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DESIGNING AND MODELLING OF SINGLE MOTOR MULTICOPTER CONTROL SYSTEM

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Gaziantep University

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Onur ACAR

”Everybody knows a certain thing is unrealizable until somebody unaware of this comes and invents it.”

A. Einstein

ABSTRACT

DESIGNING AND MODELLING OF SINGLE MOTOR MULTICOPTER CONTROL SYSTEM

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Multi-copter technology, which today dominates an area almost large enough to surround us and has popularity, has been developed and modified by following each other technologically from past to present. Compared to other aircraft suspended in the air, it has been very preferred due to its mechanical simplicity and multi-functional flight configuration. However, this simplicity restricts maneuverability and efficiency. For this reason, in this thesis, Heli-Quad, a single-engine and variable pitch quadcopter, which is a new design with high maneuverability and advanced electronic technology simplicity, has been developed. Unlike conventional quadcopters, a single motor connected to the quadcopter frame and torque tube gear mechanism is used to rotate the propellers. Propellers are moved in a negative and positive position thanks to the collective mechanism connected to the torque tube. In this study, contrary to similar studies using a belt drive system, the shaft drive system was used and the electronic design and modeling of the control system of Heli-Quad, which is generally a single-engine quadcopter were studied as the main motivation. By taking advantage of scanned literature and books, was studied and researched from the basis of the PID control system to the main operating principles of flight controllers. A small-scale controls experiment was carried out with the basic logic of PID control. In this study, were used PIXHAWK flight controller and MISSION Planner interface system. The electronic temple was configurated and the system is programmed through the mission planner interface.

Key Words: Heli-Quad, PIXHAWK, MISSION Planner, PID, Collective Mechanism

ÖZET

TEK MOTORLU MULTİCOPTER KONTROL SİSTEMİNİN TASARIMI VE MODELLENMESİ

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Günümüzde neredeyse etrafımızı saracak kadar geniş bir alana hükmeden ve popüler olan multi-copter teknolojisi geçmişten günümüze teknolojik olarak birbirini takip ederek geliştirilmiş ve modifikasyona uğramıştır. Havada asılı kalan diğer hava araçlarıyla karşılaştırıldığında, mekanik sadeliği ve çok fonksiyonlu uçuş konfigürasyonundan dolayı tercih edilir. Ancak bu basitlik manevra kabiliyetine ve verimliliğe sınırlama getirmiştir. Bu nedenle, bu tezde, yüksek manevra kabiliyeti ve gelişmiş elektronik teknoloji sadeliği ile yeni bir tasarım olan tek motorlu ve değişken hatve açılı quadcopter Heli-Quad geliştirilmiştir. Geleneksel quadcopterlerin aksine, pervaneyi döndürmek için quadcopter çerçevesi ve tork tüp dişli mekanizmasına bağlı tek motor kullanılır. Tork tüpüne bağlı kollektif mekanizma sayesinde pervaneler, negatif ve pozitif yönde hareket ettirilir. Bu çalışmada, kayış tahrik sistemi kullanan benzer çalışmaların aksine, şaft tahrik sistemi kullanılmış ve genel olarak tek motorlu bir quadcopter olan Heli-Quad kontrol sisteminin elektronik tasarımı ve modellenmesi ana motivasyon olarak incelenmiştir. Taranan literatür ve kitaplardan yararlanarak, PID kontrol sisteminin temelinden, uçuş kontrolörlerinin temel çalışma prensiplerine kadar incelenmiş ve araştırılmıştır. PID kontrolünün temel mantığı ile küçük ölçekli bir kontroller deneyi yapılmıştır. Bu çalışmada PIXHAWK uçuş kontrolörü ve MISSION Planner arayüz sistemi kullanılmıştır. Elektronik şema konfirige edilmiş ve sistem görev planlayıcı arayüzü aracılığıyla programlanmıştır.

Anahtar Kelimeler: Heli-Quad, PIXHAWK, MISSION Planner, PID, Kollektif Mekanizma

''Dedicated to my precious family''

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LIST OF ABBREVIATIONS

EMF	Electromotive Force.
FPV	First-person view
CCW	Counterclockwise
CW	Clockwise
KV	KV refers to R.P.M./Volt.
GCS	Ground Control Station
RPM	Revolution per minute
UAV	Unmanned aerial vehicle
SDRE	State-Dependent Riccati Equation
ESC	Electronic speed controller
RX	Receiver
TX	Transmitter
LCD	Liquid-crystal display
GND	Ground
GPS	Global Position System
BLDC	Brushless DC electric motor

LIST OF SYMBOL

Pout	: The proportional portion of controller output
Kp	: Proportional gain
e	: Error signal
Ti	: Integral time, or reset time
Ki	: Integral gain
W_m	: The mechanical speed of the rotor
R	: Phase resistance
L	: Each phase inductance
i_a, i_b, i_c	: The phase current
V_a, V_b, V_c	: The phase voltage
e_a, e_b, e_c	: The back emf voltage
J	: The moment of inertia of the drive
P	: The number of poles
B	: The damping constant
F	: Force of lift
M	: Momentum inertia
(φ)	: Roll
(θ)	: Pitch
(ψ)	: Yaw
ω	: Angular velocity
V	: Air Speed
ρ	: The density of the air

CHAPTER 1

INTRODUCTION

1.1. Description of Unmanned Aerial Vehicle (UAV)

The main motivation of this study is to encompass types of drones coming from the past to nowadays as well as traditional helicopter, variable pitch single motor quadcopter technology, history and experiment about PID control, and ordinary drone development. The drone is derived from a word in English that means male bee. But today, it is used in the sense of UAV (Unmanned Aerial Vehicles). Unmanned aerial vehicles are a type of aircraft carrying purpose-controlled equipment (video camera, laser scanning device, etc.) with GCS (ground control station) that can be remotely controlled and/or autonomously guided without a pilot or passenger [1].

Figure 1.1 DJI model drone (UAV) [3]

The use of drones can be assorted in general three different fields or more. Generally, these are military, civilian, and hobbyists that are available for use as shown in Figure 1.2 and Figure 1.1. Its scientific and technological development has become a rapidly growing field of popularity. As the main reasons why it is becoming increasingly popular, high speed, reliable information, cost reduction, time profit, and more can be expressed. In particular, civilian UAVs have a wide range of applications and provide high accuracy, time, and cost savings in many occupational (eg mapping) applications [2].

Figure 1.2 Unmanned Aerial Vehicle (UAV) [5]

Great advances have been achieved in order to stay in the air for a long time, especially in the drones that make observations in the military field.

1.2.History of the Drones

The history of unmanned aerial vehicles dates back to 1849. Unmanned balloons, considered the first drone, were used by the Austrians in the bombing of Venice. For the first time in 1915, the British managed to take more than 1,500 photographs of German trenches by shooting from the air during World War I. The United States began working on unmanned aerial technology during World War I, and in 1916 created the first unmanned aerial vehicle. In 1930, the American Navy began experimenting with radio-controlled drones. In 1937 the drone called Curtiss N2C-2 appeared [4].

In 1982, the Israelı army used drones to destroy Syrian aircraft with minimal casualties. In 1986, Israel and the United States signed a joint project to create a new drone. This drone, a medium-sized reconnaissance aircraft, was known as the RQ2 Pioneer.

In the 1990s, the size of drones was reduced and made more miniature. In 2000, Predator, a miniature drone in the United States, used its unmanned aerial vehicle in search and rescue duties[4].

In 2014, Amazon offered to use drones for the first time to shoot promotional videos. Since then Drone’s has been used in many sectors, especially for making promotional videos, and its commercial use is growing day by day worldwide [4].

1.2.1. Drone’s Current Developments

Nowadays, UAVs that are used in many fields are continuously developing in terms of technology and usage. It is used in many fields such as mapping, military, film and photography, agricultural spraying, and so on. As an example of one of these areas, with the development of autonomous systems, it has become quite easy to observe on a specified route.

Figure 1.3 DJI Model Unmanned Aerial Vehicle (UAV) [3]

Also, programming, re-modifying, and developing is more possible and easier than in the past. Today's unmanned aerial vehicles (UAVs) duration of staying in the air depends on the size and power of the battery or fuel tank that they can carry. Together with the advancing technology, their useful load capacities and staying airborne times have been increased. The pilot's workload decreased as well as the margin of error was reduced to a minimum. Thus, the place and importance of unmanned aerial vehicles in our lives has increased and is increasing day by day.

1.3. Conclusion

UAVs are used in many fields including daily life. Developing technology in the UAV field offered this opportunity. As with any technology, there are disadvantages besides its advantages of UAV. Each UAV has its airspace, regardless of size and weight. This is a threat to certain regions. These regions are public indoor areas, airport aprons, etc.

Besides, when it comes to its advantages, it enables us to obtain more accurate and faster information. The importance of UAVs is increasing day by day. It has become one of the most important criteria showing the technological and military development of a country [6,2].

There are many variations of drones used in many areas. They differ in maneuverability, flight times, and performance. Besides, their systems are structurally different. In this study, unlike conventional four-rotor quadcopter, a drone called single-engine Heli-Quad is studied.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, a summary of the literature review which is related to a quadcopter that independently controlled with collective pitch mechanisms with four rotors is given. As it is known, traditional helicopters have structurally very complex designs rather than commercial aircraft. But in this system, it is included built one quadcopter with the addition of the four tail rotor mechanism. Also, this Heli-quad system studies involve work like structure, control, aerodynamic, mechanism, and analysis of the systems.

2.1.1 Studies on Heli-Quads

Generally, quadcopters are used to fulfill duties such as search and rescue, to make the video, taking photographs, etc in many different fields. In this regard, varieties of quadcopters have been studied from the control system to the fuselage structure and rotor structure by the researchers. Furthermore, there are many studies about the aerodynamics, flight controller system, and electronic hardware configuration. These studies have been reviewed as follows.

2.2 Materials and Methods

2.2.1 Flight Control of the Quadcopter

Multi-copter can be described as UAV in which lift and thrust are provided by single or four engine-driven rotors. Flight controllers of the quadcopters have been investigated by many scientists and researchers for many years. Quadcopter systems was a matter of curiosity for years. In this respect, it has been studied about how to work the flight controllers and connect to the quadcopter system. The flight controller is one of the basic required components for quadcopter systems and it provides autopilot support. It ensures the aircraft's balance by processing commands coming from a transmitter and sends commands to the engines.

Tomáš Jiřinec et al [7] tried to find a suitable mathematical model for such a device and develop a complete control architecture that will allow the quadrotor to fly autonomously. The quadcopter was produced as four rotors with fixed pitch blades and investigated mathematical model and the flight controller infrastructure was configurated according to this mathematical model by Tomáš Jiřinec.

Besides, ACAR et al [8] have made it much easier to select flight controllers between closed source and open source flight controllers and he has made comparison tables between open source flight controllers in its publication. In ACAR's publication, all features from the processor speeds of artificial intelligence product controllers, which are very popular today, to serial communication interfaces such as S-BUS, TELEMETRY, SPI, are evaluated and it is mentioned that PIXHAWK is today's best flight controller.

There are a lot of different studies as given in these scopes. Flight controllers which are comprised of composite structural integrated with an electronic circuit board are the main element for a quadcopter project. In a study, performed by Kemao et al, autonomous flight control law was investigated in terms of the design and implementation for the small-scale unmanned aerial vehicle (UAV) helicopter [9]. A fully autonomous flight control law has been implemented by Kemao et al, with a decentralized scheme incorporating the newly developed composite nonlinear control technique and tried the dynamic inversion approach. The design performed by Kemao et al implemented a non-linear control technique and also been successfully verified in the actual flight tests.

Similarly, in March 2009, in a research article, Song Yanguo and Wang Huanjin carried out a study about 'Design of Flight Control System for a Small Unmanned Tilt Rotor Aircraft' [10]. This article presents the progress of the research work on the design of the flight control system at Nanjing University of Aeronautics and Astronautics (NUAA). In this study, to obtain the flight control law of the tilt rotor, a proper mathematical model that is already verified by a wind tunnel was used.

By using the flight control law obtained from the mathematical model, the flight tests were performed. Now, the flight tests are still underway on a prototype of small unmanned tilt-rotor aircraft.

2.2.2 Aerodynamics

Like all aircraft, the flying principles of helicopters are based on aerodynamic laws. These rules include gravity, lift, drag, and thrust. The helicopters have a different flying configuration and design than the planes. Its rotor and propellers rotate in the same central mechanism to produce lift force. For the propeller, aerodynamic laws depend on two different theories. These theories are momentum theory and blade element theory.

Momentum theories are based on the application of the conservation laws of fluid mechanics, energy, and momentum while blade element theory uses the standard process of aerofoil theory to the rotating blades. The researchers have been studying momentum theory and blade element theory for many years. If the researchers want to perform on the optimization process or analysis for the aircraft propellers, they use the basics of fluid dynamics.

MARIO HEENE, who comes from Stockholm, Sweden, conducted a study about the Aerodynamic Propeller Model for Load Analysis which is his thesis [11]. In his study, on an aerodynamic propeller model, which can contribute to the prediction of structural loads exposed by aircraft in different flight maneuvers are implemented in order to obtain good results. Furthermore, this thesis is used in the blade element theory. Eventually, an aerodynamic model using implementation and model analysis methods have been presented. Validation of the steady-state model showed harmony with experimental data for parallel and non-parallel inflow-conditions. The question of whether the accuracy of the model is sufficient for structural load analysis also could be studied as a topic for future work. A similar static load analysis test was done by Burak et al and published in October 2019 as a paper [12]. After the tail rotor parts of traditional helicopters are designed in a tail rotor SolidWorks program of Heli-Quad, which will be studied on this thesis, a virtual wind tunnel was created by compiling the mesh structure in the ANSYS engineering simulation and 3D design software, and the analysis technique was applied the blade element, momentum theories, and mathematical expressions were also mentioned.

Finally, in the aerodynamic section, researched by Tao Pang, Kemao Peng, Feng Lin and Ben M. Chen, design and implementation of a variable-pitch gasoline-engine quadrotor project [13] have performed on 9 Aug 2017.

In this study, they made both constructions of the quadcopter and flight controller programming. Their methodology is comprised of three steps. Firstly, rotor and engine sizes are determined using experimentally-validated results from aerodynamics. The second step is to design and build a reliable drivetrain and airframe. The third is that the gasoline prototype has also been designed, built, and flown with manual control. In this thesis, some reference information about the Pixhawk applying on the quadcopter will be discussed and resulted. Performed projects by researchers in the past contribute to new project works [13].

2.2.3 Configuration Electronic Hardware of the Quadcopter

Quadcopter, a four-rotor is a drone type with four arms, each being connected to an engine. Each engine is equipped with an ESC (electronic speed controller) and four ESCs with one flight control. Many unmanned aerial vehicles, such as the Quadcopter, have Li-Ion and Li-Po batteries. There are a transmitter and receiver to send and receive commands in the quadcopters. The diameter of the propeller depends on the size of the frame. Motor and propeller are selected according to frame size and quadcopter weight. ESC is selected by comparing the min and max power consumed by the motors. The receiver, the number of channels depends on the user's request. Flight controllers are selected according to speed, stabilization, and serial peripheral units.

Quadcopter electronic hardware and the flight controller system are similar to other drone systems. Hexacopter, three copters, octocopter, etc drones types have the same configuration hardware. There are many studies about the flight controller and quadcopter hardware system. Flight controller configuration and interface and design of the drones are still improved by many researchers and companies.

Nathan M had carried out a study about "Flight Control and Hardware Design of Multi-Rotor Systems" in August 2016. In his thesis, the main purpose was to develop both the hardware and software for a quadcopter system [14]. The thesis also presents researchers with comprehensive hardware and software specifications for a quadcopter system. In his thesis, he demonstrated a control system to achieve stable auto-leveling flight using a series of PID controllers. Finally, the conclusion demonstrated flight results and performance of the overall system.

In August 2011, in a study carried out by M. Cutler, N. Kemal Ure, B. Michini, and J. P. How. have mentioned the subject about 'Comparison of fixed and variable pitch actuators for agile quadrotors'[15]. Even though the study performed is a four-engine quadcopter or traditional quadcopter, in every rotor, the variable-pitch mechanism, and corresponding propellers were used. In this study, the UberPilot control board as a flight controller is used and the UberPilot power distribution board also is used as a power distribution unit. Furthermore, many changes have been made to hardware and software. A detailed analysis of the potential benefits of variable-pitch propellers over fixed-pitch propellers for a quadrotor is presented in every meaning [29].

2.3 Results and Discussion

There are a lot of research topics about Quadcopter so far. The quadcopter, which has played a big role in the commercial field, especially in military technologies and also has a big place in the toy industry is widely used in today's technology. With the developing technology, control systems and aerodynamic structures have been developed and renewed. Various variations of quadcopter or unmanned aerial vehicles have emerged. As presented in this thesis research, benefits, advantages, building process, and programming process, of single rotor variable pitch quadcopter or on the other hand called Heli-Quad have been handled.

The main objectives of the thesis;

1. Unlike traditional quadcopters, simplifying the construction process of the variable pitch quadcopter.
2. To provide a simple understanding of the PID control systems underlying drone technology.
3. To comprehend the advantages, the building process of the shaft drive mechanism selected from Chain, Belt, and Shaft drive mechanisms.
4. To simplify the set-up and programming, which is one of the most difficult parts of this work, with pictures.
5. Finally, to master the subject with small-scale experiments.

CHAPTER 3

INTRODUCTION TO PID CONTROLLER

3.1 History and Background of PID Control

The first theoretical analysis of a PID controller dates back to 1922 when the Russian American engineer Nicolas Minorsky developed an automatic ship steering system that is base on the observations of the steersmen's use of current error, past error and rate of change. These are developed for the U.S. Navy in order to keep the ship on a course. Controllers with electrical systems were developed after World War II. PID control was used to control and maintain processes. It can be used to control physical variables such as temperature, pressure, flow rate, and tank level. The technique is widely used in today's manufacturing industry to achieve accurate process control under different process conditions. PID is simply an equation that the controller uses to evaluate the controlled variables [19].

Control means that the output of a system shows a time behaviour fitting following predetermined criteria. In this respect, as shown in figure 3.1, the most basic controller is the operator standing at the beginning of the system. So the operator observes the system, makes predictions before based on their perceptions, and changes the system input accordingly. This is the most basic control way.

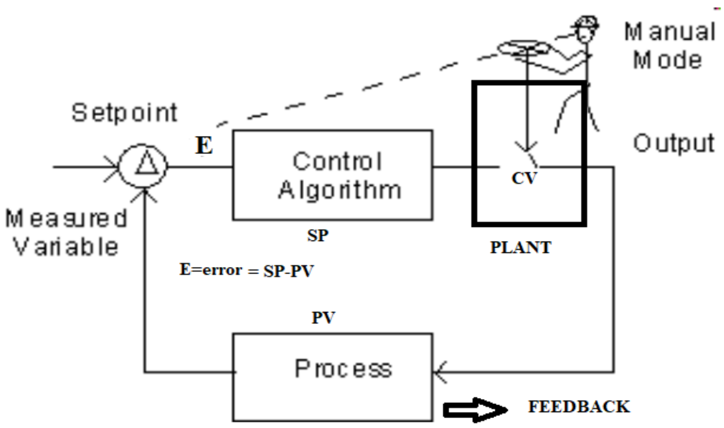


Figure 3.1 The most basic control system.

A process variable (PV) temperature, for example, is measured, and a feedback signal is sent to the controller. The controller then compares the feedback signal to the setpoint (SP) and generates an error value. The value is examined with one or more of the three proportional, integral, and derivative methodologies. As a result, the controller issues the necessary commands or alters the control variable (CV) to correct the error (E).

These procedures form an iterative process. Below is a common control loop application. With advancing technologies, manual control systems have been replaced by automatic control systems. This system means that the automatic control system. The system controlled by a system is called the controller.

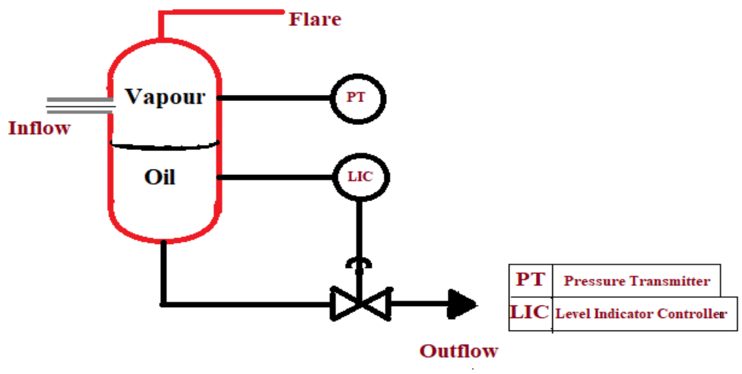


Figure 3.2 A typical control loop application.

The event wanted to be described as in 3.2 is to keep the amount of oil stored in an oil tank at the level desired by an operator. The oil enters the tank non-constant rate from the inflow. The oil level in the tank is our variant and this information is the feedback for the control. An operator enters a set point for the desired level. The controllers compare the current level with the newly entered level and generate a new value. It then sends commands to the valve and keeps the valve open until it reaches a new level. This loop continuously goes on as long as power is active on the circuit [19].

3.1.1 Theory of PID Control

The first thing that comes to our mind when it comes to controls is to stay constant in the desired value variables which can be electrical, mechanical, or in different ways. The work behind this process is to first calculate the difference that is named as an error function, which is the difference between the desired set point and the measured process variable. The controls will then try to continually bring this error function closer to zero. This ensures that the control variable in the process at the input of the controls is brought to the desired position by increasing or decreasing it via feedback. This method is very useful in mathematically unknown or complex systems. In order to increase the performance of the system when responding, PID parameters need to be adjusted privately to the application [19].

3.1.2 Proportional Control

The proportional element of PID examines the magnitude of the error, and the PID control reacts proportionally [16].

In mathematical terms, the proportional term (Pout) is expressed as (3.1):

$$Pout = Kp \times e \tag{3.1}$$

From here, it is defined as Kp proportional gain, e error signal, and Pout proportional portion of the controller output.

$$e = SP - PV \tag{3.2}$$

In here represents a reverse acting loop.

When e = SP – PV, it refers to a direct-acting loop. In a direct-acting loop, the process variable is greater than the setpoint; therefore, the appropriate controller action is to increase the output [16].

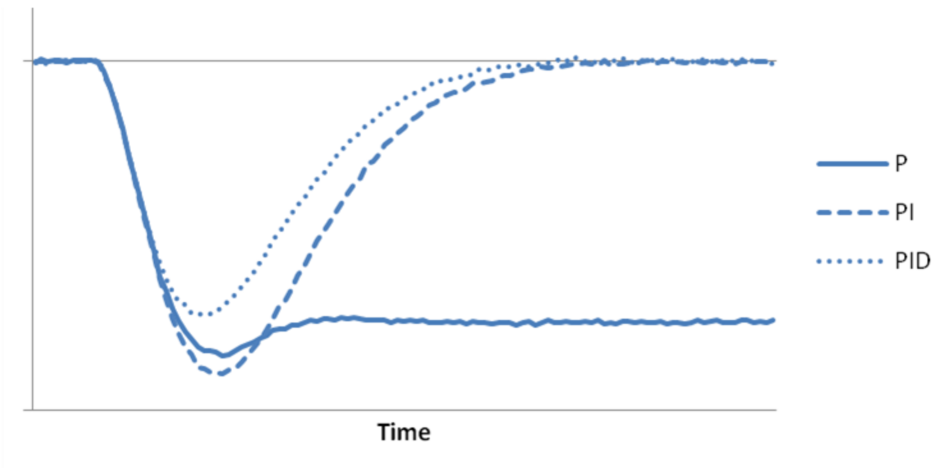


Figure 3.3 Steady-state error in P, PI, and PID control [16]

Integral control attempts to correct a small error over time (offset) to minimize the first issue with proportional control. Since the changes between the values will warn each other, the PI will not allow exiting the control diagram as shown in Figure 3.3. The mathematical expression of an integral-only controller (Iout) is:

$$I_{out}=\frac{1}{T_i}\int edt=K_i\int edt \tag{3.3}$$

From here, it is defined as Ki integral gain, Ti integral time, or reset time and I-out integral portion of the controller output.

3.1.3 Derivative Control

The derivative part of the control output attempts to look at the rate of change in the error signal. The derivative will cause a greater system response to a rapid rate of change than to a small rate of change [16].

In mathematical terms, the derivative term (Dout) is expressed as:

$$D_{out}=T_d\frac{d}{dt}e = K_d\frac{d}{dt}\ e \tag{3.4}$$

From here, it is defined as Kd derivative gain, Td derivative time, and Dout derivative portion of the controller output.

When it comes to summarizing your task in all three controllers, proportional control induces an input signal to change as a direct ratio of the error signal variation. It responds immediately to the current tracking error, but it cannot achieve the desired set point accuracy without an unacceptably large gain.

Thus, the proportional term usually needs other terms. Integral control induces the output signal to change as a function of the integral of the error signal over a time duration. Derivative action reduces transient errors and causes an output signal to change as a function of the rate of change of the error signal. The contributions of the three terms will yield the control output or the control variable.

$$\text{Control Variable} = \text{Pout} + \text{Iout} + \text{Dout} \tag{3.5}$$

In practice, most PID controllers can be run in two modes. These are manual and automatic:

In manual mode: The controller output is regulated directly by the operator, typically by pushing buttons that increase or decrease the controller output. This system is open-loop. Open-loop control systems are the type of control when the system is controlled that doesn't require any measurement of the controlled variable, and without any feedback to the input section [16].

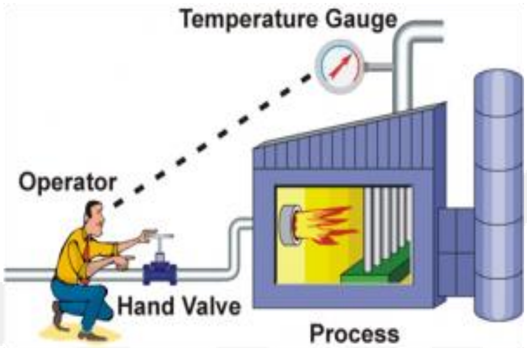


Figure 3.4 The operator is performed as a manual [16]

In automatic mode: The PID parameters are the mode that constantly tries to reduce error function to 0. This system is closed-loop. Closed-loop control systems are the system where some part of the system output is fed back to the inputs with a sensor or measuring mechanism for editing. In order to reach the desired performance values, they are compared with the standard values, and corrections are made on them [16].

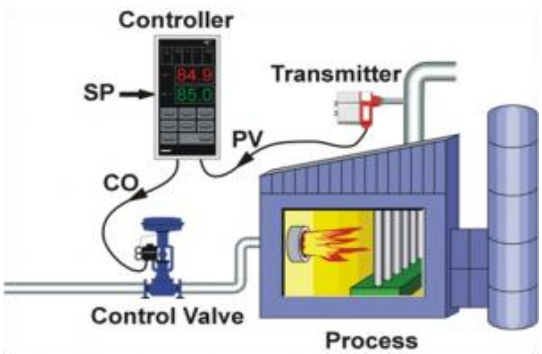


Figure 3.5 A PID controller is performed as automatic [16]

3.2 State-Space and Transfer Function Model in Controller Design

State-space and Transfer functions are mathematical models that are expressed the input, output, and state variables with differential equations or other equations that define the mathematical equations of physical systems. A state-space model is a modern approach for physical systems. Another approach model is the Transfer function that is named the frequency domain approach.

The state-space and the Transfer-function approach model can be used for controller design. Besides, the multi-copter controller design can be expressed with the state-space model. The state-space mathematical model is generally expressed as follows [37,24].

General representation of the state-space model shown in equation (3.6) and (3.7):

$$\dot{x} = Ax + Bu \quad \text{\} state equation} \tag{3.6}$$

$$y = Cx + Du \quad \text{\} output equation} \tag{3.7}$$

In this equation, x state vector, y output vector, A state matrix, B Input matrix, C, output matrix, D feedforward matrix.

The transfer function is called differential equations in which the output of a system is associated with its input. It can also be accepted the ratio of the output's Laplace transform to the input's Laplace transform. Both the Transfer Function and State-space model approach are used for an explanation of the physical systems. But what distinguishes these systems is their linear and non-linear states.

While the state-space model can be used in non-linear and linear applications, the transfer function can only be used in linear applications. In the figure, there is a block diagram of a PID controller created with the state-space model. Consider a system modeled by the second-order differential equation for the transfer function shown in Equation (3.8) [25].

$$a\frac{d^2y}{dt^2} + b\frac{dy}{dt} + cy = f(t) \tag{3.8}$$

Now, taking the Laplace transform of the differential equation, gives in (3.9):

$$(as2 + bs + c)Y(s) = F(s) \tag{3.9}$$

In this case, result is shown in equation (3.10):

$$H(s) = \frac{Y(s)}{F(s)} = \frac{1}{as^2+bs+c} \tag{3.10}$$

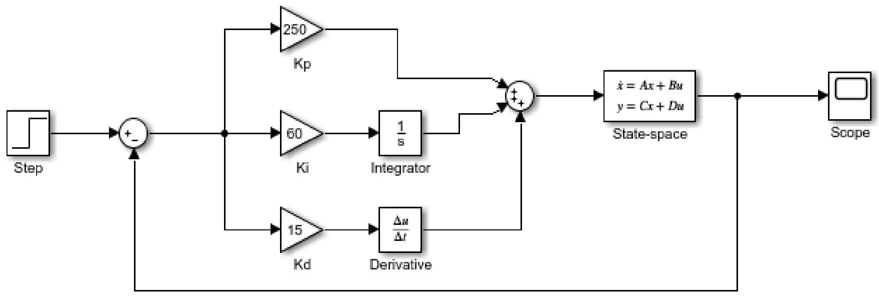


Figure 3.6 Simple pitch PID controller block design

Multicopter and unmanned aerial vehicles generally have a common control trajectory. Therefore, since physical movements are the same, they can use common trajectories and controls. In this study, a PID control block diagram in Figure 3.6 is created for a pitch angle. There are two graphics in Figure 3.7. These graphs are given the adjusted version of the PID parameters on the left side and the unadjusted version on the right side. As shown in Figure 3.6, control parameters can be viewed here.

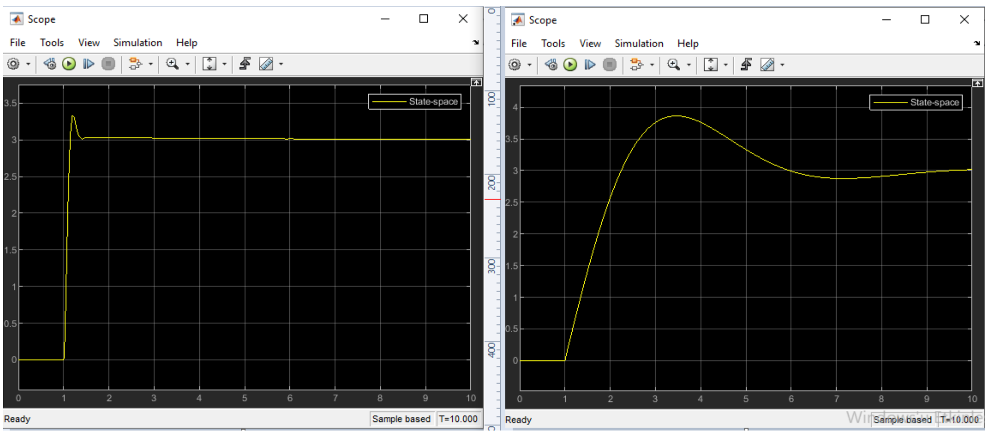


Figure 3.7 Pitch angle linear plotting graph

In the trajectory of the quadcopter's pitch axis data information is taken from the MPU6050 sensor and this sensor produces between 0 and 3-volt energy, so when this data is taken from the sensor, data will move like 0 and 1 in a binary system. This system represents the function of the pitch but it is used as the voltage in the graph [23].

Another non-linear feedback controller is SDRE, providing feedback by minimizing complicated and messy problems. It is to give the linear ordinary differential equation with a new variable form by converting an ordinary nonlinear differential equation with the given variable coefficients of form. This is the SDRE approach [18].

3.3 Implementation of PID Control

A PID controller is thought basically that consisted of proportional, integral, and derivation integrity. These inertias are fluctuating in a specific value to provide stabilization. Aim of this study, the PID control system is to evaluate an example. This example is composed of some electronic components.

Figure 3.8 Components for the PID example

In this experiment, Arduino UNO, breadboard kit, MPU6050 accelerometer sensor, servo motor, LCD screen components, and wires will be used as in Figure 3.8. The purpose, as shown in Figure 3.9, is seen in how the servo reacts when turned outside and inside the axis in this schematic.

The PID control system allows you to move the servo between the values you gave to the axis speed meter. This schematic was drawn by using Fritzing Creator Kit [22,32].

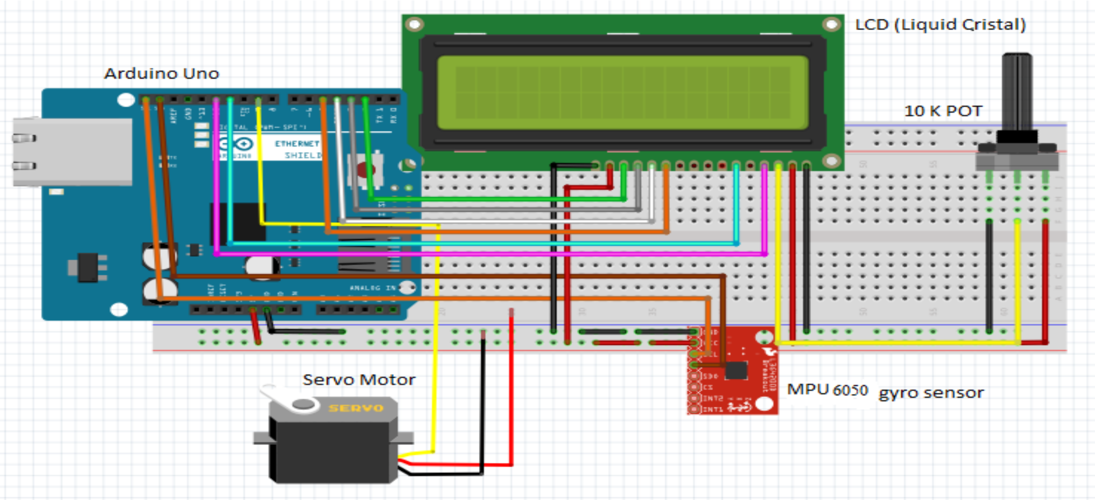


Figure 3.9 Schematical representation of the Arduino controlling a servo with 6 axis speed meter

3.3.1 Programming and Application

Arduino is an artificial intelligence developer programming board. Arduino software consists of a development environment (IDE) and libraries. The IDE has been written in Java and based on the environment of processing.

The libraries are written in C and C ++ and are compiled with AVR-GCC and AVR Libc. The basis of the Arduino control board language is based on the C ++ and C programming languages. C Language forms the basis of programming.

In this study, to understand better the working principle of this device that its purpose proves the PID system to make sense, it is needed to look at the coding part. The entire code that is written for this application is given in Appendix A.

This system has been created in order to protect the constant of a variant in between certain values against negative reactions coming from outside related to used technologies in aircraft, etc [19].

Table 3.1 Accelerometer connection pins (I2C) to Arduino are shown.

Arduino	Accelerometer MPU6050	Arduino	Servo No.1
SCL	SCL	5V	5V (Red Wire)
SDA	SDA	GND	GND (Black Wire)
3.3V	VCC	D9	
GND	GND		

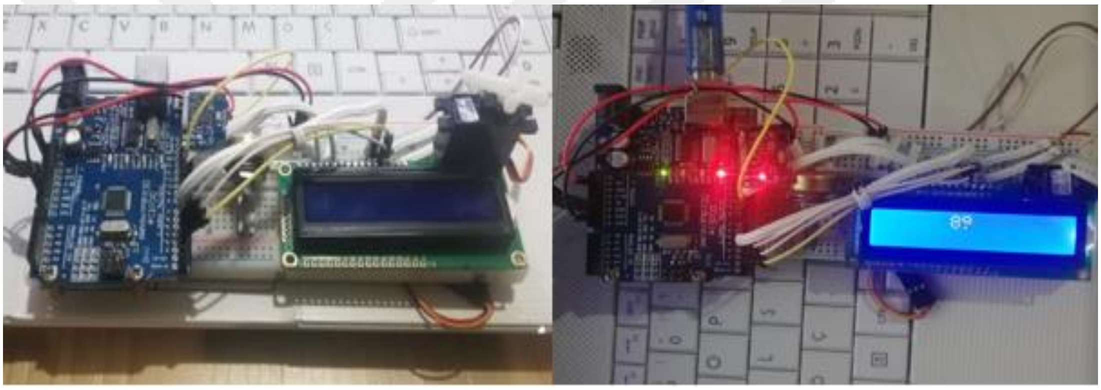


Figure 3.10 Original circuit with all component connections

The photograph is about PID control. The servo on the board is driven by getting information from the MPU6050 sensor. In Figure 3.10, it is seen a similar circuit of the gyro system in real model aircraft with its original photograph, and it is also shown in the connection diagram in Table 3.1.

Sampling: This study aims to learn how a gyroscope works in aircraft, quadcopter, and ship. In the aircraft, when wind power affected to aircraft’s balance, a reaction is applied through the opposite side of the aircraft. This reaction is called stabilization and signals are produced from the gyro mechanism. The angle of pitch is illustrated in blue color.

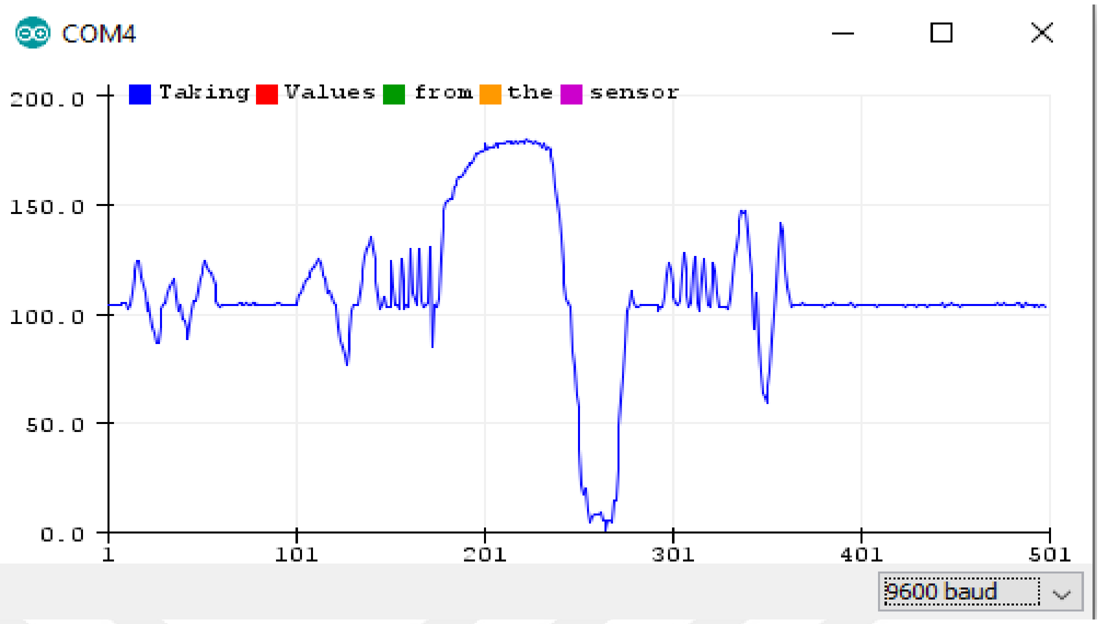


Figure 3.11 MPU6050 accelerometer output in serial monitor diagram

3.4 Conclusion

In this study on a diagram, the servo's angle stays in a new position which depends on the gyro position when the angle of the gyroscope is changed as shown in Figure 3.11. As shown in the graphic, the pitch axis is represented in the blue clour. As the MPU 6050 sensor is moved, it will move in the 180-degree angle range in the servo as shown in the graph.

In a quadcopter control, a PID system process is provided by the control card to control the stability of the quadcopter. Firstly to understand how a quadcopter works, it is necessary to grasp the PID system.

In this chapter, it is aimed to understand how PID control systems work. Nowadays, PID control, which is used in many systems and machine program control structures, forms the basis of the control base. In this study, one of the inferences is to control the system using PID control without the need for continuous manual adjustment with an automatic control system. Such as autopilot and fly-by-wire that are advanced systems use the most advanced version of the PID control system in aircraft equipped with high technology today. In addition, Transfer function and State-space approaches have been applied to convert physical systems into mathematical equations. As a result, the ongoing functions of a controller in its internal structure are explained [17,19].

CHAPTER 4

CONTROL SYSTEM ELECTRONICS AND FRAME DESIGN

4.1 Introduction

Traditional Quadcopters and Helicopters are not new technological advances or inventions. They have been the subject of research and development for many years because of their simplicity and efficiency in manufacturing.

Today, they are used for various tasks in many fields. Quadcopters play an important role in many fields such as vision/laser-based navigation and simultaneous localization and mapping. Traditional Quadcopters consist of four equal power motors and fixed propellers. Each engine has an electronic speed controller. At the same time, they have advantages as well as disadvantages. This may also be a research topic. One of the most important features required from a quadcopter is the long flight duration. To expect this from a quadcopter with four rotors, it is necessary to increase the battery capacity, which is disadvantageous in terms of excess weight. This also makes it a disadvantaged position. In addition to the long flight duration to be requested from a quadcopter, it is maximum efficiency with advanced maneuverability and minimum energy. It is difficult to see this in traditional quadcopters with the fixed pitch propellers because the center of gravity cannot be reversed due to the pitch angle that could not change so they are not able to do some movement and also they consume more energy with four motors.

In this study, unlike conventional quadcopters, a single motor quadcopter design with four variable pitch mechanism will be studied. In this thesis, only the control system of a single motor quadcopter has been designed. Therefore, detailed information about frame design has not been given. In any aircraft, the electronic configuration is determined according to the frame design and the programming part depends on the mechanical movement of the object. Some movements that we can simply describe are described as landing, take-off, and cruise flight. Even these movements have mathematical expansions.

4.1.1 Identification of the Project

In this thesis, the project to be studied has been defined as Heli-Quad and has been named as HeliQuad because it uses a four-rotor and swashplate mechanism. The control system for this Heli-Quad uses independently controlled with the collective pitch mechanism on each of four-rotor, with a single electric motor that powers all four-rotor at the same RPM via belts or torque tubes. It is highly aerobatic, with extremely rapid control available.

A drive shaft, driving shaft, tail shaft, propeller shaft, or Cardan shaft is a mechanical component for transmitting torque and rotation. Generally, they are used to connect other components of a drive train that cannot be connected directly because of distance or need to allow for relative movement between them.

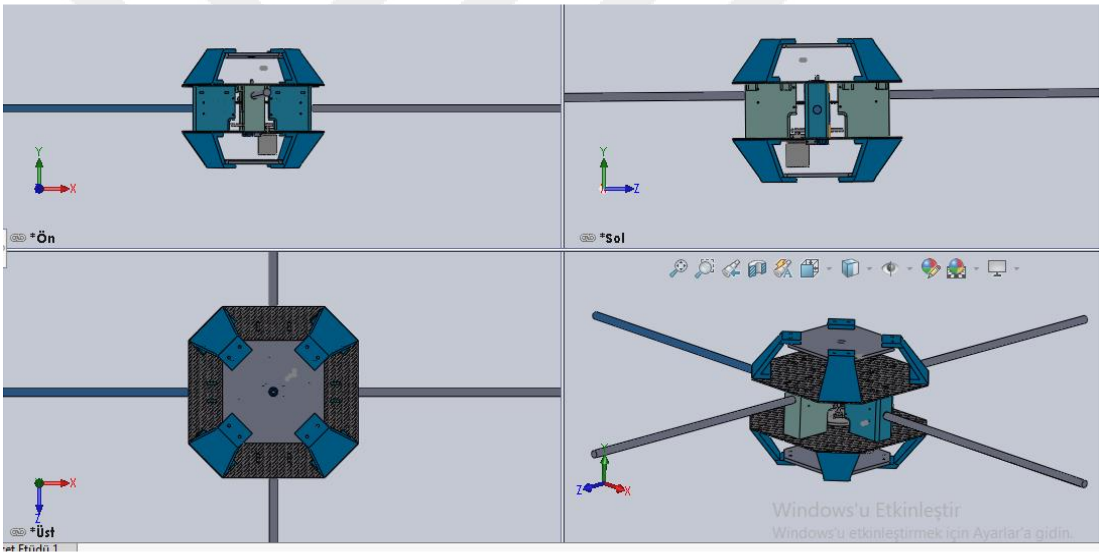


Figure 4.1 The mainframe displays images from different angles

The driveshaft system requires a different number of gears and torque tubes. To connect all of the systems, you need torque-tubes, gears, and mile if not use a belt mechanism system. These narratives are depicted and drawn in Figure 4.1 and Figure 4.2. Although they have the same fixed frame structure as traditional quadcopters, the gears and torques tübes moving within the frame produce vibration, which is a disadvantage for Heli-Quad. This vibration can be prevented by shock absorbers. The torque value increases with increasing engine body diameter and main gear tooth count. Thanks to this, in fast and agile movements, the movements are going to become in a series without decreasing the RPM.

Mainframe assembly has been drawn through the SolidWorks program and extracted from the 3D printers. Separate parts have been combined to create an assembly. The frame which is divided into three includes electronic hardware on the upper floor, main rotor gear, and torque tube gear in the middle floor and batteries and landing gear on the lower floor. These floors will be better seen in Figure 4.2, which is shown as more understandable.

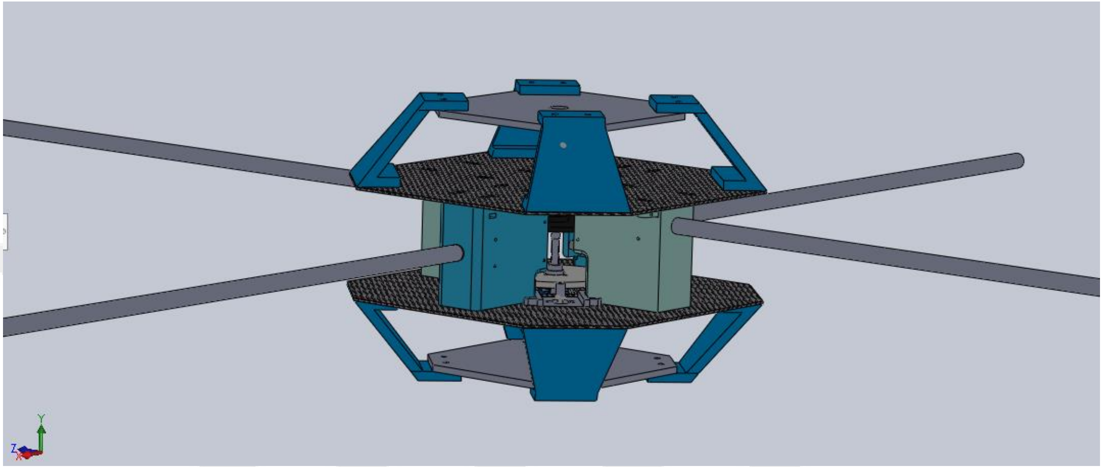


Figure 4.2 Main frame solid drawing

4.2 Process of the Design

In this thesis, everything is shown with a process graph in certain phases. As understood in Figure 4.3, every section is connected to each other for building and performing the research study. The beginning of this process starts with component selection, then the component installation procedure and the flight electronic software set-up procedure follow each other. The feed-backs represent the experiments and tests made in the meantime.

There are four sections for the building process for the project. These successive stages each other are given in the following four sections.

These are;

1. Selection of the components
2. Design of the control system and drive-shaft frame mechanism
3. Set-up (Assembly)
4. Programming

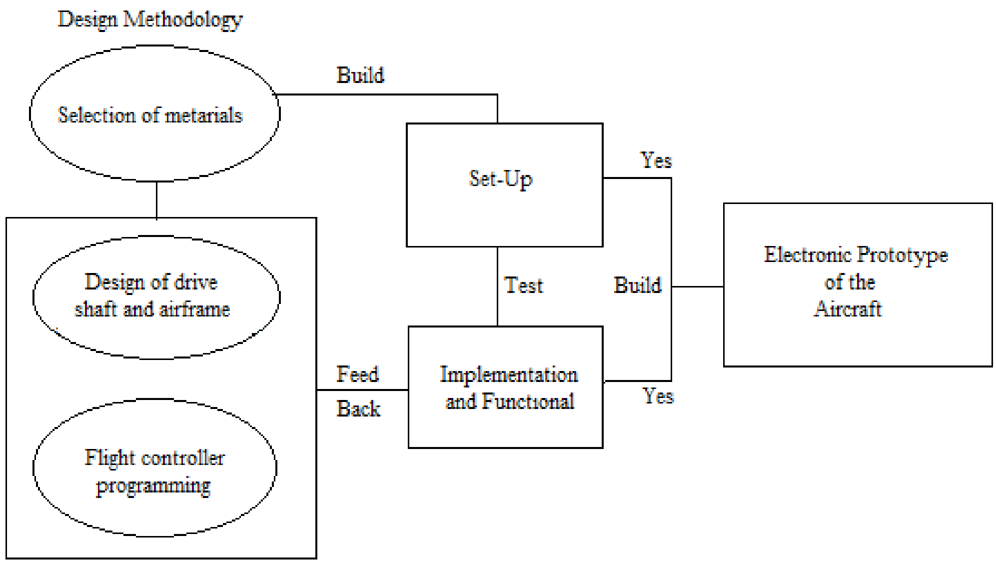


Figure 4.3 Design Flowchart

4.2.1 Selection of the Components

Unlike conventional Quadcopter, the first-ever collective pitch quadcopter consists of one engine and four servos. Furthermore, there is an ESC (electronic speed control) for one motor. Receiver, transmitter, and flight controller are basic elements for making a quadcopter. Their numbers do not change.

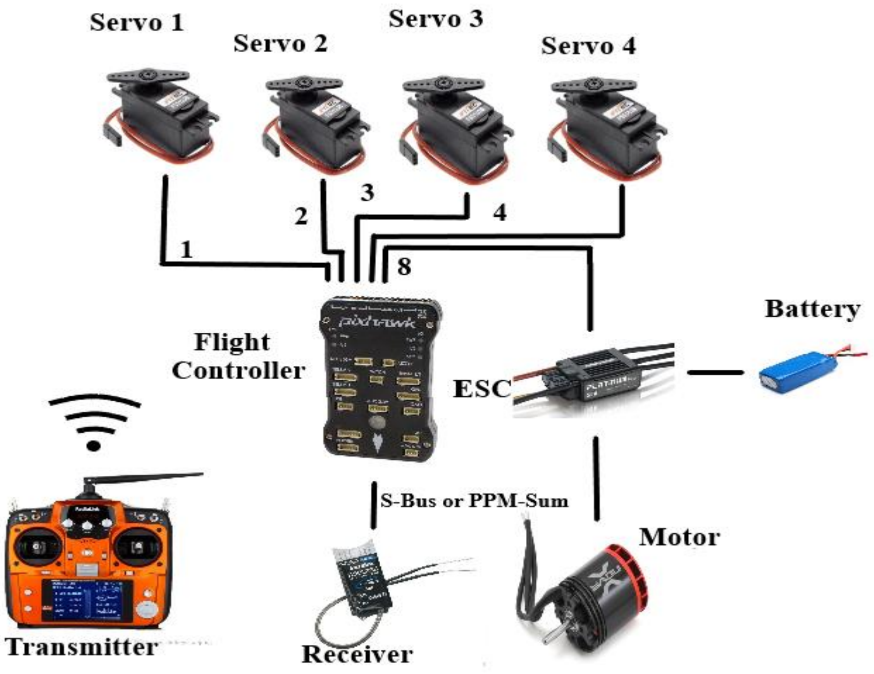


Figure 4.4 Heli-Quad simple layout

As shown in an integrated circuit template of Heli-Quad above Figure 4.4, servo connections are installed according to the procedure of the traditional helicopter servos setting. Since our Heli-Quad has a single motor and flight configuration, is similar to Helicopter flight configuration, the wiring diagram is like Figure 4.3. All necessary materials for Heli-Quad are listed and explained on the next page.

a) Transmitter
b) Receiver
c) Motor
d) ESC (electronic speed controller)
e) Flight controller
f) Battery
g) Servo
h) Frame type
i) Drive system type
j) Propellers

a) Radio Transmitter (TX): In electronics, remote control or transmitter is an electronic device used to operate another device from a distance, usually wirelessly.

b) Receiver (RX): In electronics, information coming from a remote control is processed by a receiver and conveyed to the flight controller via communication cables.

c) Motor: In electronics, Quadcopter and UAVs with other frames types use generally two types of engine. These are brushless and brushed type. In this study, will be used the brushless type motor. You can access more information about the brushless motors in the titles below. Most model aircraft use a brushless motor type like below Figure 4.5 [37].

Figure 4.5 Xnova XTS 2618-1860KV [35]

4.2.1.1 Brushless Direct Current (BLDC) Motors

BLDC motors are one of the motor types. They have rapidly become popular usage in UAVs. They are classified as synchronous motors. The rotor of the BLDC motor consists of a powerful permanent magnet. The structure of the BLDC motor looks like synchronous machines [28].

Brushless motors have two type winding methods, delta and star types which are shown in Figure 4.6. These types of windings are also used in asynchronous motors. Delta winding type is more common than the star winding type. Both of them have different usage places. Star type winding produces more torque and runs lower speed, but the delta type runs in high-speed RPM and produces lower torque [22].

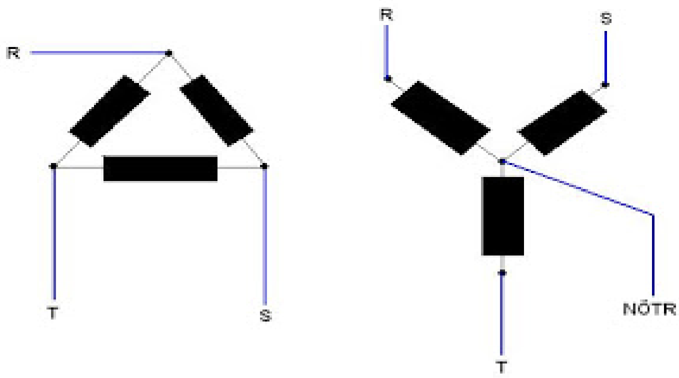


Figure 4.6 Star and Delta connection [44]

Brushless motors have more poles than can be seen. Poles number depends on the size and torque of the motors. Generally, motors with more poles are used to obtain more torque. To be able to do winding, you need a winding schematic diagram as in Figure 4.7.

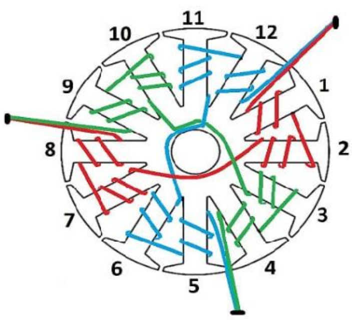
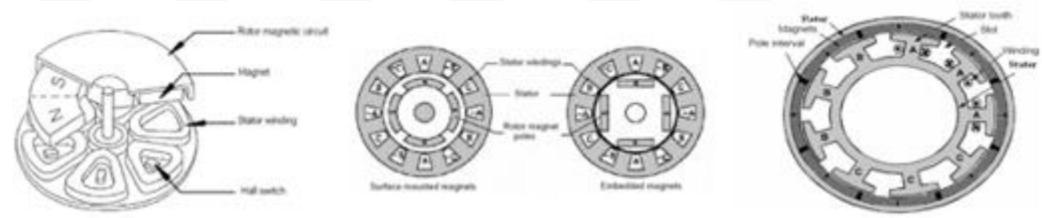


Figure 4.7 Brushless motor winding [44]

In today's technology, brushless motors are used commonly in UAV's technology, different systems, many machines. Due to technological improvement, brushless motors got an important place. In multi-rotor or traditional helicopters, brushless motor is used. Motor values are selected according to the weight of the aerial vehicle, size, useful load capacity of the aircraft. Motor values include KV value, RPM, operating voltage range, and weigh of the engine.

4.2.1.2 Types of the BLDC Motors

There are three types of BLDC motors. These motors are called in-runner, outrunner, and disc type as shown in Figure 4.8. Furthermore, BLDC motors have two types between themself. These are BLDC with sensor and some BLDC has no sensor [25,26].



a)Disk Type Motor b) Inrunner Motor c) Outrunner Motor.

Figure 4.8 Motor types

4.2.1.3 BLDC Operating Principle

BLDC motor has stator windings which are fed by inverter and a strong permanent magnet on the rotor. The inverter is a processor card that is fed by a current source. The inverter consists of power switches or control switches to run the brushless motor. The power switches (semiconductor switches) respectively based on the rotor position. The working order of the power switches is determined by a position detector in the rotor or a sensorless control algorithm.

BLDC motor is controlled electronically. The direction of current flow is altered in stator windings by using rotor position information. This process is performed by the power switches or control switches. Hence, current roaming in between the windings creates a magnetic field.

This magnetic force makes the rotor move from the right to the left or from the left to the right. As a result, the torque occurs. The values of torque depend on stator and rotor magnetic field strength [25].

4.2.1.4 Mathematical Model of the BLDC Motor's Torque Measurement

BLDC motor consists of at least three-phase or three windings. Like other motors, BLDC motor also has a mathematical equation for measuring torque value. To work the system properly, it is required to be linear. If the system is nonlinear, the same approach is used by assuming it as a linear system.

The current equations of the three windings in phase variables are defined as (4.1);

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{d_t} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4.1)$$

In this equation;

V_a, V_b, V_c are the phase voltage, i_a, i_b, i_c are the phase current, e_a, e_b, e_c are the back emf voltage, R is phase resistance and L is each phase inductance. Mutual inductance is for instance L-M [26,28].

The electromagnetic torque is defined as (4.2);

$$T_e = \frac{(e_a i_a + e_b i_b + e_c i_c)}{W_m} \quad (4.2)$$

In this equation, the mechanical speed of the rotor is W_m.

The equation of motion is defined as (4.3);

$$\frac{d}{d_t} W_m = \frac{T_e - T_l - B.W_m)}{J} \quad (4.3)$$

The load torque is TL, the damping constant is B, the moment of inertia of the drive is J. Besides, the last equation defines the relationship between the electrical frequency and mechanical speed as shown in (4.4);

$$W_e = (\frac{P}{2}) W_m \quad (4.4)$$

P is the number of poles [26,28].

d) ESC (Electronic speed controller): ESC uses the receiver's output signals. It provides power to engines by processing these signals. At the same time, ESC produces SBEC Voltage Output that supplies servo, receiver, and extra peripherals. In this study, this Platinum 50A V3 ESC is selected as shown in Figure 4.9 [39].

Figure 4.9 Platinum 50A V3 [3]

e) Flight controller: As it is known, the flight controller consists of a processör inside of the composite structure. The flight controller is the brain of the UAV. By processing ınformations coming from the receiver, it provides directional control to UAV. In this study, with an embedded STM32F765 processor with 32 bit ARM-based, PIXHAWK flıght controller in Figure 4.10 with 512 KB RAM is used.

Figure 4.10 PIXHAWK [46]

f) Battery: It is the power of the UAV electronic system. The number of the cell and power rate change according to used motor type and other assemblies. There are NiCad/NiMh /LiPo / LiFe type batteries. Generally, LiPo batteries that are shown in Figure 4.11 are used in model aircraft.

Figure 4.11 Li-Po Battery [3]

g) Servo: The tail rotor mechanisms are operated by servos motor to change the angle of attack of variable pitch propellers. These servos are selected according to easily lifting the required weight on each arm. In this study, the KingMax CLS2875H servo is used. There is an example of a servo that is used in our project in Figure 4.12.

Figure 4.12 KingMax [3]

h) Frame Types: Quadcopters have various configurations, and also the most common types are the X configuration, the H configuration, and the + configuration [31]. These are various configurations as shown in Figure 4.13.

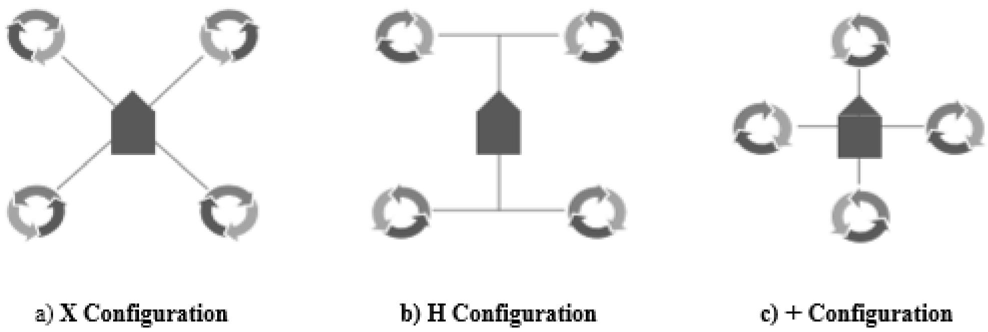


Figure 4.13 Quadcopter Frame Configuration Types [14]

In Figure 4.13, arrows represent the propeller direction, wires represent a fixed frame, and the center represents the quad frame body. Each type of configuration has advantages and disadvantages. It depends according to the place where it is used. In this study, the X type is selected.

4.2.2 Design of the Control System and Drive-Shaft Frame Mechanism

In this chapter, all essential controllers for the Heli-Quad system are studied. The Heli-quad system mechanism is built in different methods according to conventional quadcopters. The conventional multi-copter system consists of multi-motor systems and they have a fixed frame and fixed pitch propellers.

Four or more motors that are separate from each other run different speeds and electronically connect diverse from each other. In this thesis, like other multi-copter, the main purpose is to keep the Heli-Quad's orientation and administration controlled in the air and to protect its altitude air above. From here, a commonly used reference system will be presented for explicitly defining this control objective.

4.2.2.1 Heli-Quad's Reference Frame

The commonly used coordinate system is the Cartesian x,y,z system for all aerial vehicles. As shown in Figure 4.14, the Heli-Quad, quadcopter, and other aerial vehicle reference frames include three axes. These are Roll (φ), Pitch (θ), and Yaw (ψ). The origin of the aircraft represents to axes of the Heli-Quad and center of mass.

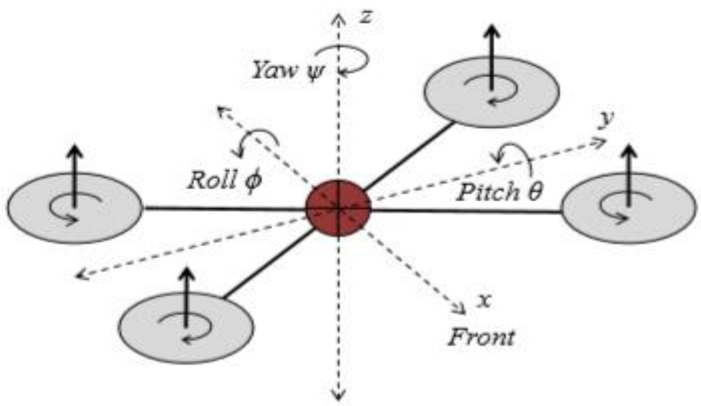


Figure 4.14 Heli-quad reference frame [14]

They use the same frame types even though the Heli-quad system has different configurations from other Quadcopters in meaning electronically and programming. There are diverse frame types. These are the X configuration, the H configuration, and the + configuration.

4.2.3 Forces and Moment on Quadcopter

In the Quadcopter dynamic model, every propeller produces torque force opposite the direction of rotation of the propellers. A torque effect occurs on the frame. By taking advantage of this torque, momentum is created on the plane, and thanks to this momentum, the direction of the plane are determined. Propellers have two directions of rotation. These are CW (Clockwise) and CCW (Counterclockwise) rotations.

As shown in Figure 4.15 and Figure 4.16, the mathematical model of quadrotors is explained simply.

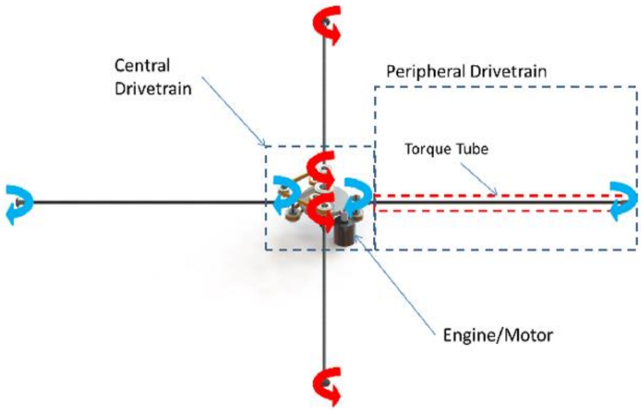


Figure 4.15 Frame configuration with a single rotor [5]

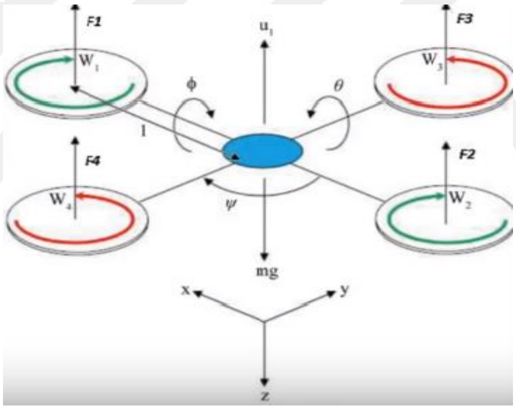


Figure 4.16 Quadcopter control frame [28]

The thrust that propellers produce depends on the angular velocity of the propellers. In the vertical direction of the propellers, there is F upwards while mg is downward. As propellers rotate, they produce thrust. Therefore the angular velocity of the propellers depends on propeller head speed RPM [26,28].

F is determined the force of lift This thrust formula is defined as (4.5);

$$F_i = K_f \times \omega_i^2 \tag{4.5}$$

As the propellers rotate the great reaction moment Mi on the quadcopter about the center axis, these reaction moment is determined with the equation as in (4.6);

M: momentum inertia,

$$M_i = K_m \times \omega_i^2 \tag{4.6}$$

Thrust produces moment M_x and M_y in the opposite of each other. These are defined as in (4.7) and (4.8),

$$M_y = (F_1 - F_2) \times L \tag{4.7}$$

$$M_x = (F_3 - F_4) \times L \tag{4.8}$$

This moment reaction changes the direction of the quadcopter.

i) Drive System Type: There are three drive systems as shown in Figure 4.17. These are a belt-drive, shaft drive, and chain drive. In this study, a drive shaft system is used for running a tail rotor mechanism.

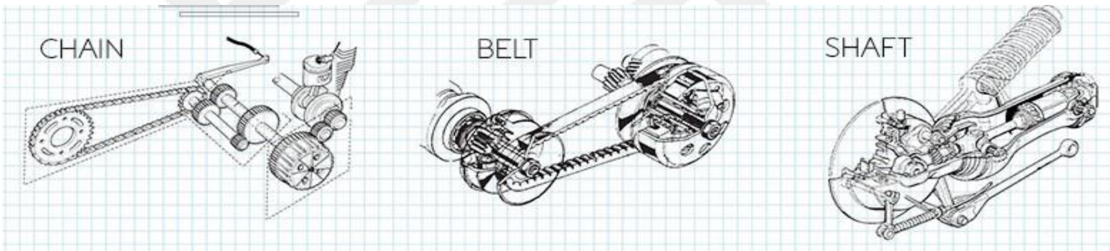


Figure 4.17 Belt Drive, Shaft Drive, and Chain Drive [33]

1. Belt Drive

This mechanism made up of driving pulleys towards the gearbox output of the shaft and driving pulleys at the wheel the two pulleys are connected by a belt which has teeth, or grooves on the inner side, matching the grooves on the outer side of the pulleys [33].

2. Shaft drive

This system, as a named, comprises a shaft that's connected to the gearbox output via a universal joint, which is essentially a coupling that equips the transmission of rotary power at any selected angle [33].

3. Chain Drive

This setup is old as well as common. Comprising of a simple chain of linkages connecting sprockets is the drive system that an overwhelming majority of motorcycles implement [33].

j) Propellers: Propellers are a mechanism for the propulsion of an aircraft. In its general form, a propeller consists of rotating blades mounted on a central shaft that houses with the engine. While the engine operates, the propeller turns to suck a large amount of air. As this air passes through the rotating blades, it gets energized, its speed and sucked air mass increases. In the process, the required thrust to propel the aircraft is produced.

4.2.3.1 Propeller Theory

As shown in all aircraft, the flying principles of helicopters are based on aerodynamic laws. These rules include gravity, lift, drag, and thrust. The helicopter has different flying methods than the planes. Its rotor and propellers rotate in the same central mechanism to produce lift force.

Traditional helicopters also use a collective mechanism that is mounted centrally in the rotor. Heli-quad configuration has the same feature with a traditional helicopter but the Heli-Quad system has four rotor blades separated from each other [29,36,40].

Heli-quad system has four tail rotor mechanism and each tail rotor assembly consist of a collective mechanism. The collective mechanism can move independent two propellers from the negative position to the positive position or vice verse.

Figure 4.18 CW and CCW propeller rotation [46]

The main rotor system has three different combinations and these are the fully articulated rotor, semi-rigid rotor, and rigid rotor. These are shown in Figure 4.19 [27,40].

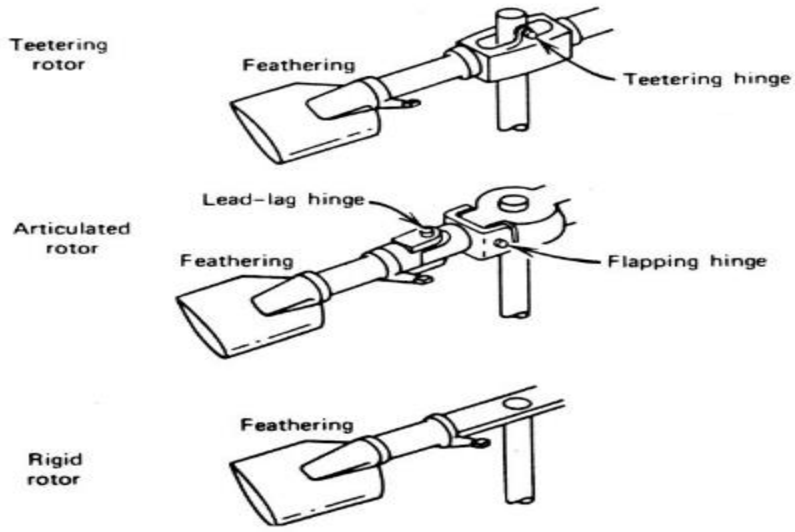


Figure 4.19 Main rotor systems [45]

a) Rigid rotor; Generally, propellers are flexibly attached without root-to-tip hinges.

b) Semirigid rotor system; Usually, there are two blades tightly mounted on the main rotor hub mechanism, and these blades are allowed to engage together as a unit. The main rotor hub is free to tilt with respect to the main rotor shaft on what is known as a teetering hinge.

c) A fully articulated rotor system; It usually consists of 3 or more blades. The blades allow it to perform movements such as flap, feather, lead or lag independently of each other.

As seen in Figure 4.20., the simple collective mechanisms are made up of a lot of different small parts and quite fragile. In this picture, there are represented three Figure**s**. One of them is shown for quadcopters that have one motor in every arm. Every part of the collective mechanism is drawn by calculating distances to each other. The parts in this structure are very fragile and not durable because they are small.

They may have been used as a combination of carbon plastic or metal-plastic composite parts. In this case, producing in the aluminum casting method is both easier and make it stronger than via a three-D printer (3D).

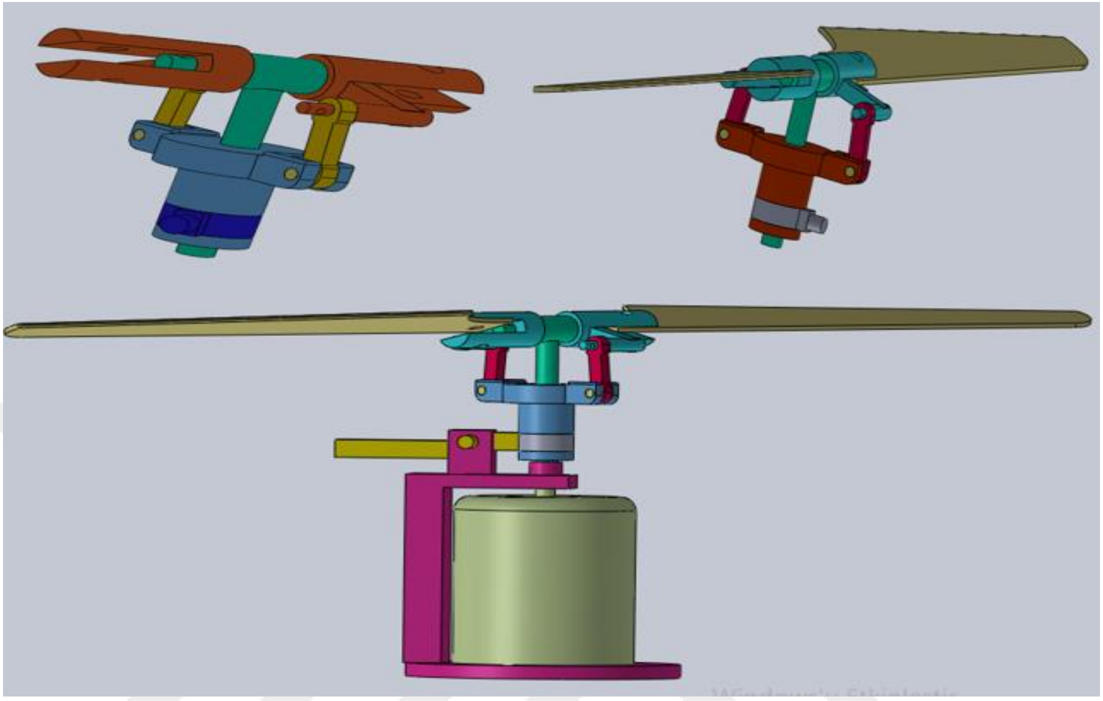


Figure 4.20 Collective pitch mechanism drawn in solid works

An example drawing was made in SOLID WORKS above for its tail rotor machine and it was introduced and explained with the types of these rotor mechanisms that are given above Figure 4.20.

All of these rotor systems allows controlling of the direction for the helicopter. Helicopter propellers work according to two basic theories: The Momentum Theory and the Blade Element Theory [34].

Propeller is a mechanism to produce the propulsion of the helicopter systems. Its torque power is taken from the main rotor mechanism. As the engine operates, the propeller turns to suck a large amount of air. As this air passes through the rotating blades, it gets energized and its speed increases. In this process, the required thrust to move the aircraft is produced. Bernoulli equation is the one that best describes this process [37].

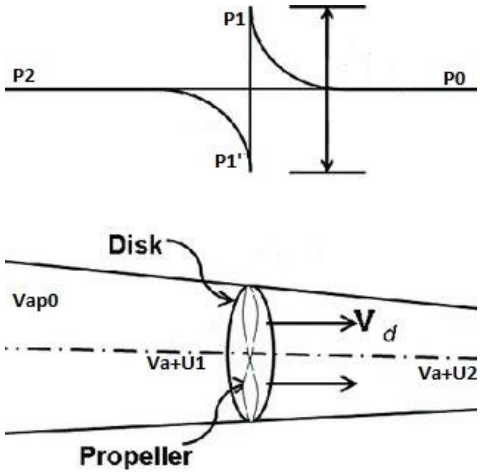


Figure 4.21 Free stream velocity

The basic description of the Bernoulli Equation:

As the fluid passes through a narrow throat, the speed increases and the pressure decreases. When passing through a wide throat, the speed decreases, and the pressure increases. This process is depicted in Figure 4.21 [27,34,42].

An application of the Continuity Equation gives (4.9) and (4.10).

V: Air Speed

ρ: The density of the air

P: Absolute pressure in the ducted fan

$$P_1 = P_1'$$

$$m = PA_0\,(V_A + U_1)$$

$$\text{Thrust} = m[(V_A + U_2) - V_A]$$

$$= PA_0\,(V_A + U_1)\overline{U_2}$$

$$\text{Power} = T(V_A + U_1) \tag{4.9}$$

$$\text{Kinetic energy} = \frac{1}{2}m[(V_A + U_2)^2 - {V_A}^2] \tag{4.10}$$

$$= \frac{1}{2} PA_0(V_A + U_1)[U_2{}^2 + 2U_2V_A]$$

$$T(V_A + U_1) = \frac{1}{2} PA_0(V_A + U_1)\ U_2(U_2 + 2V_A)$$

$$= PA_0(V_A + U_1)U_2(U_2 + 2V_A)$$

$$\frac{1}{2}\ [U_2 + 2V_A] \ = \ V_A + U_1$$

$$U_2 \ = \ 2U_1$$

CHAPTER 5

SETTING UP THE HELI QUAD SYSTEM

5.1. Introduction

Assembling of the traditional helicopters, tandem rotor, and variable pitch quadrotor, named Heli-Quads have similar features, unlike other MultiCopters. Heli-quad's assembling of the electronic system moves the same feature with traditional Helicopters but from mechanic assembling point of view, they are different. Therefore, also as electronic, they are required to become different. These copter flight configurations support traditional single rotor, tandem rotor, variable pitch quadrotor, and helicopters including all the same features as MultiCopters. The majority of assembling of the Heli-Quad is generally the same as multi-copters. Maneuverability and flight configuration depends on how you built your Heli-Quad and how to set-up parameters. In this study, it has been researched upon the assembling of Heli-Quad electronic. Heli-quads electronic assembling and frame type are not a new technological improvement, but it is new with drive shaft method and the electronic montage of the Heli-Quad. However, there is a small difference when comparing to the traditional helicopter, quadcopter, etc. These differences are the programming flight controller, modeling electronic hardware, and the design of the frame. These copters use servos that move the swash-plate mechanism instead of a motor in each arm. Copter's propellers can move in both directions as negative and positive. This type of copter takes torque power from the single motor.

The motor is connected with the gears system to send torque power to the tip of the swashplate mechanism. In this system, the drive shaft system is used. To connect rotors to each other, after assembling four tail rotor mechanism, they are positioned to connect to main gear on designed mold at the center of the Heli-Quad. In this study, PIXHAWK flight controller has been used. Flight configuration of the Heli-Quad has been programmed via the MISSION PLANNER program. This program supports Ardupilot, APM2, PIXHAWK, etc controller software base. The PIXHAWK hardware controller has been chosen in this study.

PIXHAWK is a type of controller for UAVs. PIXHAWK has a 32-bit ARM processor system and supports S.BUS input. As shown in Figure 5.1, PIXHAWK's simple feature is also presented for the project in Table 5.1 [22,38,40].

Figure 5.1 PIXHAWK autopilot controller [46]

Table 5.1 PIXHAWK's features [46]

Processor	32-bit ARM Cortex M4 core with FPU 168 Mhz/256 KB RAM/2 MB Flash 32-bit failsafe co-processor			
Sensors	MPU6000 as main accel and gyro ST Micro 16-bit gyroscope ST Micro 14-bit accelerometer/compass (magnetometer) MEAS barometer			
Power	Servo rail high-power (7 V) and high-current ready			
Interfaces	Futaba S.BUS input (output not yet implemented) I2C, SPI, 2x CAN, USB 3.3V and 6.6V ADC inputs			
Dimensions	Weight 38 g	Width 50 mm	Height 15.5mm	Length 81.5mm

ArduPilot (PIXHAWK) can support a conventional helicopter, tandem rotor, or variable pitch quad-rotor frames. The system can be configured with CCPM swash mixing or single-servo swash-plate types [46].

In the ordinary MultiCopters, instead of servos are used motors. They don't need servos taking into consideration that ordinary MultiCopters use fixed pitch propellers because lifting force could be adjusted by changing motor speed.

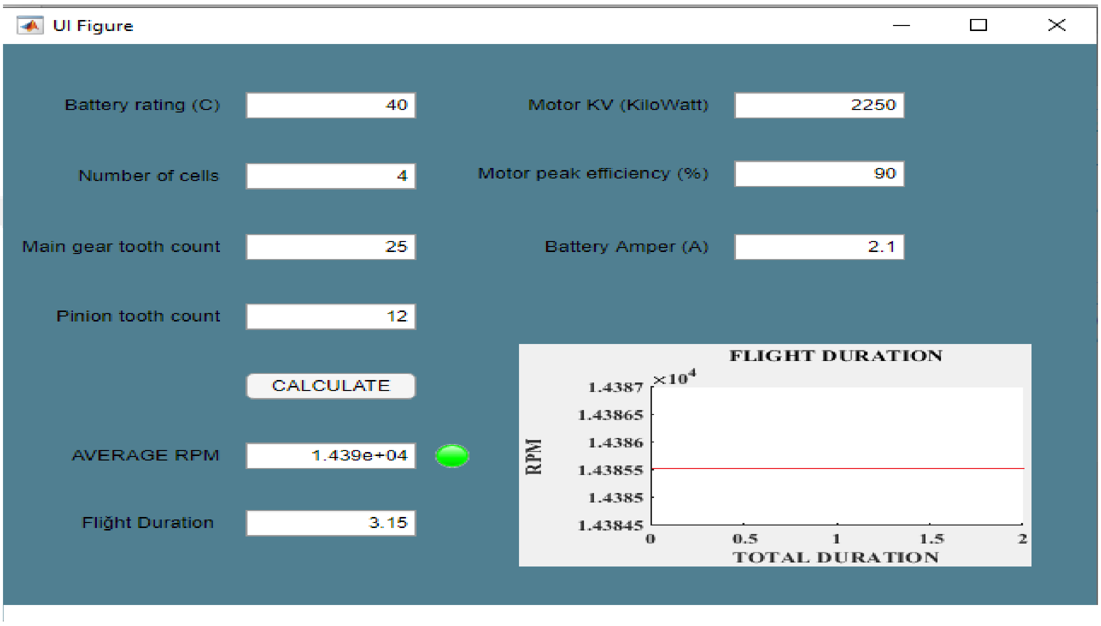


Figure 5.2 Matlab flight duration and RPM calculation app

Calculating lift force depends on motor KV value and motor torque. According to motor KV values, pinion gear, main gear tooth counts, and battery voltage, RPM can be found propeller head speed by using the Matlab app that is created by the Matlab program. For used brushless motors in the UAV, KV value plays an important role. The Kv value is the coefficient of rotation that applies only to brushless electric motors. Using the Kv value, the no-load speed of a brushless motor per minute can be roughly associated with the voltage supplied to the motor. Simply put, the Kv value of a brushless motor is its revolution count that will rotate in 1 minute for 1 volt.

The interface app that is shown in Figure 5.2, has been created through the Matlab program and calculates the average RPM(revolution per-minute) value for propeller head speed and flight duration for your Heli-quad. After entering all input values in the application, it will give the average RPM and flight time with the graph. Simply, the mathematical coding of the application is given in Appendix B.

5.2. Heli-Quad Electronic Assembling

In this study, the purpose is not to build a new traditional quadcopter, all traditional quadcopter models almost being known. In daily life, they can easily be seen everywhere. Their changing functionality depends on the purpose of usage and where it is used. By taking advantage of the information on how to assemble traditional quadcopter and helicopter electronics and programming, it is aimed to make a project. Heli-quad is not also a new model quadcopter.

But they are not often seen everywhere like a traditional quadcopter. Heli-Quad has also advantages and disadvantages like traditional quadcopters. Heli-quad's name comes from the traditional helicopter and multirotor quadcopters because traditional helicopters have swashplate mechanisms in the propeller and also are supported by servos to move propeller on both sides (negative and positive). Heli-quad also uses the swashplate mechanism. While multi-copters have four motors and more and Heli-Quads use four rotor blade with the collective mechanism.

The control electronic of Heli-Quad is supported by the PIXHAWK flight controller card. Connecting instruction of the Heli-Quad electronic system is described in items. Items that will be used in the project are determined and explained with Figures and tables. These items are given respectively. ESC, Motor cable connections, ESC programming, Program type to be used for folding wings, PIXHAWK features, programming and Compass, Calibration are covered in the topics [19,46].

5.2.1 Wires Connection for ESC, Motor, Transmitter, and Receiver

The ESC (electronic speed controller) can be connected to the motor by soldering directly or with high-quality connectors to transmit the electric current. At the same time, the connectors are valid for the battery pack wires connection. The receiver is also connected to the ESC with the signal cable connector as shown in Figure 5.3.

NOTE: New connectors should always be used, and also should be soldered carefully to the cables and insulated with the heat-shrink plastic isolation material for protection.

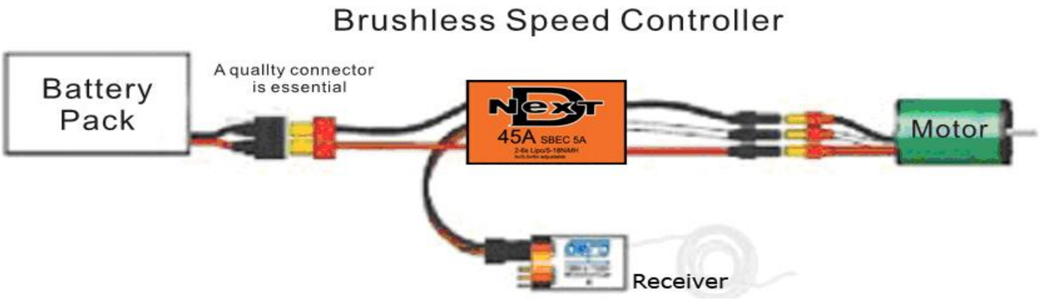


Figure 5.3 Motor, ESC, and Receiver connection wires schema [35]

5.2.1.1 Standard Programming Tracking Following for All ESCs

The standard procedure for programmıng ESC by transmitter:

- Entering the programmable menu
- Selecting the programmable item
- Selecting the desired value in programmable item menu
- Disconnecting the Battery Connector

Entering the programming mode:

- Firstly, switch your Transmitter ON and set the throttle stick to its maximum position.
- Connect the battery's connector to the ESC's connector
- Wait for approximately 2 seconds until hearing two short beeps which are repeated 4 times (●● ●● ●● ●●) confirming that the ESC has now entered the programming mode.

Selecting the programmable item:

Audible tones according to ESC type depending on the number of programming items comes respectively and each Programmable Item has a special audible tone which is repeated four times. When selecting the programming item at the beginning, the throttle that is aligned to the maximum position should be brought to the minimum position when the rising tone for the desired mode is reached and then will be emitted one custom tone which enters the mode [35].

Selecting the desired value of the programmable item:

During the programming section, the motor will release new tones sequentially. When the desired rising tone is reached, move the throttle stick to its maximum position. One special rising tone that is confirming to the new setting will be emitted, and then immediately the main programming menu will return with the next programming item [35].

Disconnecting the battery connectors for safety:

Batteries should be disconnected if programming is not desired to continue. if the programming is going on, you will hear the rising custom audible tone that is desired for your ESC mode. Now, your ESC's calibration is completed and it is ready to run.

NOTE: Safety instruction should be respected and followed step by step. If your propeller is installed, please remove it before ESC calibration. Double-check for all connection it's your responsibility, before connecting the battery pack to avoid short circuit and damaging to ESC. Debugging methods are given in Appendix 3 with my explanations. Our ESC calibration mode must be aligned throttle calibration BRAKE mode as shown in Table 5.2. For all aircraft with folding propellers, it is the same and also includes Stingray, WLToys v383 models.

Table 5.2 ESC calibration mode

Throttle Calibration Mode=Brake	**Brake On/Off**

5.2.1.2 BIND Processing for RC Transmitter and Receiver

The process of pairing the controller and receiver with each other before the first use is called BIND operation. Each controller has a single and unique ID code. This ID code must be learned by the receiver for the control and receiver to communicate with each other. Here BIND task is the process of learning the receiver's ID code and storing it in the memory. Moving to a different model, as long as the same receiver is used with the same controller after this operation is done, does not change the situation. If we want to use the receiver with a different controller, this will have to be done again from the beginning, they must be paired.

NOTE: BIND operation may vary according to the remote control brands, so it is necessary to read the user manual of the control before doing it.

5.2.2 Connecting Instructions for Heli-Quad Model

NOTE: Due to there are a lot of different methods for building the Heli-Quad assemblies, it should be changed simple parameters according to the project that you will make. If simple parameters are set directly for the Heli-Quad, it will not work properly .

1. In this study, four servos will be used as shown in Figure 5.4. One controller, one receiver and one ESC (electronic speed controller) will be available. Also, there is an engine that is connected to the ESC (electronic speed controller).

Here, the standard parameter will be processed under a separate heading, because the configuration of the Heli-Quad, which is carried out for the main purpose of this project, is similar to the standard conventional helicopters.

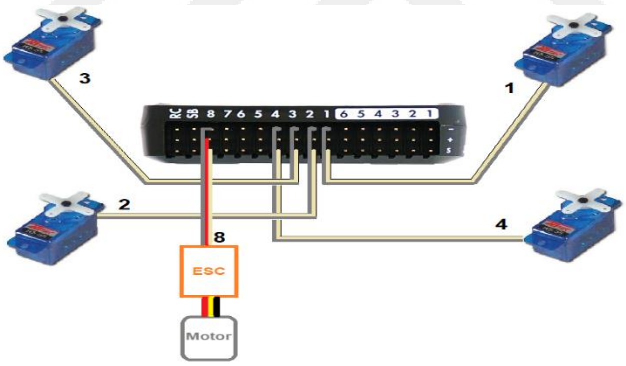


Figure 5.4 Servos, and RX connection schema for Heli-quad [46]

2. Each servo will use the same outputs as in ordinary multi-copter. Adhering to it, each servo should be connected using the same outputs that would be used for motors.

NOTE: The First 4 pins are color-coded for connecting a Heli-Quad servo harness as shown in Figure 5.5.

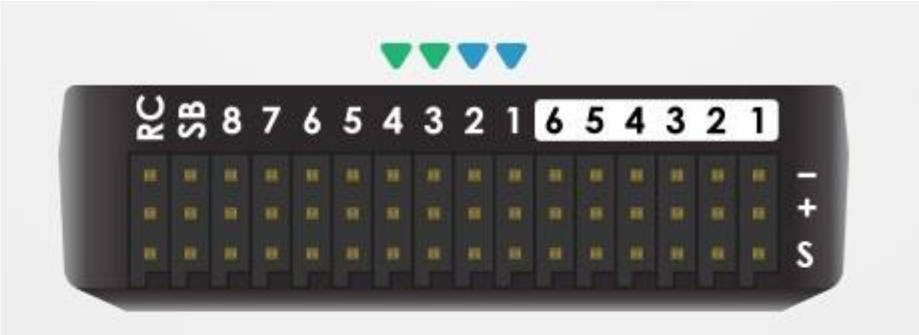


Figure 5.5 PIXHAWK's output-pins (numbered) [46]

3. The ESC that is called the electronic speed controller should be connected with the channel number 8 output of the PIXHAWK flight controller.

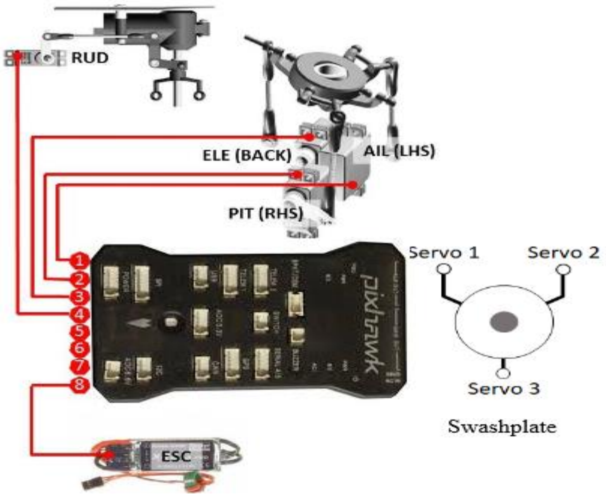


Figure 5.6 Traditional helicopter and Heli-quad swashplate servo and Rudder servo connection.

As shown in Figure 5.6, taken from a traditional helicopter, it is represented as a swashplate mechanism connected with three servos, directed by Servo 1, Servo 2, and Servo 3. However, as this project is known to be composed of 4 tail rotor mechanics, connections should be supported as follows: Servo 1 - aileron, Servo 2 - elevator, Servo 3 -collective, Servo 4 - rudder.

4. The motor should be connected to ESC(electronic speed controller) outputs that electric power is obtained.

NOTE: This harness of the ESC is made up of three cables that have generally different colors. If they do not have a different color, then it is read on ESC placard or marking. In marking, it can easily be seen how to connect to the motor.

5. Traditional helicopter firmware should be loaded into the vehicle.

In PIXHAWK's interface application, there are also standard parameters for Heli-quad. There is a standard parameter for WLToys_V383_HeliQuad in MISSION Planner, but every Heli-Quad is different from each other because every Heli-Quad has a different frame and driving shaft mechanics. For other builds, there are the standard params that should be set.

FRAME_CLASS to 13 (HeliQuad)

FRAME_TYPE to 1 ("X" if front right motors spin counter-clockwise) or 3 ("H" if the front right motor spins clockwise).

While some of them are assembled with shaft drive, some are made up of belt drive mechanism. Accordingly, their parameters depend on frame type and which shaft mechanism will be applied. In this study, the drive shaft mechanism is used, and also frame type is X type.

Table 5.3 Pin input/output of the PIXHAWK

RC Receiver Channel	Ardupilot RC Input Function
1 (Aileron)	Roll (note)
2 (Elevator)	Pitch (note)
3 (Throttle)	Collective(note)
4 (Rudder)	Yaw (note)
5 (Gear)	Flight Mode(open-ended)
6 (Aux 1)	Tuning
7 (Aux 2)	Aux(optional)
8 (Aux 3)	Motor Interlock (throttle)

6. Similar to a traditional helicopter, an auxiliary switch should be set to "Motor Interlock" in order to turn on/off the motor. Normally this is channel 8 so you could set CH8_OPT to 32 by obeying Table 5.2 instructions.

7. Your transmitter & receiver must support a minimum of 8 channels (these should be for elevator, aileron, collective pitch, rudder, flight mode, tuning knob, auxiliary function switch, throttle hold).

NOTE: These options can be adjusted or changed between them, but the first main flight control knops should stay the same.

This study explains how to connect the ESCs, motors, and receiver to a flight controller. The PIXHAWK is used as in this study but other flight controllers are also connected correspondingly.

8. Connect the power (+), ground (-), and signal (s) wires for each ESC to the flight controller's main output pins by motor number. Find your frame type in Figure 5.5 to determine the assigned order of the motors.

Figure 5.7 Clockwise and Counterclockwise direction [46]

Motor rotation diagram: The diagrams below show motor rotation for each frame type. The numbers indicate which output pin from the flight controller should be connected to each motor propeller. The propeller direction is shown in green (clockwise, CW) or blue (counter-clockwise, CCW) in Figure 5.7 and Figure 5.8.

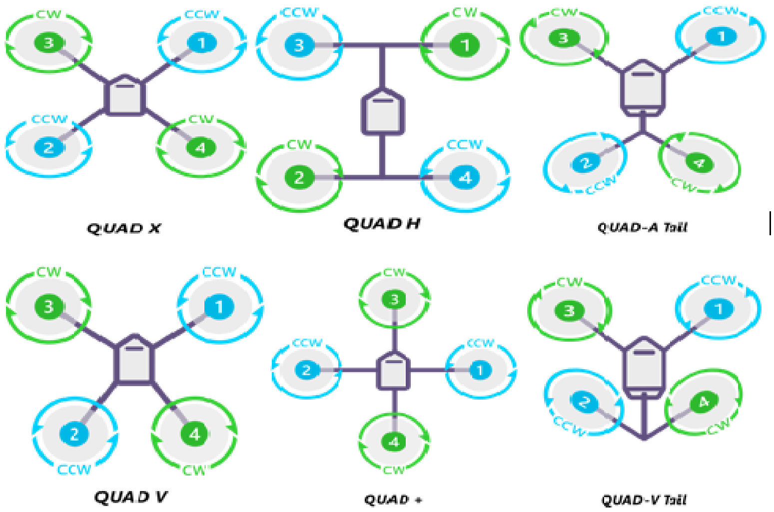


Figure 5.8 Quadcopter-frame types [46]

In this study, counterclockwise or clockwise rotation of propellers is also important because they will use the collective mechanism. Tail rotor mechanisms will rotate in different directions taking into consideration that the servo mechanism has to behave like a traditional quadcopter's motors.

Servos are used instead of motors used in traditional quadcopters. While two servos turning in a positive direction, the others running in a negative direction, to keep quadcopter fix in directional rotation. Therefore, when Quadcopter wants to turn its direction in the vertical direction or nose direction, it increases or decreases the speed of the counter-rotating propellers.

9. Select the COM port.

Select AUTO or the specific port for your board. Set the baud rate to 115200 or PIXHAWK's baud rate as shown in Figure 5.9. Don't hit Connect just yet.

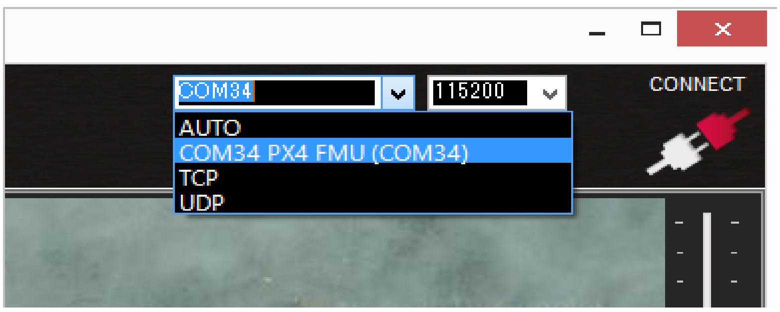


Figure 5.9 Connecting PIXHAWK to the mission planner app [46]

10. Firstly the firmware should be set (In Initial Setup section / Install Firmware screen, select the appropriate icon that matches your frame).

During the initial installation phase of the autopilot on your UAV (unmanned aerial vehicle), firstly the installation of the GCS (ground control station) on the computer, the assembly of the flight controller, and then the connection of the receiver, ESC and motor electric cables are included. Subsequently, the Ardupilot version is installed.

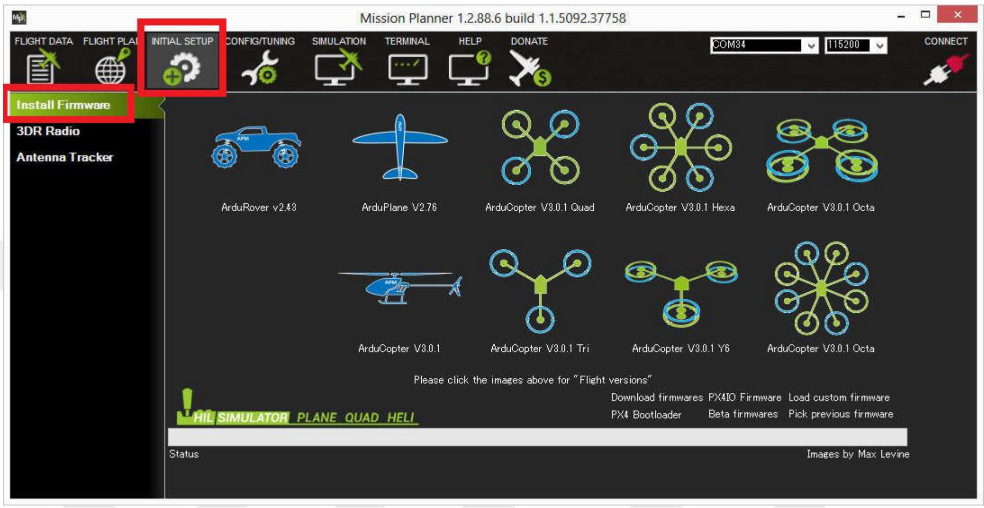


Figure 5.10 Loading firmware to the controller [46]

As shown in Figure 5.10, this section takes place in the initial setup. It includes the version that is necessary for your device. To install the version, PIXHAWK should not be paired with your computer. Chapter 5 the setup section should be taken good care. After connecting Pixhawk to Mission Planner via USB protocol, you have to load firmware to Pixhawk Board. As shown in Figure 5.10, our firmware should be traditional Helicopter namely, Copter 4.0.3 Official.

After the firmware is installed, you have to go to the Initial setup option and complete all the operations. These operations are Mandatory Hardware and Optional Hardware. Mandatory hardware consists of these options: Firmware type, Accel calibration, Compass, Radio calibration, Servo output, ESC calibration, Flight modes, and Failsafe. Frame type should be selected as shown in Figure 5.11.

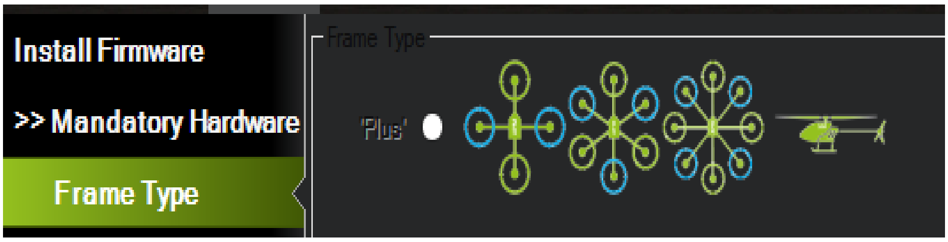


Figure 5.11 Frame type should be Plus option [46]

Radio Calibration should be aligned according to propeller angles by looking radio calibration menu in Figure 5.12. Every Propeller must be zero degrees and parallel with the ground. Propeller parameters are determined according to this setting.

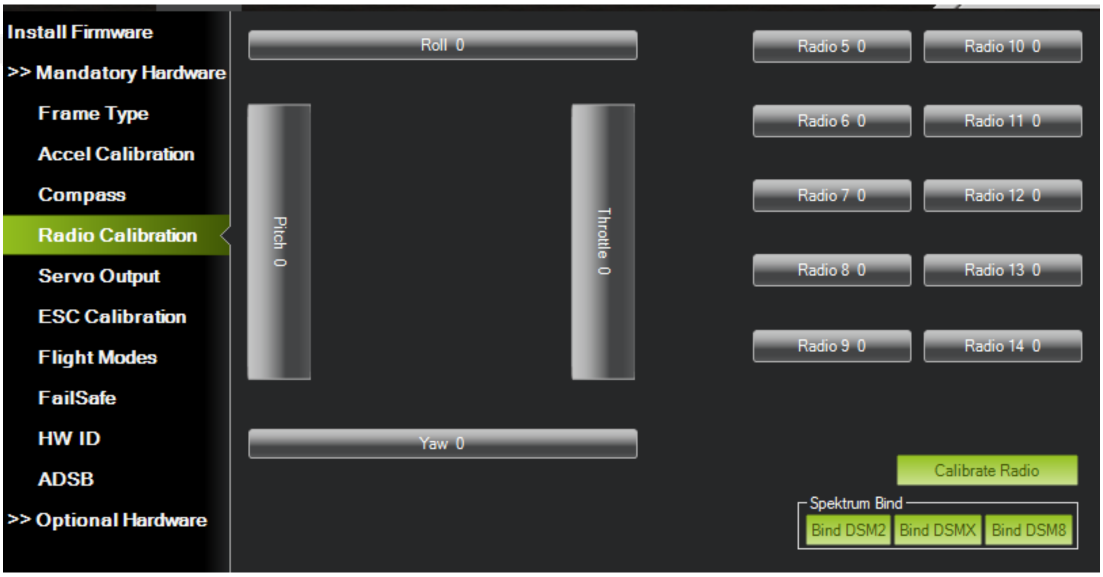


Figure 5.12 Radio calibration menu.[46]

This chapter is mandatory. After completing this section, your installation is finished and sensitive settings are passed. Accel calibration and Compass are mentioned in section 5.2.3. Sensitive settings are tuned in the Config/Tuning option. In this option, two important options are remarkable for our project. These are Flight Modes and Extended tuning. After selecting all parameters and tuning all values, we can extract all flight parameters from the printer by using the Advanced Params option. The parameter values used in the project in this thesis are given in Table 5.4 and 5.5 with the explanation [41,46].

Table 5.4 Heli-Quad all parameters

ATC_ACCEL_P_MAX	75000.0	H_LAND_COL_MIN	420.0
ATC_ACCEL_R_MAX	75000.0	H_RSC_CRITICAL	500.0
ATC_ACCEL_Y_MAX	20000.0	H_RSC_IDLE	0.0
ATC_ANG_PIT_P	4.5	H_RSC_MODE	2.0
ATC_ANG_RLL_P	4.5	H_RSC_PWM_MAX	2000.0
ATC_ANG_YAW_P	4.5	H_RSC_PWM_MIN	1000.0
ATC_HOVR_ROL_TRM	0	H_RSC_PWM_REV	1
ATC_RAT_PIT_D	0.005	H_RSC_RAMP_TIME	1
ATC_RAT_PIT_FILT	20.0	H_RSC_RUNUP_TIME	2
ATC_RAT_PIT_FLTE	20.0	H_RSC_SETPOINT	800
ATC_RAT_PIT_I	0.125	H_RSC_SLEWRATE	0
ATC_RAT_PIT_ILMI	0.4	IM_ACRO_COL_EXP	0.0
ATC_RAT_PIT_IMAX	0.7	IM_STAB_COL_1	0.0
ATC_RAT_PIT_P	0.125	IM_STAB_COL_2	400.0
ATC_RAT_PIT_VFF	0.0	IM_STAB_COL_3	600.0
ATC_RAT_RLL_D	0.0008	IM_STAB_COL_4	1000.0
ATC_RAT_RLL_FILT	20.0	INS_ACCEL_FILTER	10.0
ATC_RAT_RLL_FLTE	20.0	INS_GYRO_FILTER	15.0
ATC_RAT_RLL_I	0.095	PILOT_ACCEL_Z	250.0
ATC_RAT_RLL_ILMI	0.3	PILOT_VELZ_MAX	250.0
ATC_RAT_RLL_IMAX	0.5	POS_XY_P	0.7
ATC_RAT_RLL_P	0.095	POS_Z_P	1.0
ATC_RAT_RLL_VFF	0.0	RC_FEEL_RP	50.0
ATC_RAT_YAW_D	0.040000	SERVO1_MIN	950
ATC_RAT_YAW_FILT	2.5	SERVO1_MAX	2050
ATC_RAT_YAW_FLTE	2.5	SERVO1_REVERSED	0
ATC_RAT_YAW_I	0.018000	SERVO2_MIN	950
ATC_RAT_YAW_ILMI	0.0	SERVO2_MAX	2050
ATC_RAT_YAW_IMAX	0.1	SERVO2_REVERSED	0
ATC_RAT_YAW_P	0.130000	SERVO3_MIN	950
ATC_RAT_YAW_VFF	0.0	SERVO3_MAX	2050

ATC_SLEW_YAW	6000.0	SERVO3_REVERSED	1
FRAME_CLASS	13	SERVO4_MIN	950
FRAME_TYPE	3	SERVO4_MAX	2050
H_COL_MAX	1950.0	SERVO4_REVERSED	1
H_COL_MID	1500.0	SERVO4_TRIM	1570
H_COL_MIN	1350.0	VEL_XY_I	0.7
H_CYC_MAX	2500.0	VEL_XY_P	0.3

The explanation of the abbreviations expressed in the values in Table 5.4 is given in Table 5.5. In line with these parameters, it is possible to change at certain intervals if desired. The mission planner home page on the website is shown as a reference to the parameter ranges [35].

Table 5.5 Explanation of the parameter abbreviations [46]

ATC_RAT_YAW_FLTE	Yaw axis rate controller error frequency
ATC_RAT_RLL_FLTE	Roll axis rate controller error frequency
ATC_RAT_PIT_FLTE	Pitch axis rate controller error frequency
ATC_RAT_YAW_ILMI	Yaw axis rate controller I-term leak min.
ATC_RAT_PIT_ILMI	Pitch axis rate controller I-term leak min.
ATC_RAT_RLL_ILMI	Roll axis rate controller I-term leak min.
ATC_RAT_RLL_P	Roll axis rate controller P gain
ATC_RAT_PIT_P	Pitch axis rate controller P gain
ATC_RAT_YAW_P	Yaw axis rate controller P gain
ATC_RAT_YAW_I	Yaw axis rate controller I gain
ATC_RAT_RLL_I	Roll axis rate controller I gain
ATC_RAT_PIT_I	Pitch axis rate controller I gain
ATC_RAT_RLL_IMAX	Roll axis rate controller I gain maximum
ATC_RAT_YAW_IMAX	Yaw axis rate controller I gain maximum
ATC_RAT_PIT_IMAX	Pitch axis rate controller I gain maximum
ATC_RAT_RLL_D	Roll axis rate controller D gain
ATC_RAT_YAW_D	Yaw axis rate controller D gain
ATC_RAT_PIT_D	Pitch axis rate controller D gain

ATC_RAT_RLL_VFF	Roll axis rate controller feed-forward
ATC_RAT_PIT_VFF	Pitch axis rate controller feed-forward
ATC_RAT_YAW_VFF	Yaw axis rate controller feed-forward
ATC_ACCEL_R_MAX	Acceleration Max for Roll
ATC_ACCEL_P_MAX	Acceleration Max for Pitch
ATC_ACCEL_Y_MAX	Acceleration Max for Yaw
FRAME_CLASS	Frame class for MultiCopter component
FRAME_TYPE	Frame Type (+, X, V, etc)
PILOT_ACCEL_Z	Pilot vertical acceleration
H_COL_MIN	Minimum Collective Pitch
H_COL_MAX	Maximum Collective Pitch
H_COL_MID	Zero-Thrust Collective Pitch
H_CYC_MAX	Maximum Cyclic Pitch Angle
H_RSC_SETPOINT	External Motor Governor Setpoint
H_RSC_RAMP_TIME	Throttle Ramp Time
H_RSC_RUNUP_TIME	Rotor Runup Time
H_RSC_CRITICAL	Critical Rotor Speed
H_RSC_IDLE	Throttle Output at Idle
H_RSC_MODE	Rotor Speed Control Mode
H_RSC_SLEWRATE	Throttle Slew Rate

5.2.3 Adjustment of the Compass and Calibrating Gyro

As usual, also the other vehicles, all of the autopilot controllers are required to calibrate their gyro and compass under instruction which is given in the Mission planner application. The recommended easier method is to follow the steps in the calibrating section of the app. All calibration methods are similar to each other. There are two calibration methods. These are the onboard method and without the onboard method. Both of them are similar but one of them is easier than the other. The onboard method is difficult to calibrate but more precise. Steps to be respected in order to perform the onboard calibration: Initially, after connections are done, it should be clicked on the "Onboard Mag Calibration" section's "Start" button. If your autopilot has a buzzer, you hear a single tone followed by a short beep once per second.

The vehicle is held in the air and rotates it according to directions desired in the mission planner app. These directions are (front, back, left, right, top, and bottom) at the same time is shown in Figure 5.13.

Figure 5.13 Full 360 degrees align process [46]

It is imagined a full 360 degree to turn the board and the turn represents to each turn pointing a different direction of the vehicle to the ground. It will complete in 6 full turns and if it initially does not pass, it is wanted you to turn to confirm the calibration of retry. As the vehicle is rotated in the axis given in the app, green bars should be complete as in Figure 5.14.

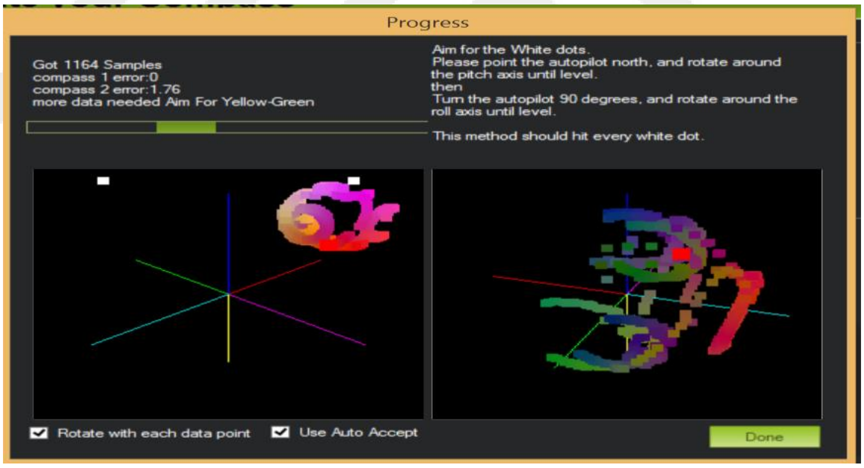


Figure 5.14 Three dimensional visual, in 360 degrees in every direction [23]

Upon this section completed successfully, three rising tones will be heard, and “Please reboot the autopilot” window will appear and the autopilot will need to restart.

NOTE: Do not keep the compasses near any metallic or magnetic field producing objects (computers, cell phones, metal desks, power supplies, etc.) when you do the calibration. If you do, incorrect calibration may occur [35,38,46].

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Introduction

The focus point of this study is designing and modeling of the single rotor variable pitch quadcopter. In this framework, the necessary literature searches have been collected and a conventional variable pitch quadcopter has been theoretically searched by scanning similar literature surveys and references in Chapter 2.3 material and method section.

In this study, in order to build a variable pitch quadcopter, torque tube and drive-shaft mechanism have been used. The rotor parts in each arm of the quadcopter have the collective mechanism. Lifting and payload tests have been performed manually for dynamic analysis on one arm only. In the Programming section, ready parameters have been used and parameters have been changed according to the frame size of the quadcopter. The frame has been designed in SolidWorks computer application. The variable pitch quadcopter electronic design has been suitably placed on the frame. After that, electronic harness connections have been made and got ready for programming. In the programming section chapter 5, Mission Planner computer application (GCS) has been used for programming. Step by step programming section has been illustrated and explained in Figures. Finally, after the programming has been completed, the test section has been started. Tests have been carried out by using the test platform that is similar in reference [34,46].

6.2 Experimental Results

The PID control system, which forms the basis of the control systems used today, has been explained by the experiment and the study has been handled from the simplest level in Chapter 3 and modeling section 3.2 implementation of PID Control. In this study, it was aimed to measure the response time of the servo in the PID control experiment, and it is seen that the servo speed plays a critical role in stabilization. And PID gain values also play an important role.

Speed of servos as seen at 0.03sec / 60 °, digital type servos that scan the 60-degree angle in 0.03 seconds have been used. In this way, the stability of Heli-Quad has been increased.

In the selection of components of Heli-Quad, which has an important place in the construction of quadcopter, the function of each component and its working principle are explained by using mathematical expressions in a theoretical and experimental way Chapter 4.2.1. The propeller head speed and average flight time were calculated with an application prepared in Matlab, and theoretically, these values may decrease under 24 Celsius room temperature, 1 atm pressure, and gravity conditions, which means the outdoor environment.

6.3 Theoretical Results

In this thesis, a Heli-Quad developed using traditional helicopter tail rotor mechanisms has been examined and tail rotor parts have been installed in the center with main and pinion gears by applying drive shaft mechanism method. The main problem of such Heli-Quads, where the number of rotating parts and friction is quite high, is represented by vibration. To reduce these problems, some suggestions are given in the future works section in the conclusion Chapter 7. Besides, the vibration absorption apparatus as seen in Figure 7.2 is placed under the flight controller and the gyro values are prevented from being damaged by vibration. As seen in Figure 3.11 in Chapter 3, how the MPU6050 Accelerometer gyroscope responds to very small vibrations has been monitored from the Serial Monitor Diagram.

CHAPTER 7

CONCLUSION AND FUTURE WORKS

7.1 Summary

At the beginning of this study, the main purpose of the research was how to built advanced variable pitch quadcopter. By taking advantage of a number of the researches that are related to topics each other, obtained information about the variable pitch quadcopter's working principle was collected, and at the end of the research, one project was designed.

In the majority of research on Heli-Quads, a fixed-pitch propellers system that is a common methodology, have been used because stability by simplifying the design was increased. The amount of thrust of fixed pitch propellers is restricted by the rotor input speed information. Although fixed-pitch multi-copters are good stability, variable pitch designs are better in terms of maneuverability and agility. The focal point of this study was to explore the quadrotor control algorithms and simple design application of variable pitch propellers [24,46].

7.2 Contributions

As the main objective of this thesis:

1. Structural and manufacturing differences between variable-pitch and fixed-pitch propellers for quadrotors have been studied.
2. Electronic hardware and programming for variable pitch quadcopters have been simply described.
3. Before preparing for flight tests the test platform for rotary-wing unmanned air vehicles has been utilized.
4. The project has been gradually told for people who want to benefit from the beginning of the project to the end.
5. Flight tests have been carried out on a new design variable-pitch quadrotor.

7.3 Future Works

As it is known, it is obvious that there are disadvantages besides the advantages of single motor variable pitch quadcopter, which are different from traditional quadcopters.

One of the disadvantages is vibration on arms. To avoid this, a more sensitive tail rotor mechanism, named the collective mechanism, can be used. Furthermore, to absorb the vibration of arms, the distance between the gears should be installed in a good position as shown in Figure 7.1.

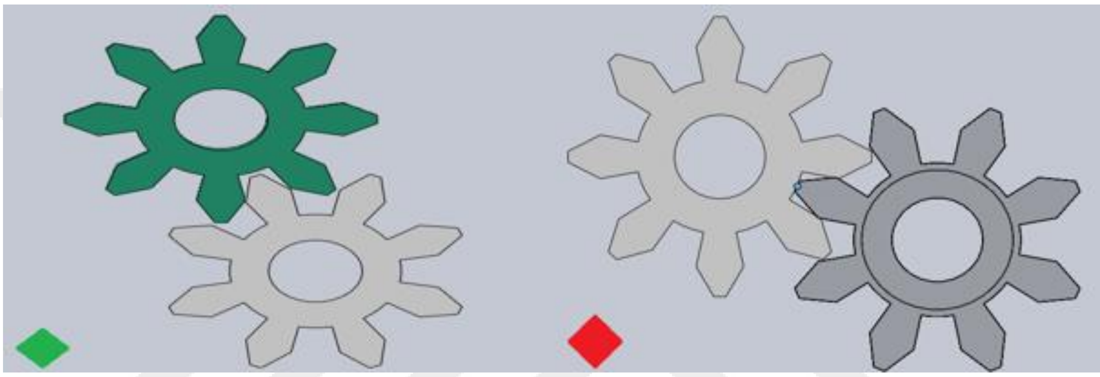


Figure 7.1 The best position between gears

In this type of Heli-Quads, which are highly maneuverable, speed rate can be increased in speeds of the servos used. The actual speed of the servo, called the application speed, is defined as the time required for the servo motor shaft to reach a certain position (normally 60 º). Generally, the application speeds of servo motors are between 0.05 s / 60 º and 0.2 s / 60 º.

Speed (7.4V): 0.12sec/60°

Speed (7.4V): 0.11sec/60°

Speed (8.4V): 0.03sec/60°

Speed (8.4V): 0.06sec/60°

Speed (8.4V): 0.07sec/60°

Each of the speeds exemplified above belongs to different servos. Speed is the most important comparison for tail rotor mechanics. Accordingly, the fastest servo should be selected for tail rotor sensitivity in each arm.

Besides, vibration absorber is given for flight controls in Figure 7.2 as mentioned in section 6. The anti-vibration apparatus can be used for a quality flight.

Figure 7.2 Anti-Vibration Shock Absorber for PIXHAWK [46]

By using GPS technology, better compass and altitude setting information can be provided to flight controls. It is also necessary for good stabilization information. Due to its single-engine, the engine and ESC count have been reduced, so the battery capacity can also be increased to increase the airborne time. Later, many things such as the Go-Home button and completing the given task can be added with the help of GPS in line with the commands given to flight controls.

Also, there are studies such as automatic landing and take off, and automatically pouring and collecting landing gear before landing and after take off.

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APPENDICES

Appendix A

The code loaded on the Arduino control board of the application made in Chapter 3, Figure 3.11 is given here.

The codding:

```
#include    <LiquidCrystal.h>

#include    <Servo.h>

#include    <I2Cdev.h>

#include    <MPU6050.h>

#include    <Wire.h>                    //MPU6050 I2C needs this library

const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;        //initialize the library by associating any needed LCD interface pin

LiquidCrystal lcd(rs, en, d4, d5, d6, d7);        //with the Arduino pin number it is connected

MPU6050 sensor;            //The MPU object is required to name

Servo actuator;               // create aeleron actuator object

int16_t accx, accy, accz; //16-bit variable is used because data coming from the sensor are 16 bit.

int16_t gyrx, gyry, gyrz;

int present, past, x ;

void setup() {

Serial.begin(9600);
```

```
lcd.begin(16, 2);               // Our LCD has 16 columns and 2 rows.

sensor.initialize();            // connection test

Serial.println(sensor.testConnection() ? "CONNECTED" : "CONNECT FAILED!!!");

lcd.print("Initializing");    // Print a message to the LCD.

actuator.attach(8);

actuator.write(90);// servo is fixed at 90 degree.

delay(50);

Serial.println ( "Initializing the ACC_GYR" );

delay (5);

Serial.println ("Taking Values from the sensor" );

delay (5);

lcd.clear();

}

void loop() {

lcd.setCursor(6,0);            // Change the cursor to column 6, line 0 // (note: line 1 is the second row):

sensor.getMotion6(&accx, &accy, &accz, &gyrx, &gyry , &gyrz); // data are collected from sensor.

present = map(accx, -17000, 17000, 0, 180); // x axis values are aligned between 0 and 180 degree.

if (present != past) {

      x =present-30;                        //Adjustment for actuator, it maybe different.

      actuator.write(x);                  // Actuator is fixed it at 90 degree.
```

```
        past = present;
        Serial.print("x ekseni:");
        Serial.println(present);
    }
delay(50);
}
```

Appendix B

In Chapter 5, the code of Matlab application shown in Figure 5.2, where the average RPM and flight time that is calculated by writing the number of engine KV, pinion gear, and main gear tooth count, as well as some battery information, are given as follows.

```
function CALCULATEButtonPushed(app, event)   %When you enter all value, press
the calculate button.

    Bat=app.BatteryratingCEditField.Value;
    Cell=app.NumberofcellsEditField.Value;
    Tooth1=app.MaingeartoothcountEditField.Value;
    Tooth2=app.PiniontoothcountEditField.Value;
    KV=app.MotorKVKiloWattEditField.Value;
    Efficiency=app.MotorpeakefficiencyEditField.Value;
    Amper=app.BatteryAmperAEditField.Value;
```

The calculation equation is as given under.

```
 AVERAGERPM=Cell*3.7*KV*(Tooth2/Tooth1)*Efficiency/100;
 app.AVERAGERPMEditField.Value=AVERAGERPM;
 Time=60*(Amper/Bat);
 app.FlihtDurationEditField.Value=Time;
```

This section is for the lamp that is next to the RPM resulting section in the app interface. For the Heli-Quad, it gives a sign signal. For example, When the green light is on, your RPM is in the good value range. If the lamp is red, your Heli-Quad RPM value is not in the good range.

```
  app.Lamp.Color='g';
elseif AVERAGERPM>15000 && AVERAGERPM<=20000
  app.Lamp.Color='1.00,0.41,0.16'; %The orange color is represented with these
numbers,
```

```
elseif AVERAGERPM>6000 && AVERAGERPM<10000
   app.Lamp.Color='1.00,1.00,0.00'; %The yellow color is represented with these
numbers,
else AVERAGERPM<6000 &&   AVERAGERPM>20000;
   app.Lamp.Color='r';
end
   x=1:1:Time;
   y=(AVERAGERPM*x)/x;
   plot(app.UIAxes,y,'b')
   end
```

Appendix C

The mechanical and electronic errors to be encountered in unexpected situations and the activity to eliminate these errors are called trouble-shooting. Some trouble shots related to ESC and remote control are given in the table provided.

Table C.1 Trouble-Shooting for ESC and Remote Control

Trouble	Possible Reason	Action
After energized to the ESC, there is no movement in the motor and non-rising audible tone even though servos work properly.	The ESC throttle calibration has not been set.	ESC calibration should be aligned according to the ESC calibration procedure.
After the battery connected to ESC connectör, motor and servos do not work and no audible signal heard.	Charge is over	Replace with a freshly charged or charge battery pack
	a soldered connection is a poor situation or oxidized	Re-solder the cable connections or clean oxides
	Poor/loose connection between battery connectors and ESC connectors	Clean connector terminals with electronic cleaner or replace the connector.
	Battery cable polarity is low acc to Amper.	Check and verify cable polarity
	ESC throttle cable connected to the receiver in the reverse polarity	Check the ESC cable connected to the ESC to ensure the connectors are in the correct polarity.
	ESC Faulty	Replace ESC with new ones
If the motor runs in the opposite direction	Cables polarity is wrong between the ESC and the motor.	Change any places of two cable of the three cable connections between the ESC and the Motor or access the Motor Rotation function via the ESC programming mode and change the pre-set parameters.
If the motor stops running in flight.	Lost throttle signal	Check the proper operation of the receiver. Check the placement of the ESC and the receiver to prevent RF interference and check the route of the receiver's aerial and ESC cables to ensure there is adequate separation.

		A ferrite ring can be installed on the ESC’s throttle cable.
No communication between the remote control and the receiver	No BIND setting	Check the BIND procedure according to the remote control and set up again
Communication is interrupted in flight	Remote control battery low	Recharge or replace the control battery.
	Receiver supply cable	Check the contact cable for contactless