WIRELESS CONTROL QUADCOPTER WITH STEREO CAMERA AND SELF-BALANCING SYSTEM

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ABSTRACT

This research focused on develops a remotely operated Quadcopter system. The Quadcopter is controlled through graphical user interface (GUI). Communication between GUI and Quadcopter is done by using wireless communication system. The Quadcopter balancing condition is sensed by FY90 controller and IMU 5DOF sensor. For smooth landing, Quadcopter is equipped with ultrasonic sensor. All signals from sensors are processed by Arduino Uno microcontroller board. Output from Arduino Uno microcontroller board used to control Quadcopter propellers. GUI is designed using Visual Basic 2008 Express as interface between control base and Quadcopter. The experiment shows that Quadcopter can hover with maintain it balancing and stability. Quadcopter can accept load disturbance up to 250g during it hover condition. Maximum operated time of Quadcopter is six minutes using 2200mAh Lipo battery and operate time can be increase by using largest battery capacity.

ABSTRAK

Penyelidikan ini memberi tumpuan membangunkan sistem Quadcopter yang dikendali secara jarak jauh. *Graphical user interface (GUI)* digunakan untuk mengawal *Quadcopter*. Komunikasi antara GUI dan Quadcopter menggunakan alat komunikasi tanpa wayar yang dikenali sebagai *Xbee*. Pengimbangan Quadcopter dikawal oleh *FY90* dan *IMU 5DOF*. *Quadcopter* dilengkapi dengan sensor *ultrasonic* bagi tujuan pendaratan. Semua isyarat daripada sensor diproses oleh mikropengawal *Arduino Uno*. Output dari mikropengawal *Arduino Uno* digunakan untuk mengawal pergerakan *Quadcopter*. GUI direka dengan menggunakan perisian Visual Basic 2008 berfungsi berinteraksi dengan XBee untuk tujuan komunikasi antara komputer dan *Quadcopter*. Eksperimen menunjukkan bahawa *Quadcopter* boleh berfungsi dengan mengekalkan keseimbangan dan kestabilan. *Quadcopter* boleh menerima beban sehingga 250g. Masa operasi maksimum *Quadcopter* ialah selama enam minit dengan menggunakan bateri berkuasa 2200mAh Lipo dan masa operasinya masih dapat ditingkatkan dengan menggunakan batteri yang kuasa lebih tinggi.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Research and development of unmanned aerial vehicle (UAV) and micro aerial vehicle (MAV) are getting high encouragement nowadays, since the application of UAV and MAV can apply to variety of area such as rescue mission, military, film making, agriculture and others. In U.S. Coast Guard maritime search and rescue mission, UAV that attached with infrared cameras assist the mission to search the target [1].

Quadcopter or quad rotor aircraft is one of the UAV that are major focuses of active researches in recent years. Compare to terrestrial mobile robot that often possible to limit the model to kinematics, Quadcopter required dynamics in order to account for gravity effect and aerodynamic forces [2]. Quadcopter operated by thrust that produce by four motors that attached to it body. It has four input force and six output states (x, y, z, θ, ψ, ω) and it is an under-actuated system, since this enable Quadcopter to carry more load [3].

Quadcopter has advantages over the conventional helicopter where the mechanical design is simpler. Besides that, Quadcopter changes direction by manipulating the individual propeller's speed and does not require cyclic and collective pitch control [4].

1.2 Problem statement

The main problem in Quadcopter is the balancing and stability system. Most of Quadcopter will be unbalance and lost stability in case there are disturbance direct on it such as wind. In this research, to solve above problem the full system of Quadcopter is design and construct. Graphical user interface (GUI) is design in this research to make control task of Quadcopter easier.

1.3 Project objectives

The objectives of this project are:

(a) To design Quadcopter that can control wireless base on computer.
(b) To design graphical user interface to communicate and control Quadcopter.
(c) To equip Quadcopter with stereo camera to display video.
(d) To test the performance of designed Quadcopter.

1.4 Project scopes / constrains

The scopes include the weather condition, distance and space:

(a) Quadcopter only can operate in sunny day or dry condition.
(b) Quadcopter operate distance not more than 100m in eye sight from the wireless receiver.
(c) Quadcopter is control by Arduino base microcontroller.
(d) Quadcopter is operated by brushless motor control by electronic speed controller.

1.5 Report outline

This report divided into six chapters. The first chapter is research introduction. This chapter will discuss about problem statement, research objective and scope. Chapter two is discuss the previous study of Quadcopter design and technology for controller that has been developed by researches in same field. In chapter three, it is discuss about methodology to design and construct of Quadcopter. Chapter four is discuss about result and analysis for this research. Conclusion and recommendation are discuss in chapter five of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to run “Wireless Control Quadcopter with Stereo Camera and Self Balancing System” research, several theoretical and techniques are need review through previous related research report. The review includes the technology development and control method that used in Quadcopter.

2.2 Technology development

Park *et.al.* (2001) studied on the 3-DOF attitude control free-flying vehicle. The characteristic to be heavily coupled with inputs and outputs, and the serious non-linearity appear in the flying vehicle and due to this non-linear control, multi variable control or optimal control for the attitude control of flying Quadcopter. This research result is illustrated in Figure 2.1.

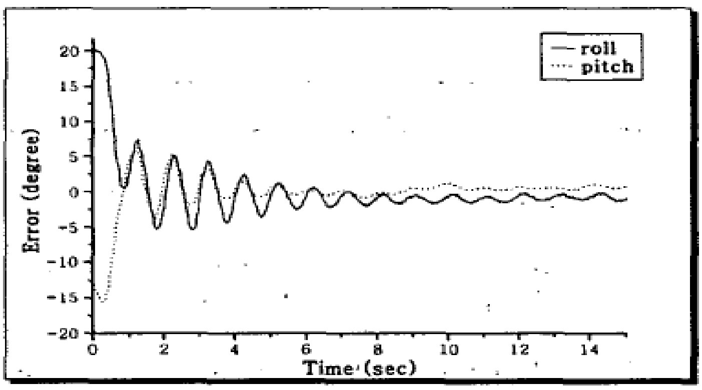

Figure 2.1: Result of 3-DOF attitude control

Ashfaq Ahmad Mian *et.al.*(2007) developed of nonlinear model and nonlinear control strategy for a 6-DOF Quadcopter aerial robot. The nonlinear model of Quadcopter aerial robot is based on Newton-Euler formalism. Model derivation comprises determining equations of motion of the Quadcopter in three dimensions and seeking to approximate actuation forces through modelling of the aerodynamic coefficients and electric motor dynamics. The respective of the applied control is described in Figure 2.2.

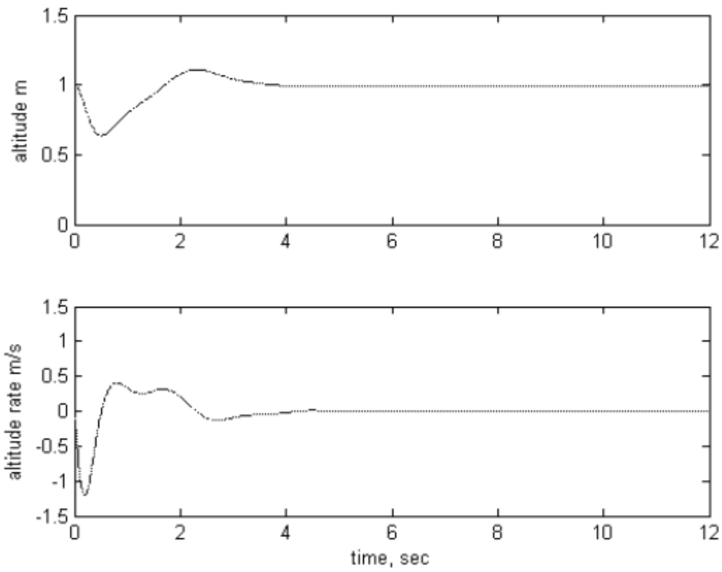

Figure 2.2: Altitude control of Quadcopter

Achtelik *et.al.* (2009) done research on control of Quadcopter by visual tracking using stereo camera. The motion of a Quadcopter is control based on visual feedback and measurement of inertial sensor. In this research, active markers were finely designed to improve visibility under various perspectives. The structure of Quadcopter controller used in this research is shows in Figure 2.3.

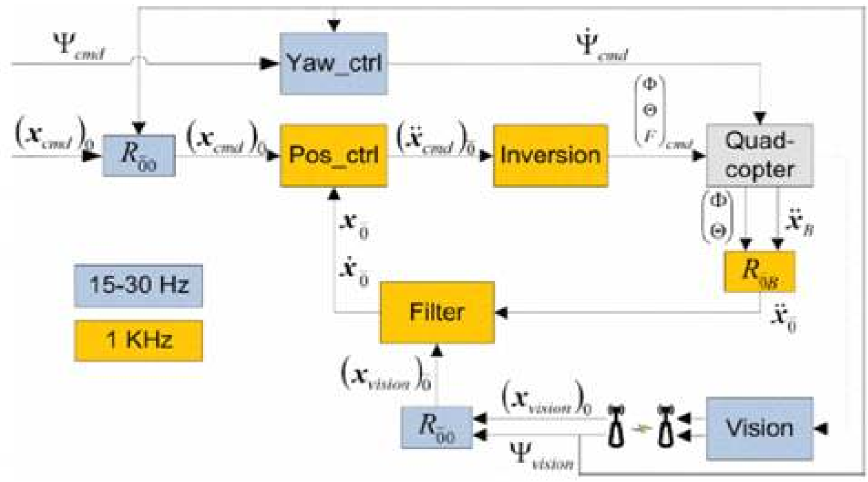

Figure 2.3: System structure

Santos *et.al.* (2010) works on intelligent fuzzy controller of Quadcopter. A fuzzy control is designed and implemented to control a simulation model of the Quadcopter. The inputs are the desired values of the height, roll, pitch and yaw. The outputs are the power of each of the four rotors that is necessary to reach the specifications. Simulation results prove the efficiency of this intelligent control strategy is acceptable. Figure 2.4 represented the fuzzy controller in this research.

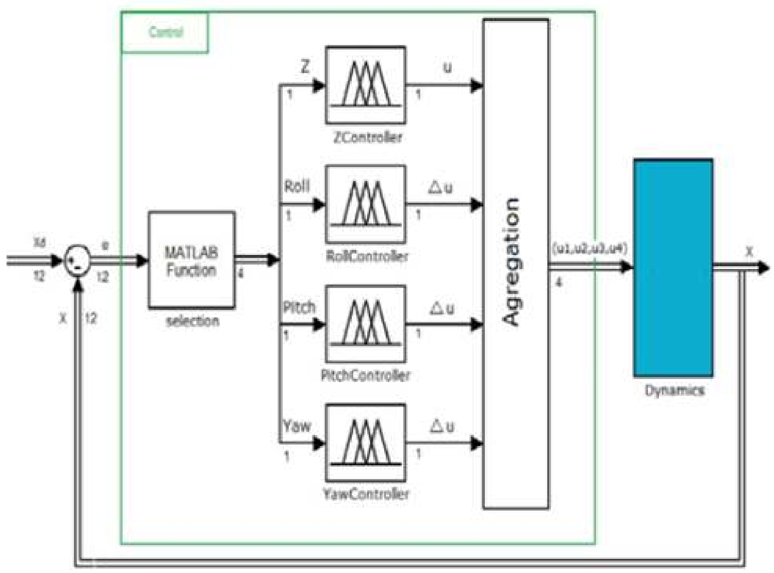

Figure 2.4: Control diagram using Fuzzy controller

Jun Li *et.al.* (2011) is done research to analyze the dynamic characteristics and PID controller performance of a Quadcopter. This paper is describe the architecture of Quadcopter and analyzes the dynamic model on it. Besides that, this paper also designs a controller which aim to regulate the posture (position and orientation) of the 6-DOF Quadcopter. Simulink model of PID controller and flying result done in this research are described in Figure 2.5 and 2.6. Summarizing and comparison of all previous work of Quadcopter are listed in Table 2.1.

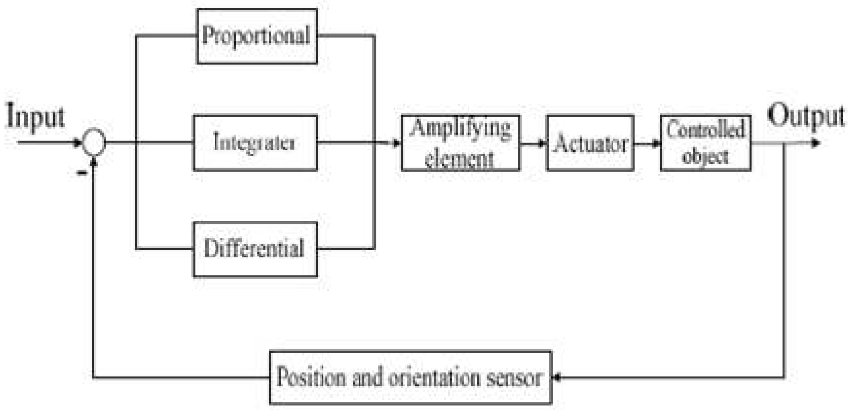

Figure 2.5: Simulink model of PID controller

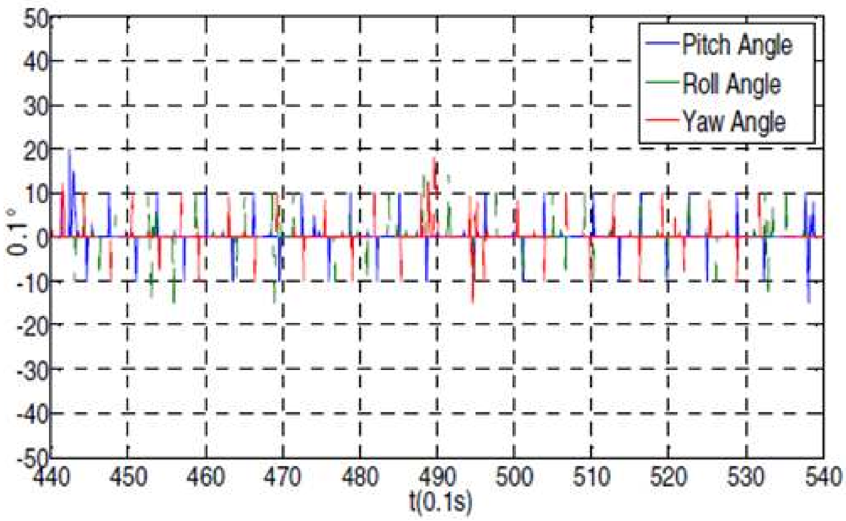

Figure 2.6: Test result of the Flying Experiment

Table 2.1: Summarize and comparison of Quadcopter previous work.

No.	**Research Title**	**Advantages**	**Disadvantages**
1.	3-DOF attitude control free-flying vehicle	Simple and basic of controller design.	Limited degree of freedom (Only 3-DOF applies).
2.	Nonlinear model and nonlinear control strategy for a 6-DOF Quadcopter aerial robot	Compensate the initial error, stabilize roll, pitch and yaw angles and maintain them at zero.	Only design for balancing during hover position of Quadcopter
3.	Control of Quadcopter by visual tracking using stereo camera	The tracking system is highly transportable, easy to set up.	Sensitive to light and not suitable to use at high illumination area
4.	Intelligent fuzzy controller of Quadcopter	Fuzzy controller has fast dynamic response and small overshoot	Controller design is too complex
5.	Analyze the dynamic characteristics and PID controller performance of a Quadcopter	Strong adaptive ability	The system will be unstable if the value of Kp, Ki and Kd is not consistent.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will divide into two phases. The first phase is understanding the Quadcopter structure and it basic mathematical modeling. The last phase is deals with design and construction of the Quadcopter. It will be built by splitting the design into different component whereby each component will be tested to ensure its working properly. This step is to minimize the risk of accidents which will lead to increasing number of component cost.

3.2 Flow chart

Designs of Quadcopter are divided into two stages that is part design in first stage and full interface at second stage. Flow chart of Quadcopter design is described in Figure below:

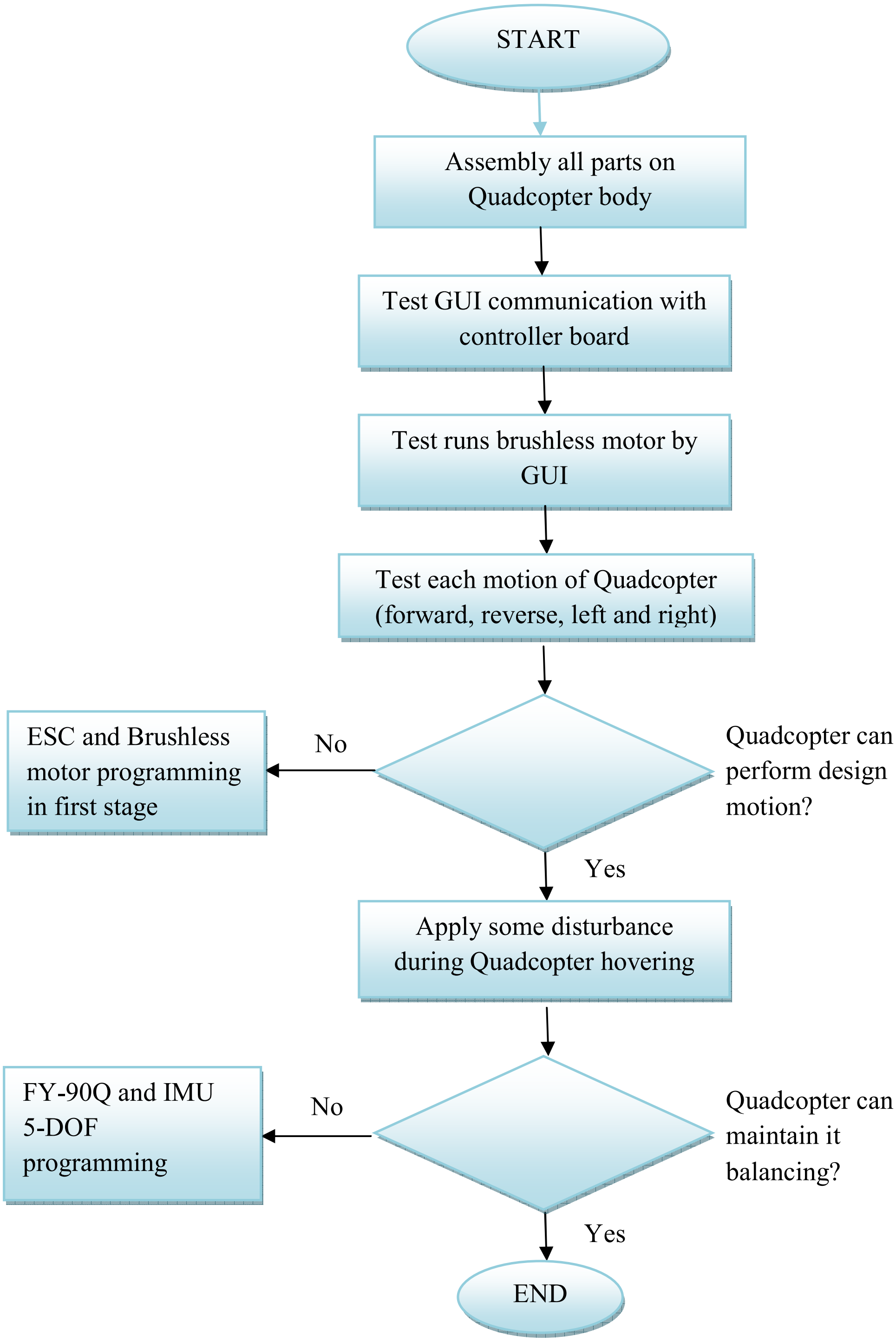

Figure 3.1: Flow chart of Quadcopter design

3.3 Quadcopter movement mechanism

Quadcopter can described as a small vehicle with four propellers attached to rotor located at the cross frame. This aim for fixed pitch rotors are use to control the vehicle motion. The speeds of these four rotors are independent. By independent, pitch, roll and yaw attitude of the vehicle can be control easily. Pitch, roll and yaw attitude off Quadcopter are shown in Figure 3.2, 3.3 and 3.4.

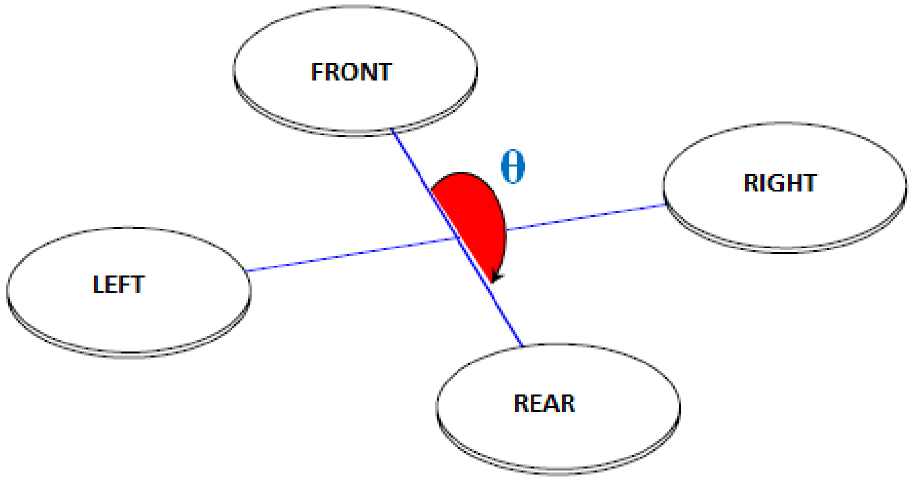

Figure 3.2: Pitch direction of Quadcopter

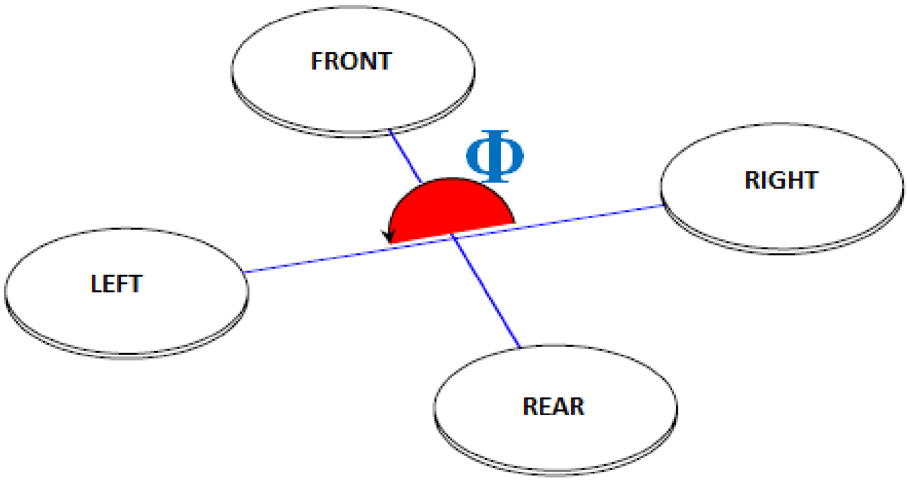

Figure 3.3: Roll direction of Quadcopter

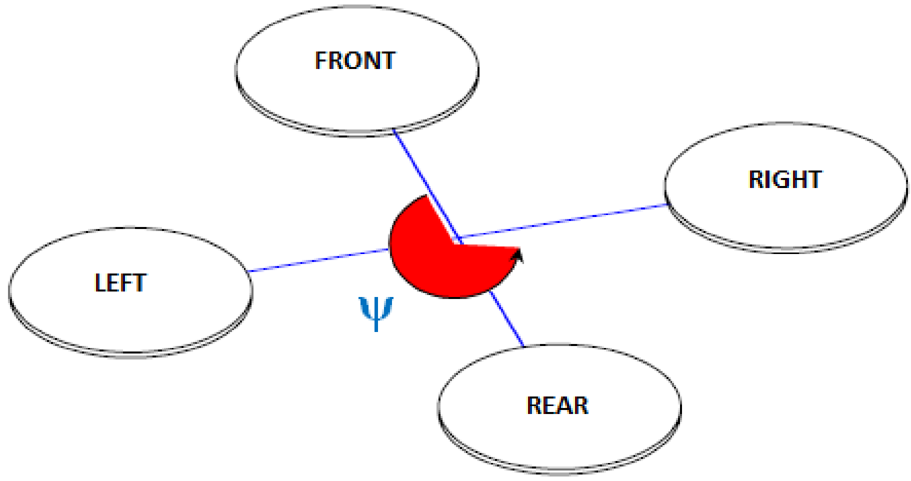

Figure 3.4: Yaw direction of Quadcopter

Quadcopter have four inputs force and basically the thrust that produced by the propeller that connect to the rotor. The motion of Quadcopter can control through fix the thrust that produced. These thrust can control by the speed of each rotor.

3.3.1 Take-off and landing motion mechanism

Take-off is movement of Quadcopter that lift up from ground to hover position and landing position is versa of take-off position. Take-off (landing) motion is control by increasing (decreasing) speed of four rotors simultaneously which means changing the vertical motion. Figure 3.5 and 3.6 illustrated the take-off and landing motion of Quadcopter respectively.

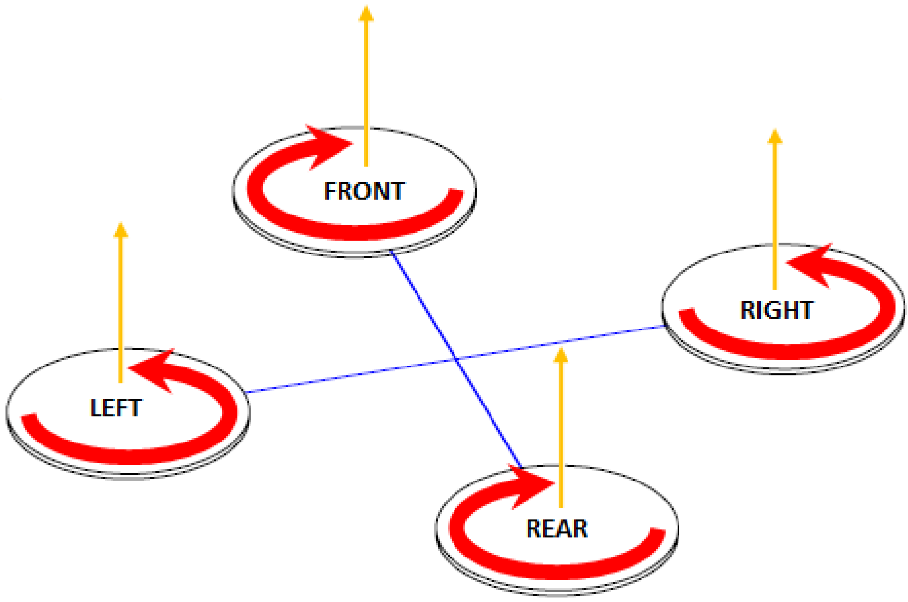

Figure 3.5: Take-off motion

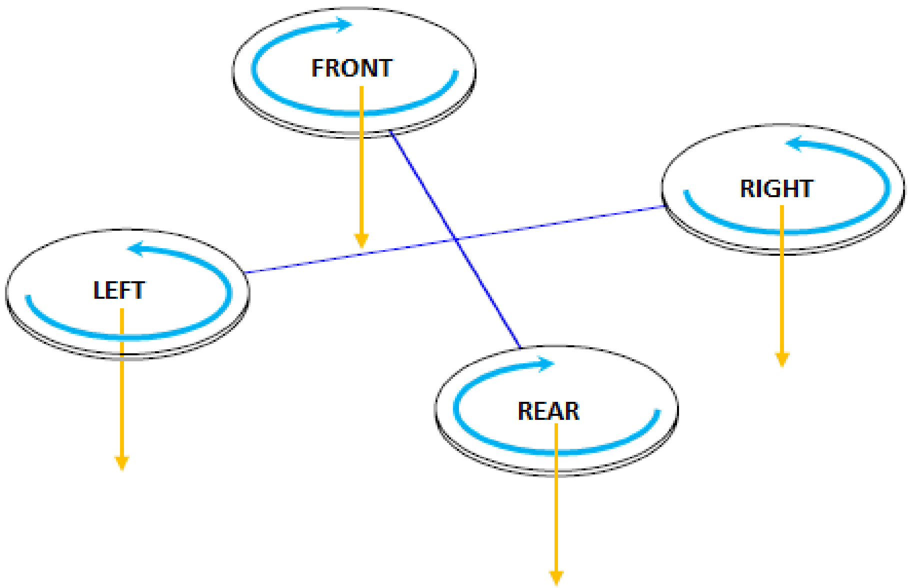

Figure 3.6: Landing motion

3.3.2 Forward and backward motion

Forward (backward) motion is control by increasing (decreasing) speed of rear (front) rotor. Decreasing (increasing) rear (front) rotor speed simultaneously will affect the pitch angle of the Quadcopter. The forward and backward motions of Quadcopter are represented in Figure 3.7 and 3.8 respectively.

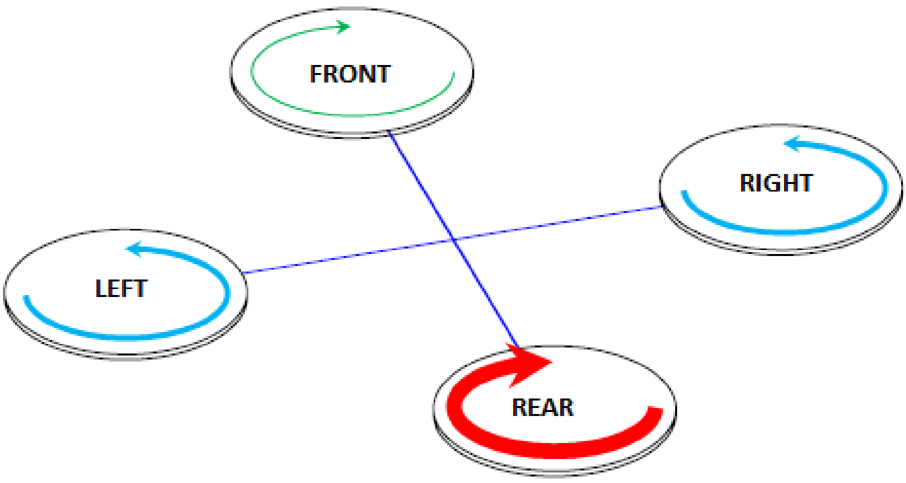

Figure 3.7: Forward motion

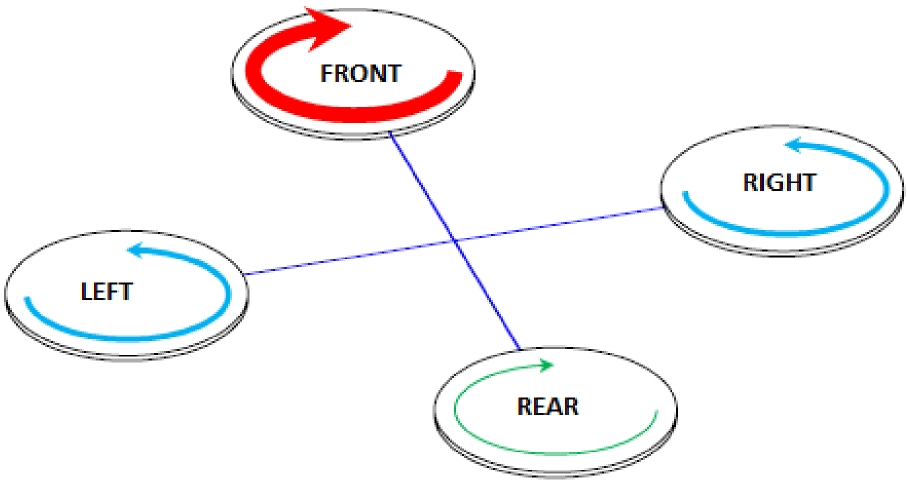

Figure 3.8: Backward motion

3.3.3 Left and right motion

For left and right motion, it can control by changing the yaw angle of Quadcopter. Yaw angle can control by increasing (decreasing) counter-clockwise rotors speed while decreasing (increasing) clockwise rotor speed. Figure 3.9 and 3.10 show the right and left motion of Quadcopter.

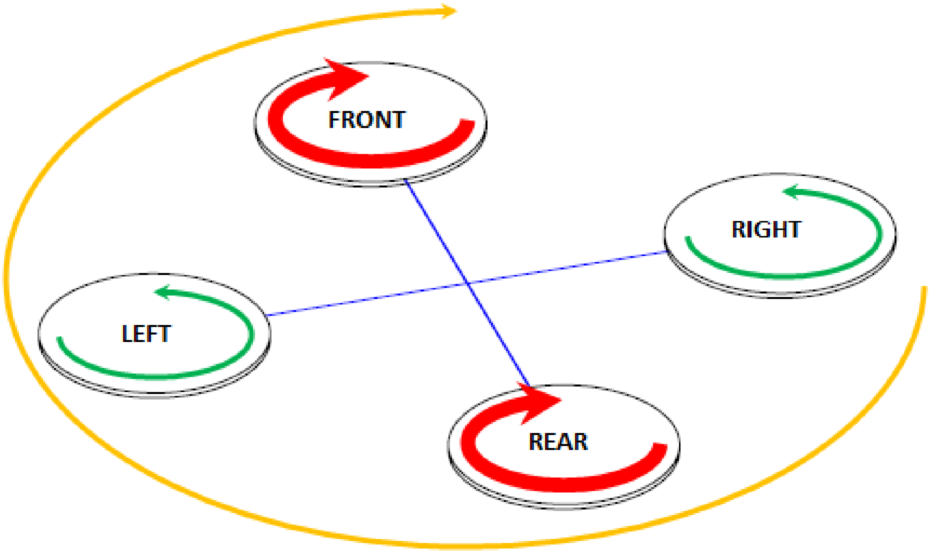

Figure 3.9: Right motion

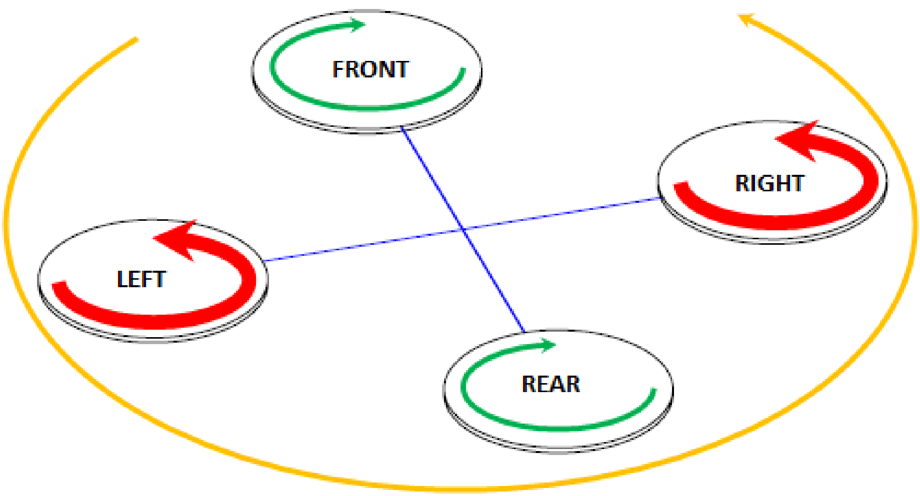

Figure 3.10: Left motion

3.3.4 Hovering or static position

The hovering or static position of Quadcopter is done by two pairs of rotors are rotating in clockwise and counter-clockwise respectively with same speed. By two rotors rotating in clockwise and counter-clockwise position, the total sum of reaction torque is zero and this allowed Quadcopter in hovering position.

3.4 Quadcopter mathematical modeling

The schematic movement of Quadcopter is represented in Figure 3.11 and based on this schematic, the Quadcopter mathematical modeling is derived as below[10]:

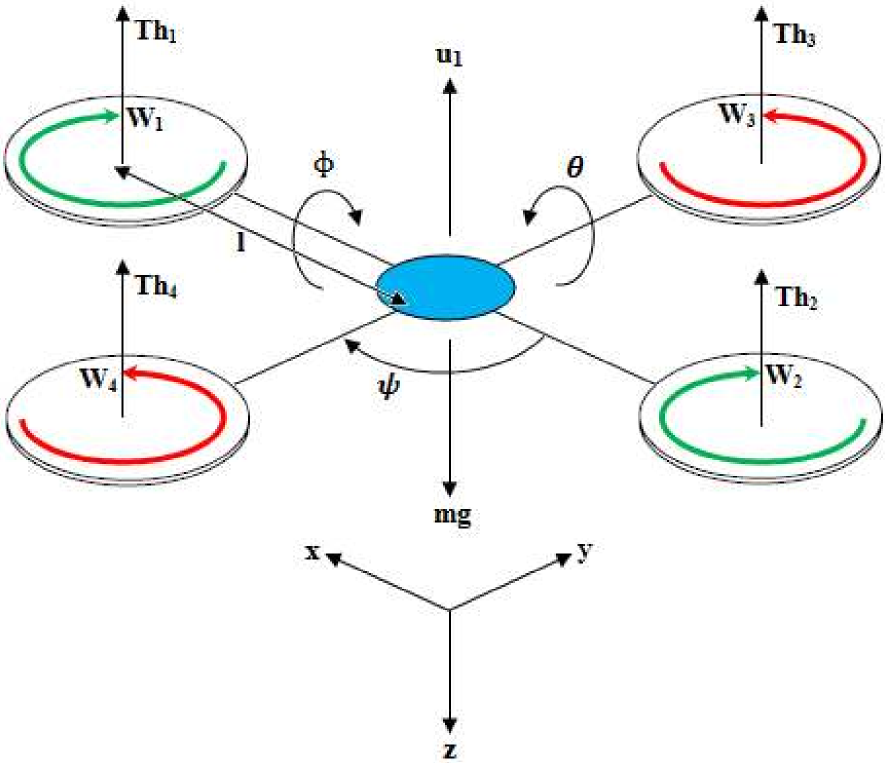

Figure 3.11: Schematic of Quadcopter

Where,

U_1 = sum of the thrust of each motor

Th_1= thrust generated by front motor

Th_2= thrust generated by rear motor

Th_3= thrust generated by right motor

Th_4= thrust generated by left motor

m = mass of Quadcopter

g = the acceleration of gravity

l = the half length of the Quadcopter

x, y, z = three position

θ, ϕ, ψ = three Euler angles representing pitch, roll, and yaw

The dynamics formulation of Quadcopter moving from landing position to a fixed point in the space is given as:

$$Rxyz = \begin{bmatrix} C\phi C\theta & C\phi S\theta S\psi - S\phi C\psi & C\phi S\theta C\psi + S\phi S\psi \\ C\phi S\theta & S\phi S\theta S\psi + C\phi C\psi & S\phi S\phi C\psi - C\phi S\psi \\ -S\theta & C\theta S\psi & C\theta C\psi \end{bmatrix} \quad (3.1)$$

Where,

R = matrix transformation

$S\theta$ = Sin (θ), $S\phi$= Sin (ϕ), $S\psi$= Sin (ψ)

$C\theta$ = Cos (θ), $C\phi$= Cos (ϕ), $C\psi$= Cos (ψ)

By applying the force and moment balance laws, the Quadcopter motion equation are given in Equation (3.2) till (3.4) and Pythagoras theorem is computed as Figure 3.12.

$$\ddot{x} = u_1\,(\mathrm{Cos}\phi\mathrm{Sin}\theta\mathrm{Cos}\psi + \mathrm{Sin}\phi\mathrm{Sin}) - K_1\dot{x}/m \quad (3.2)$$

$$\ddot{y} = u_1\,(\mathrm{Sin}\phi\mathrm{Sin}\theta\mathrm{Cos}\psi + \mathrm{Cos}\phi\mathrm{Sin}) - K_2\dot{y}/m \quad (3.3)$$

$$\ddot{z} = u_1\,(\mathrm{Cos}\phi\mathrm{Cos}\psi) - g - K_3\dot{z}/m \quad (3.4)$$

Where,

Ki = drag coefficient (Assume zero since drag is negligible at low speed)

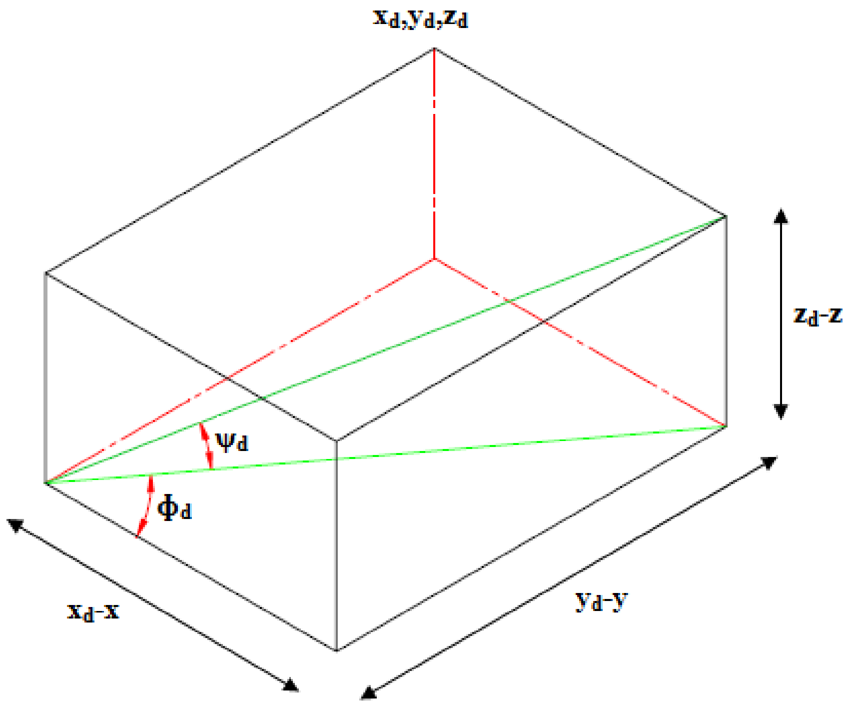

Figure 3.12: Angle movement of Quadcopter

The angle ϕ_d and ψ_d in Figure 3.12 are determined using Equation (3.5) and (3.6) respectively.

$$\phi_d = \tan^{-1}\left(\frac{yd-y}{xd-x}\right) \tag{3.5}$$

$$\psi_d = \tan^{-1}\left(\frac{zd-z}{\sqrt{(xd-x)^2+(yd-y)^2}}\right) \tag{3.6}$$

Quadcopter have four controller input forces U_1, U_2, U_3, and U_4 that will affects certain side of Quadcopter. U_1 affect the attitude of the Quadcopter, U_2 affects the rotation in roll angle, U_3 affects the pitch angle and U_4 control the yaw angle. To control the Quadcopter movement is done by controlling each input variable. The equations of them are as below:

$$U \begin{cases} U_1 = (Th_1 + Th_2 + Th_3 + Th_4) / m \\ U_2 = l\,(-Th_1 - Th_2 + Th_3 + Th_4) / I_1 \\ U_3 = l\,(-Th_1 + Th_2 + Th_3 - Th_4) / I_2 \\ U_4 = l\,(Th_1 + Th_2 + Th_3 + Th_4) / I_3 \end{cases} \tag{3.7}$$

Where,

Th_i = thrust generated by four motor

C = the force to moment scaling factor

I_i = the moment of inertia with respect to the axes

Then the second derivatives of each angle are:

$$\ddot{\theta} = U_2 - lK_4\dot{\theta}/I_1 \tag{3.8}$$

$$\ddot{\psi} = U_3 - lK_5\dot{\psi}/I_2 \tag{3.9}$$

$$\ddot{\phi} = U_1 - lK_6\dot{\phi}/I_3 \tag{3.10}$$

3.5 Component requirement

Component that required is divided into two parts that are hardware and software. Figure 3.13 shows the major component of Quadcopter that are used. FY-90Q is applied as auto balance controller of Quadcopter based on input signal from IMU 5-DOF sensor. The signal produced by Arduino Uno to control four brushless motor of Quadcopter through FY-90Q. The Quadcopter body must be rigid and light weight in order to minimize the Quadcopter weigh. For software part, Microsoft visual basic 2008 is used to design GUI as interface between control base and Quadcopter.

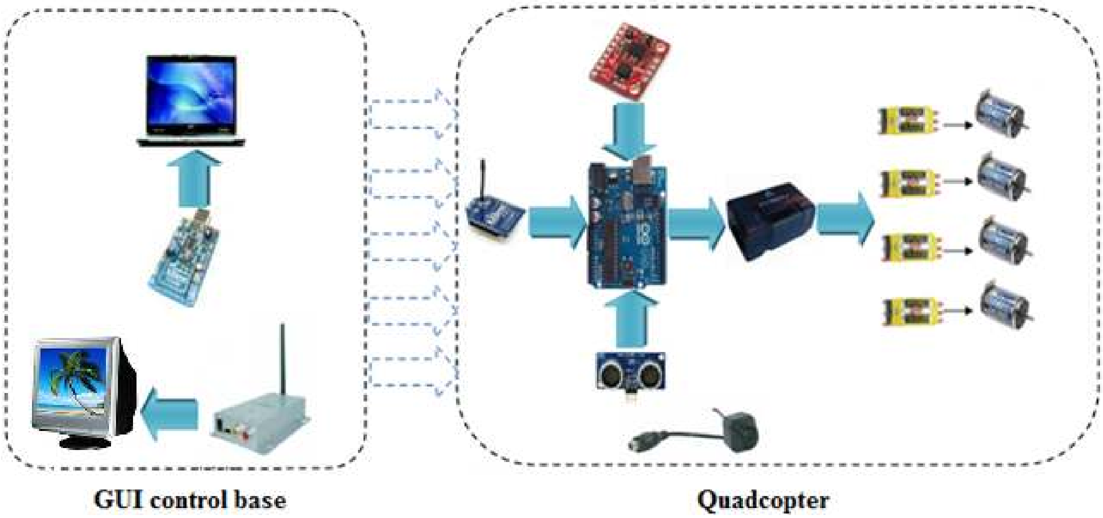

Figure 3.13: Major components of Quadcopter

3.6 Schematic diagram and PCB layout

The schematic diagram of the circuit in this project is design using PROTUES software. Certain procedure has to be done to ensure the circuit is satisfying the needs of this project. The circuit board includes controller circuit, PPM signal pin, IMU 5-DOF sensor, PING sensor pin and XBee wireless port. This circuit board is designed to attach with Arduino Uno board and Figure 3.14 represented the circuit design flow.

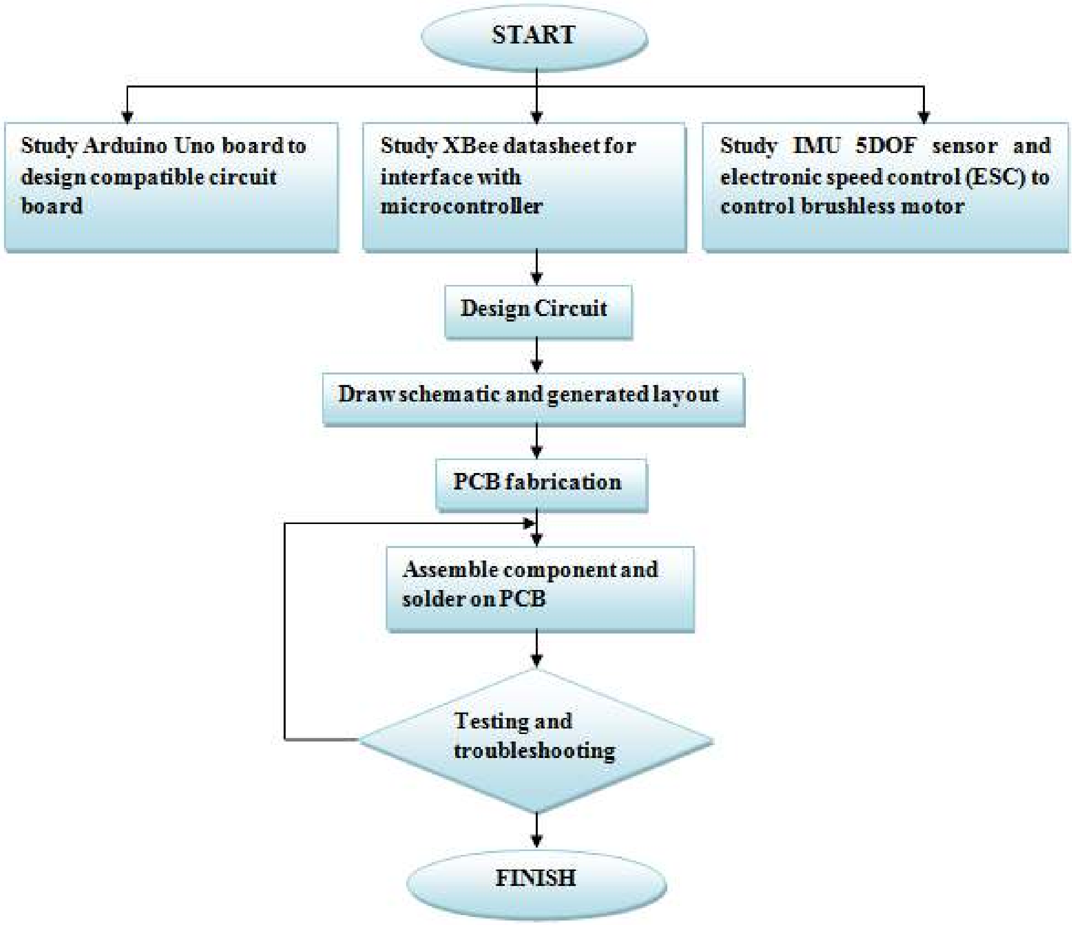

Figure 3.14: Flow chart of circuit board design

Figure 3.15 till 3.17 described the connection of Arduino Uno board and its pin assignments as listed in Table 3.1. The schematic electronics circuit is design using Proteus Ares software. For simple form the circuitry are drawn in double layer PCB. Figure 3.19 and 3.20 illustrated the PCB layout and Figure 3.21 shows the completed fabricated.

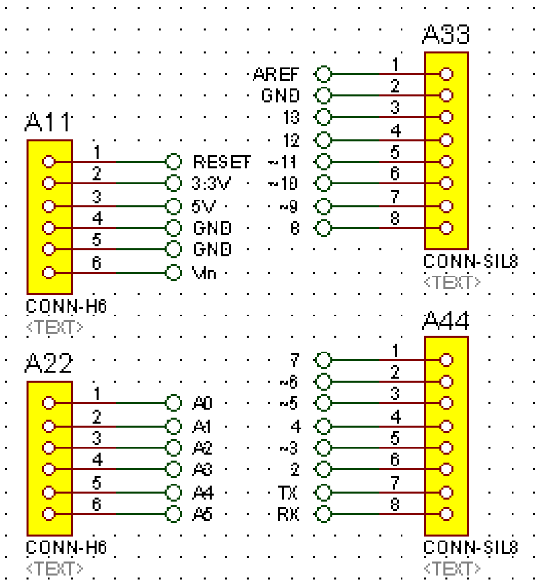

Figure 3.15: Schematic of Arduino Uno pin attach by ISIS

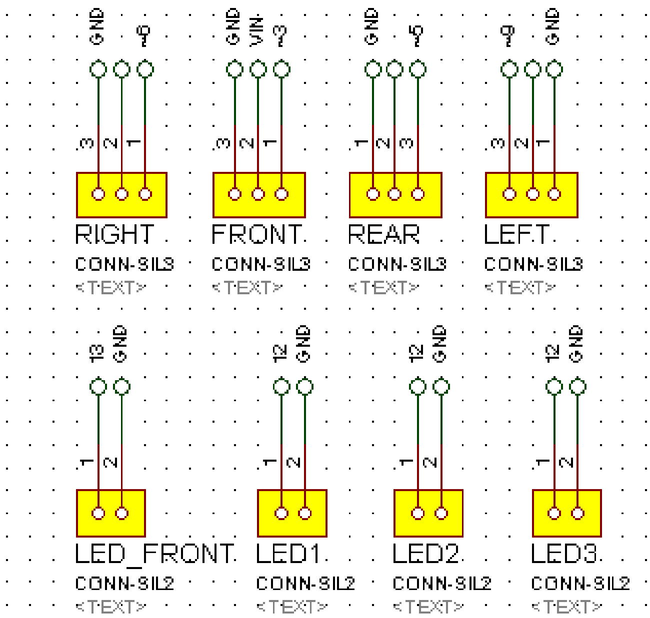

Figure 3.16: Schematic of brushless motor pin and led pin attach by ISIS

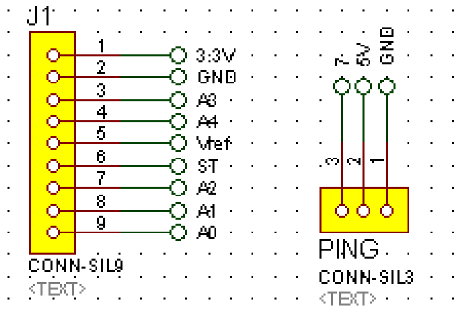

Figure 3.17: Schematic of IMU 5DOF and ping sensor pin attach by ISIS

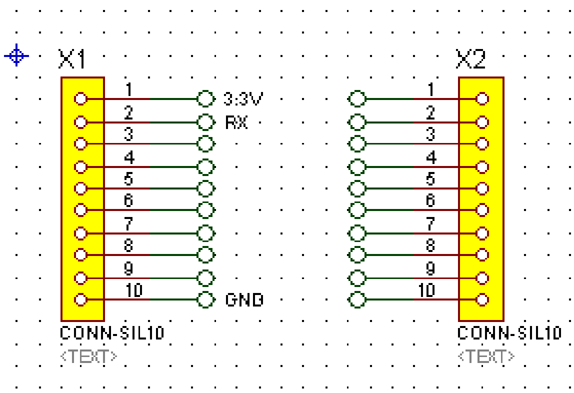

Figure 3.18: Schematic of XBee pin attach by ISIS

Table 3.1: Component and Arduino Uno pin assign.

	PIN	**ARDUINO UNO PIN**
XBEE	1	3.3V
	2	0
	3	1
	10	GND
PING Sensor	1	GND
	2	5V
	3	7
IMU 5DOF	1	3.3V
	2	GND
	3	A3
	4	A4
	5	-
	6	-
	7	A2
	8	A1
	9	A0

Table 3.1: (continued).

PPM 1	-	3
PPM 2	-	5
PPM 3	-	6
PPM 4	-	9
LED 1	-	13
LED 2	-	12
LED 3	-	12
LED 4	-	12

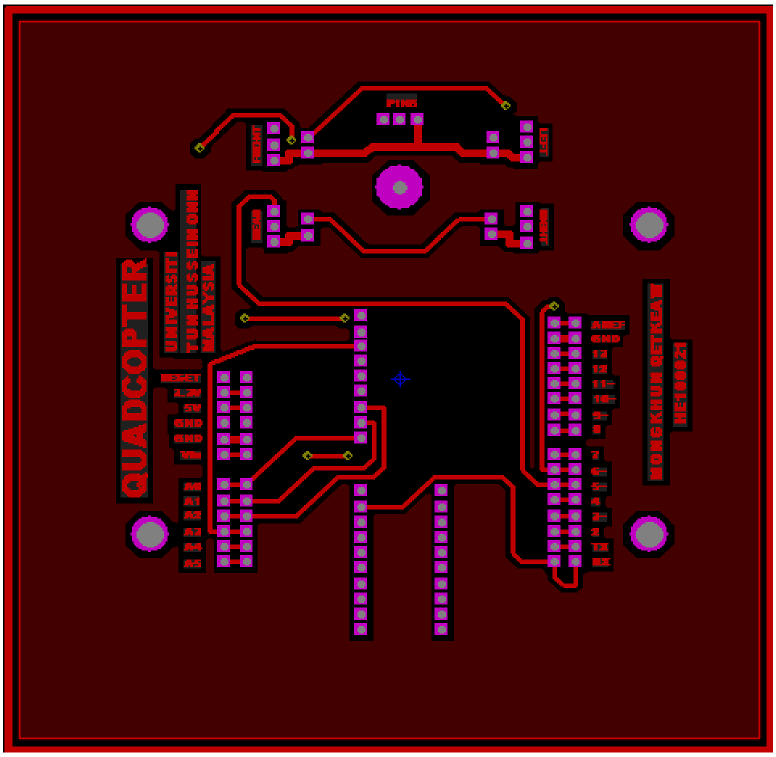

Figure 3.19: PCB layout of circuit board using Proteus ARES (Top side)

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