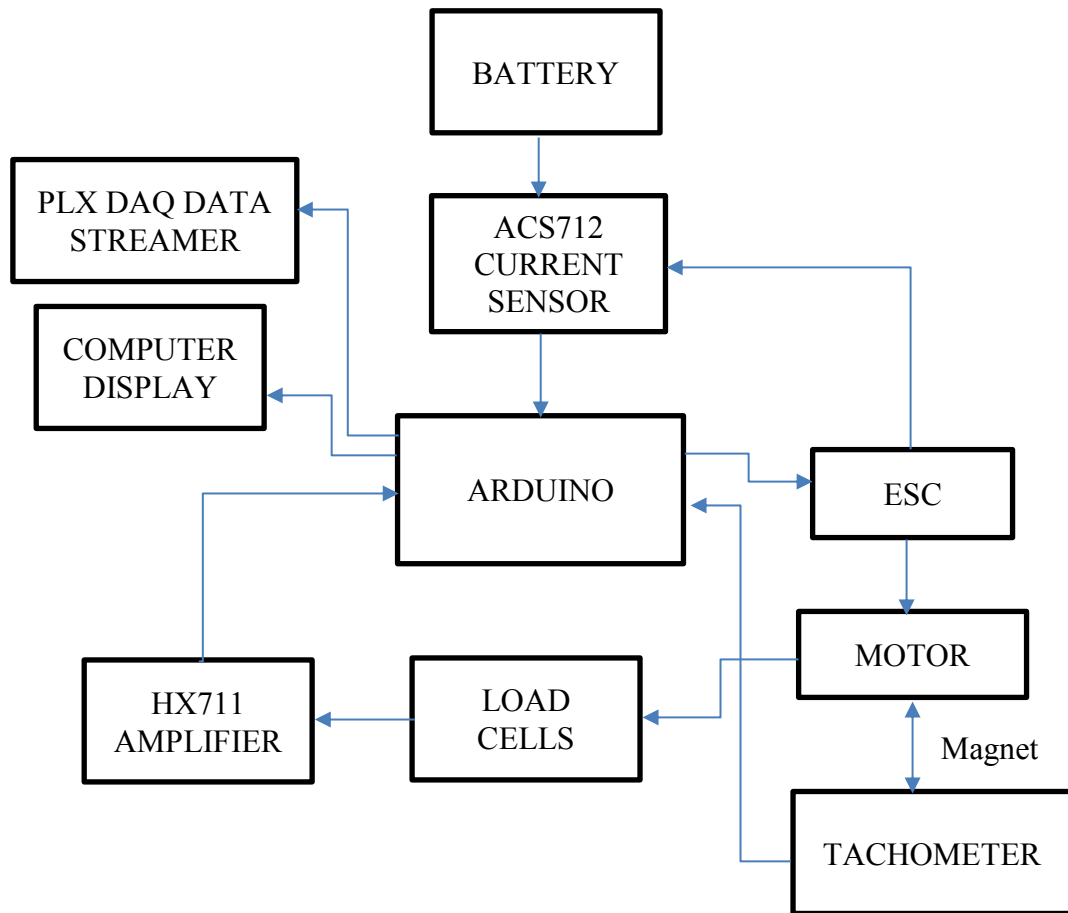


Figure 3.1 Hardware connection

The flow chart above is about the connection between the hardware of this project. All components connected by wire and should follow the poles positivity and negativity of the component. From the DC battery as the power source of this experiment, the power transferred to the ACS712 current sensor. The ACS712 current sensor will read the current-voltage current and voltage. The current and voltage data is sent to Arduino Uno and display on the PLX DAQ and computer display. ACS712 current sensor has pin VCC, output and ground. VCC pin connect to pin 5V pin, output pin connect with A0 pin at Arduino and ground current sensor connect with the ground pin of Arduino. Arduino will send a command to ACS712 in order to sense the current