Design and Development of Unmanned Aerial Vehicle (Drone) for Civil Applications

Thesis Project

A Thesis submitted to the Dept. of Electrical & Electronic Engineering, BRAC University in partial fulfillment of the requirements for the Bachelor of Science degree in Electrical & Electronic Engineering

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DECLARATION

We hereby declare that the thesis titled "Design and Development of Unmanned Aerial Vehicle (Drone) for Civil Applications" is submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is work was not submitted elsewhere for the award of any other degree or any other publication.

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Abstract

UAV is defined as an aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expandable or recoverable, and can carry a lethal or nonlethal payload. It is controlled either autonomously by on-board computers or by remote control of a pilot on the ground. Its usage is currently limited by difficulties such as satellite communication and cost. A Drone has been built that can be operated by radio frequency controller and send live audio-visual feedback. The developed Drone control system has been simulated in MATLAB/Simulink. The simulation shows a very stable operation and control of the developed Drone. Microcontroller based drone control system has also been developed where a RF transmitter and receiver operating in the frequency of 2.4 GHz are used for remote operation for the Drone. Earlier, Drones were deployed for military applications such as spying on both domestic and international threats. The developed drone in this work can be used for a number of applications, such as policing, firefighting, monitoring flood effected areas, recording video footage from impassable areas and both military and non-military security work. In addition, using an Android mobile device incorporation with GPS has been used for live position tracking of Drone and real time audio-visual feedback from Drone.

Keywords: Drone, Unmanned Aerial Vehicle, Aerial surveillance.

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Abbreviations

UAV: Unmanned Aerial Vehicle

BLDC : Brushless Direct Current

P: Proportional

MATLAB: Matrix Laboratory

M-file: MATLAB text editor file

ESC: Electronic Speed Controller

GPS: Global Positioning System

3G: Third generation mobile network

Chapter 1

1.1 Introduction

Unmanned aerial vehicles (UAV) are more properly known as Drone. Basically, drone is a flying robot [1]. Working in combination with GPS, the flying machine may be remotely controlled or can fly autonomously by software controlled flight plans in their embedded systems. Drones are most often used in military services. However, it is also used for weather monitoring, firefighting, search and rescue, surveillance and traffic monitoring [2] etc. In recent years, the drone have come into attention for a number of commercial uses. In late 2013, Amazon announced a plan to use unmanned aerial vehicles for delivery in the nearby areas future [1]. It is known as Amazon Prime Air, it is estimated to deliver the orders within 30 minutes inside 10 miles of distance [1]. So it is clear that domestic usage of UAV has vast future possibility in different fields rather than military usage.

Drones for military use were started in the mid-1990s with the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstrator (HAE UAV ACTD) program managed by the Defense Advanced Research Projects Agency (DARPA) and Defense Airborne Reconnaissance Office (DARO) [3]. This ACTD placed the base for the improvement of the Global Hawk. The Global Hawk hovers at heights up to 65,000 feet and flying duration is up to 35 hours at speeds approaching 340 knots and it costs approximately 200 million dollars [4]. The wingspan is 116 feet and it can fly 13.8094 miles which is significant distance [4]. Motherland security and drug prohibition are the main needs Global Hawk was designed for [5]. Another very successful drone is the Predator which was also built in the mid-1990s but has since been improved with Hellfire missiles. “Named by Smithsonian’s *Air & Space* magazine as one of the top ten aircraft that changed the world, Predator is the most combat-proven Unmanned Aircraft System (UAS) in the world” [6]. The original version of the Predator, built by General Atomics, can fly at 25,000 feet for 40 hours at a maximum airspeed of 120 [6].

1.2 Issues

Issues of drones can be classified in different ways like morally, ethically and legally. In many country’s drone is not permitted to fly openly, but in some advance country is now allowing drone for social purposes. Also there is a build up a decent drone marketplace in Singapore [16] but from ethical point of view it has some conflict using drone. Military drone manufacturers are also looking for an upgrade civilian uses for remote sensing drones to spread their markets and this includes the use of drones for surveillance where it’s needed. Drones will no doubt make possible the dramatic change in the surveillance state [15]. With the convergence of other technologies it may even make possible machine recognition of faces, behaviors, and the monitoring of individual conversations.

In the absence of government clearness, civil society has lead substantial research on drone strikes. The Bureau of Investigative Journalism, a not-for-profit organization based at City University, London, has published figures that give some logic of the scale of such US operations [17]. To illustrate, according to the Bureau between 2004 and 2012 there have been 330 attacks in Pakistan, with the entire reported quantity killed being between 2479 and 3180 people (and more than 1,000 other people being injured); and between 44 and 54 confirmed US operations in Yemen (with 31 to 41 drone strikes), with a possible further 87 to 96 operations (including 49 to 55 drone strikes) [15]. The total number reported killed was between 317 and 826 people. Activists for drones argue that drone operator’s distance from the battlefield allows them to base their decisions on a range of supporting data types. However, it is more likely that the greater the physical and emotional distance to a target, the easier it is to kill. There is no empirical evidence that shows that the support data enables greater legal and ethical decision making processes. Statistically the world has seen numerous civilian casualties from drone strike, which depicts that drones further dehumanize war. The rapporteur also highlighted the creating of a PlayStation mentality, where drone operators tend to regard their actions as a computer game.

However, in this thesis project mainly we are designing the Roll $T_{roll}(s)$, pitch $T_{pitch}(s)$ and yaw $T_{pitch}(s)$ angle control system design and simulation of the designed control system. In addition, we are going to integrate android mobile device, GPS and 3G communication technologies to gather real time audio visual geo location information.

1.3 Review

Many methodologies have been tried to improve real-world aircraft with vertical take-off and landing abilities. First, Nikola Tesla introduced a vertical take-off and landing vehicle concept in 1928. Advanced VTOL aircrafts uses a single engine with thrust vectoring. Thrust vectoring illustrates that the aircraft can send thrust from the engine in different directions, so that vertical and horizontal fight can be controlled by one engine [7]. The Harrier Jump Jet is one of the most famous and successful fixed-wing single-engine VTOL aircraft. In the 21st century, UAVs are becoming progressively conventional. Many of these have VTOL capability, especially the quad copter type. We were also interested by the requirements of DARPA’s UAVforge, while studying large and tiny UAVs competition which was posted around the time we started our project. The

UAVforge contest us basically to design and build a micro-UAV that can take off vertically, go to the destination and surveillance the area for three hours.

We know transporting and resupplying troops is a great challenge in war field. To meet this challenge DARPA initiated a program in 2010 demonstrating four person vertical takeoff and landing vehicle. Lockheed Martin's Skunk Works® is foremost a group with Piasecki Aircraft to improve the next generation of dynamic vertical takeoff and landing (VTOL) transport systems under the ARES program [8]. ARES VTOL flight unit is designed to work as an unmanned platform capable of transferring a variety of payloads. The flight unit has built in digital flight controls, remote command-control interfaces, power system and gasoline. Twin tilting ducted fans would deliver effective flying and landing abilities in a compact structure. It is capable of rapid change to high-speed travel voyage. However, this project is under development now. Our project has similarities with this Lockheed Martin's research and the flying methodology is partially similar to their machine.

On the other hand, using drone in firefighting has already been taken place in history. An unmanned Predator B aircraft helped firefighters and saved many lives in 2007 in southern California [9]. It delivered firefighters up-to-the-minute information.

In addition to the military practices of the drones, we were concerned in evaluating applications in the industrial, commercial and as well as government sector. In addition, new markets and uses will emerge if small drones are very available. Potential new markets in business and modern applications incorporate reviewing pipelines or actually investigating perilous regions like an emergency site at an atomic force plant [4]. Harvest evaluation or natural disaster aid seems also to be possible areas where small drones could be beneficial [4]. Although the designs of different

UAVs are charming, our interest was in attempting to produce a small UAV which could support a broad mission capability.

1.4 Objective

As has been already stated in the abstract, this thesis is turning around an unmanned flying vehicle called drone. The aim of this thesis is to find an appropriate mathematical model for such a machine and develop a complete control architecture which will allow the drone to fly. Using this features then we develop our UAV, for observation and scouting missions for civilian or even military personnel. An UAV (Unmanned Aerial Vehicle) with precise payloads can hover straight above the fire zone to record video of the fire line, as well as thermal images that are then geo-tagged and communicated in real time to mobile command centers using the planning and monitoring system for firefighting [10]. From the experience of the last few years, we have seen that many garments factories and markets burned in Bangladesh. So if we surveillance the affected area by UAV, then we can get a proper direction and make decision from where to extinguish fire. At the same time we can send a UAV close to the fire to see whether any human being exists inside the building or not. On the other hand, flood visits our country almost every year. So we can also surveillance flood effected area and we can send primary help to them like dry food, water or first aid kit. However, surveillance can be done using helicopter but it consumes huge amount of fuel thus it is costly. In addition, as the size of the helicopter is bigger it cannot hover into a narrow space and if any accidents happens then a lot of money will be destroyed as well. In contrast, electric powered drone consumes very low power and cost both plus it can hover into tiny spaces as it is small in size. So it is more efficient and environment friendly.

1.5 Organization of the project

This paper is organized into five major parts. Chapter 1 contains introduction, history and aspect of drone and detailed review. Chapter 2 is consisting the development and construction of the drone in brief. In addition, this chapter also contains elaborate discussions control system and simulation results. Chapter 3 incorporates the measurements and result analysis of the developed drone. Finally, chapter 4 contains conclusion and recommendation of the developed drone.

Chapter 2

2.1 Introduction

To build such a dynamic unmanned aerial vehicle we need to attach many complex electronic devices. In this implementation, we have used many intelligent electronic devices like brushless DC motor, KK2.1.5 Multi-Rotor board, ESC (electronic speed controller), digital servo motor and 3300 mA Lithium Polymer battery. In this chapter, we will discuss about all those electronic components and their behavior. Also development of telemetry system for real time communication with drone is introduced in this section. In addition, control system design and MATLAB simulation result analysis are included in this chapter.

2.2 Development and construction

In order to develop this project we have used Brushless DC motors, Electronic Speed Controllers (ESC), KK2 Multicolor Controller Board, 3300mAh Li-Po battery, Aluminum bar (as rotor holder) and Landing gear.

2.2.1 Brushless DC motor

We have used EMAX bl 2815/09 motor for the propeller. The Emax BL2815/09 is a 3.9 ounce, 1000KV, 450 watt out runner brushless motor. It's used for sport planes weighing 709 to 1550 gram.

Figure 2.1 – EMAX bl 2815/09 [18]

Model	Battery cell count	RPM/V	Propeller	RPM	MAX Current	Thrust
BL 2815/09	3s	920	11 × 7	8360	30A	1350 gm
			12 × 6	7000	31A	1550 gm

Table 2.1 – EMAX bl 2815/09 motor parameters

In practice, we have used 12 × 6 propellers so that we can get 1.5kg thrust form one motor. As we have used two motors in our drone so we are getting approximately 3kg of thrust.

2.2.2 KK2.1.5 Multi-Rotor control board

In this project, we have used kk2.1.5 Multi-Rotor control board to control the drone. This KK2.1 Multi-Rotor controller controls the flight of multi-rotor. Its purpose is to stabilize the aircraft during flight and to do this, it takes signals from on-board gyroscopes (roll, pitch and yaw) and passes these signals to the Atmega324PA processor, which processes signals according the users designated firmware and passes the control signals to the mounted ESCs (Electronic Speed Controllers) and the mixture of these signals commands the ESCs to make fine adjustments to the motors rotational speeds which stabilizes the craft. [6]

The KK2.1.5 Multi-Rotor control board also uses signals from radio system via a receiver and passes these signals together with stabilization signals to the Atmega324PA IC via the aileron; elevator; throttle and rudder user demand inputs. Once processed, this data is sent to the ESCs which adjusts the rotational speed of each motor to control flight orientation (up, down, backwards, forwards, left, right, yaw).

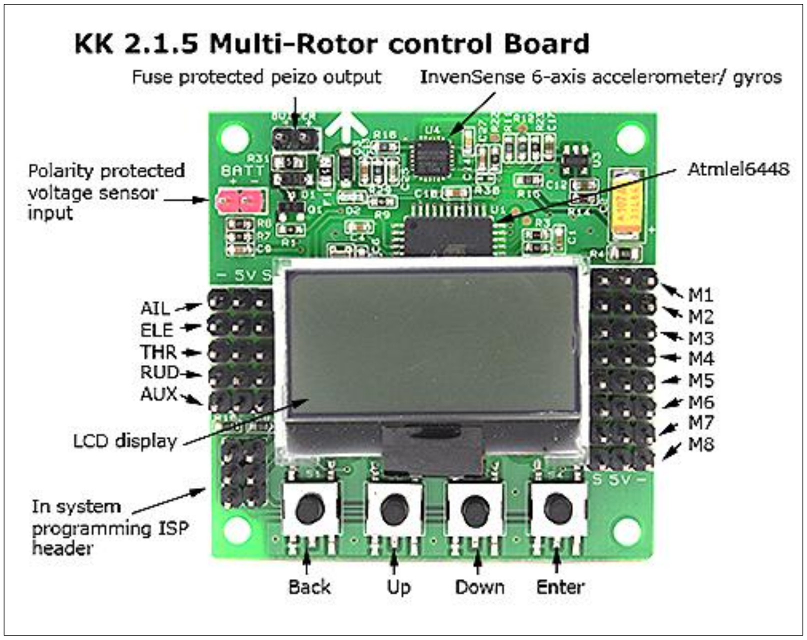


Figure 2.2 – kk2.1.5 Multi-Rotor control board [18]

Technical specifications of KK2.1.5 board:

- Size: 50.5mm x 50.5mm x 12mm
- Weight: 21 gram
- IC: Atmega644 PA
- Gyro/Acceleration: 6050MPU
- Auto-level: Yes
- Input Voltage: 4.8-6.0V
- AVR interface: standard 6 pin.
- Firmware Version: 2.1.5

We have used "Dualcopter" firmware that is pre-installed in the board. However, we had to tune it as per our model because automatic settings were not working properly for our model. Basically, settings are very different and unique for each model. Without customized settings this board is not going to work properly. So to make our drone stable and quick responsive to the disturbances, we have tuned the PI editor and all other settings. The table 5.2 shows the customized values we have set to make our drone stable.

KK2 MENU ITEM							
PI Editor		P Gain:	P Limit:	I Gain:	I Limit:		
	Axis: Roll (Aileron)	200	40	0	0		
	Axis: Pitch (Elevator)	200	40	0	0		
	Axis: Yaw (Rudder)	200	40	0	0		
Receiver Test	Aileron: 0	Elevator: 0	Throttle: 0	Rudder: 0	Auxiliary: 0		
Mode Settings	Self Level:	Link Roll Pitch:	Auto Disarm:	CPPM:			
	aux	No	Yes	no			

Stick Scaling	Roll (Ail):	Pitch (Elev):	Yaw (Rud):	Throttle:			
	36	53	52	90			
Misc. Settings	Min Throttle:	Height Dimen:	Height D. Limit:	Alarm 1/10 Volts:	Servo Filter:		
	10	16	30	105	50		
Self-Level Settings	P Gain:	P Limit:	ACC Trim Roll:	ACC Trim Pitch:			
	90	89	0	0			
Camera Stab Settings	Roll Gain: 0	Roll Offset: 50	Pitch Gain: 0	Pitch Offset: 50			
Sensor Test	Gyro X:	Gyro Y:	Gyro Z:	ACC X:	ACC Y:	ACC Z:	
ACC Calibration							
CPPM Settings	Roll (Ail):	Pitch (Elev):	Throttle:	Yaw (Rud):	Aux:		
Mixer Editor	Throttle:	Aileron:	Elevator:	Rudder:	Offset:	Type:	Rate:
Ch: 1	100	100	0	0	0	esc	high
Ch: 2	100	-100	0	0	0	Esc	high
Ch: 3	0	0	-100	-75	32	Servo	low
Ch: 4	0	0	100	-75	49	Servo	low
Show Motor Layout	②-----①						
Load Motor Layout	Dual-copter						

Table 2.2 – kk2.1.5 Multi-Rotor board setup values

Finally, with these settings from table 2.1.2 our model started hovering with stability.

2.2.3 ESC (Electronic Speed Controller)

An electronic speed controller or ESC is a device installed to a remote controlled electrical model to vary its motor's speed and direction. It needs to plug into the receiver's throttle control channel.

Figure 2.3 – Electronic Speed Controller (ESC) [18]

We have used 60A electronic speed controllers to control each brushless motors in this experiment which can constantly supply required current to drive brushless motors. It has following specifications:

- Constant Current: 60A
- Burst Current: 80A
- Battery: 2-4S Li-Po
- SBEC: 5.5v / 4A
- Motor Type: Brushless
- Size: 70 x 32 x 17mm
- Battery Wire: 14AWG
- Motor Wire: 14AWG
- Weight: 61g

2.2.4 Servo motor

For tilting the motors we have used small servo motors. In this experiment we have mounted two Futaba S-140 servo motor to tilt the brushless motors to a certain angle. This servomotor is can rotate up to 180º. So we can rotate each brushless motor up to 45º from normal as the brushless motors needs to be at 90º for vertical takeoff or landing.

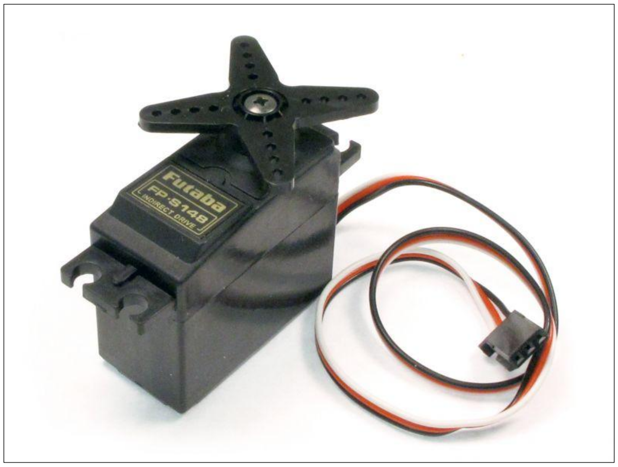


Figure 2.4 – Servo Motor (Model: Futaba S-140) [19]

This servomotor is connected with the KK2.1.5 multi-rotor board to get signals and power both.

Technical specifications of the Futaba S-140 Servo motor is given below:

- Modulation: Analog
- Torque: 4.8V: 122.0 oz-in (8.78 kg-cm)
  6.0V: 153.0 oz-in (11.02 kg-cm)
- Speed: 4.8V: 0.70 sec/60°
  6.0V: 0.56 sec/60°
- Weight: 2.54 oz (72.0 g)
- Dimensions: Length: 1.73 in (43.9 mm)

Width: 0.91 in (23.1 mm)

Height: 1.69 in (42.9 mm)

- Motor Type: 3-pole
- Gear Type: Hybrid
- Rotation/Support: Dual Bearings

2.2.5 Li-Po battery

As the brushless motor we have used in this experiment needs high amount of current so we have used 3300mAh 11.1V 3 cell Li-Po (Lithium Polymer) battery. It can provide approximately 3A current constantly.

Figure 2.5 – 3300mAh 3 cell Li-Po battery [19]

Specifications:

- Capacity: 3300mAh
- Voltage: 11.1V
- Max Continuous Discharge: 25C (82.5A)
- Max Burst Discharge: 50C (165A)
- Weight: 284g
- Dimensions: 133×42×23mm
- Charge Rate: 1-3C Recommended, 5C Max

2.2.6 Landing gear

For safe landing and to reduce landing pressure we have used a flexible plustic landing gear. It is very efficient and usefull. It spreard the landing pressre and saves the body parts from crash.

Figure 2.6 – Landing gear [19]

2.3 Control System Design

2.3.1 Introduction

This chapter contains control system, software, electrical and wireless communication part. Different electrical components were used to implement this machine such as brushless DC motor, electronic speed controller (ESC), KK2 multicomputer board, and high torque servo motor. We have built a GPS tracking android application to keep a track where it is traveling and used an IP camera software to get live video stream from the Drone which is also described elaborately in this chapter.

2.3.2 Control system

Considering all environmental disturbances we have designed our UAV’s control system. In this section step by step everything is described. Figure 2.7, 2.8 and 2.9 illustrates the roll, pitch and yaw control system where,

G1 = Left BLDC motor transfer function

G2 = Right BLDC motor transfer function = G1

G3 = Left Servo motor transfer function

G4 = Right Servo motor transfer function =G3

PI = PI controller transfer function

D = Gaussian noise (Disturbances)

F = feedback

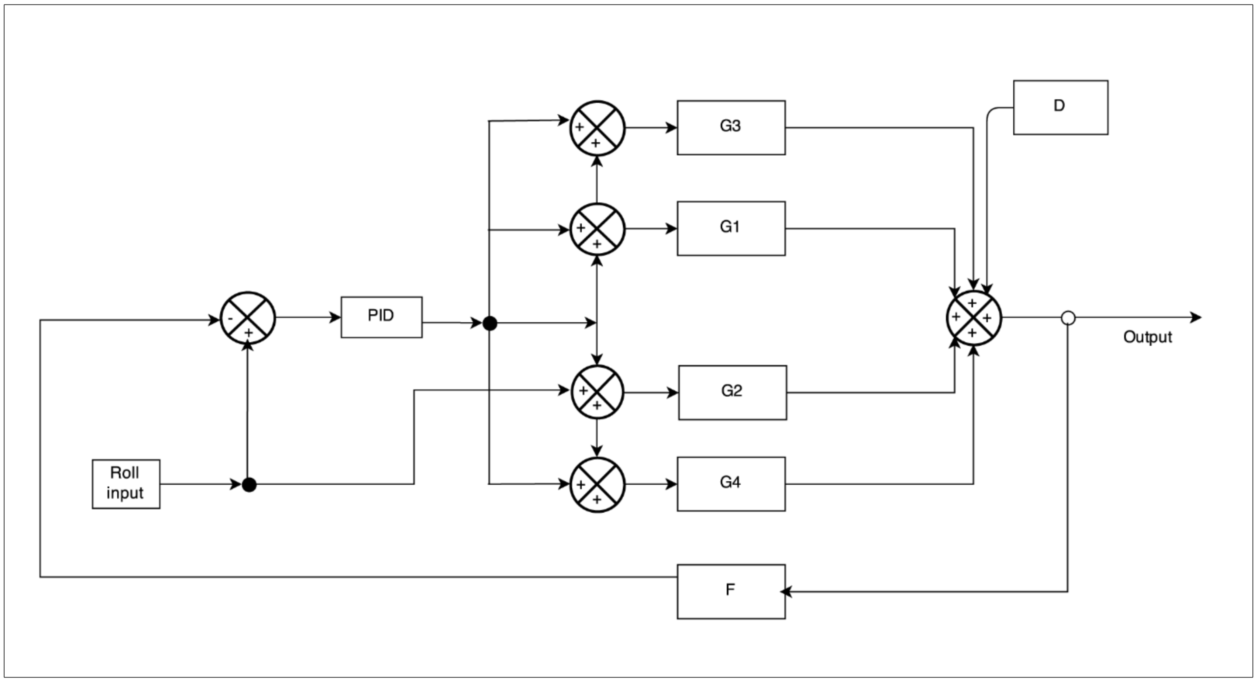


Figure 2.7 – Roll control system

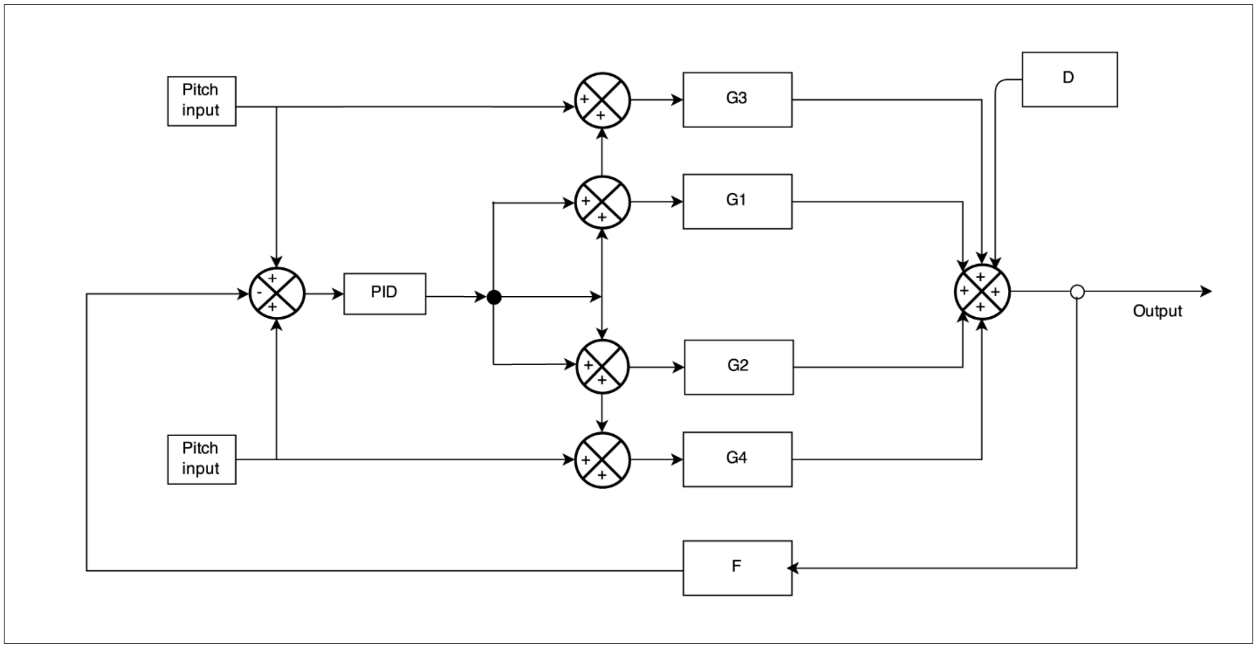


Figure 2.8 – Pitch control system

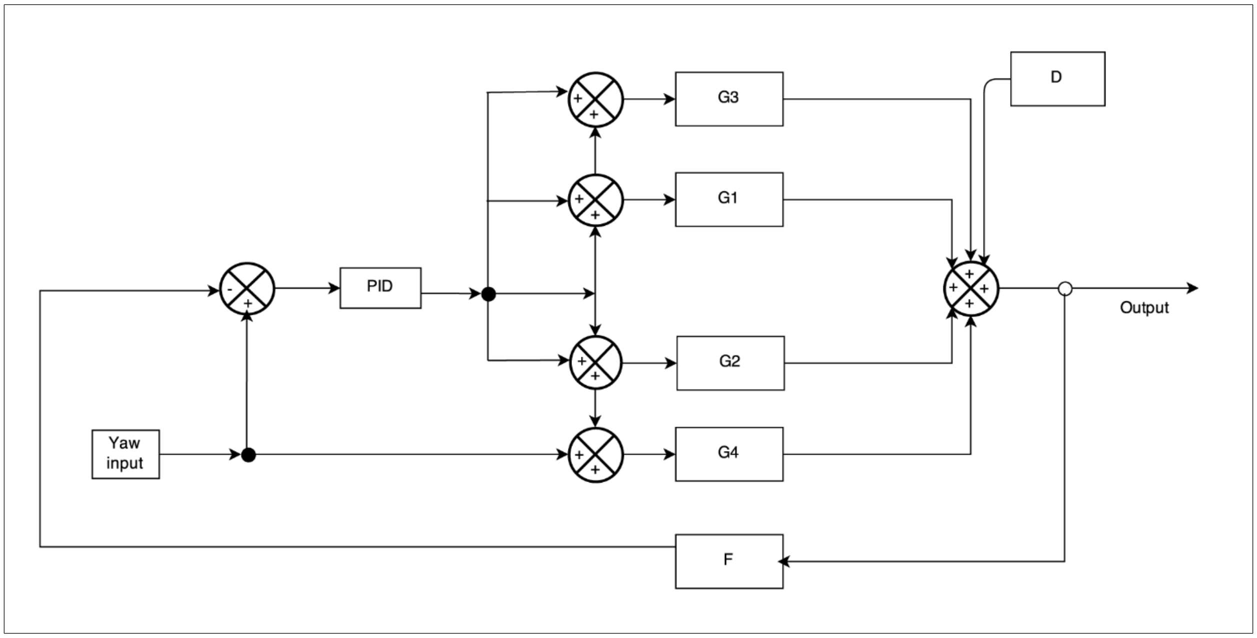


Figure 2.9 – Yaw control system

2.3.2.1 BLDC motor transfer function

The BLDC motor we have utilized for this project is the Emax Bl4030. It is a 385kv, 11.5 ounce (326g), 1300 watt out runner brushless motor. Contingent upon the propeller and battery utilized, it is generally comparable to .60 to .90 2 stroke nitro engines.

The parameters we used in the modeling are extracted from the datasheet of this motor with corresponding relevant parameters used. Table 2.3 contains the major extracted parameters used for the modeling task.

The physical parameters for our example are:

RPM (n)	6100
Power (P_w)	1300 W

Electric resistance (R)	0.22 ohm
Electric inductance (l)	8.5 mH
Maximum Current	55 A
Moment of inertia of the rotor (j)	0.089 kg m^2

Table 2.3 – BLDC motor parameter used

Mechanical constant [11],

$$\tau_m = \frac{j \times 0.004 \times R}{k_e \times k_t} \tag{2.1}$$

Electrical constant [11],

$$\tau_e = \frac{l}{0.004R} \tag{2.2}$$

Phase value of the EMF constant [11],

$$\mathrm{k}_e = K_t \times 0.0605 \tag{2.3}$$

Where k_t is torque constant [11].

Torque,

$$\text{Torque} = \frac{P_w \times 9.554}{n} \tag{2.4}$$

$$= \frac{1300 \times 9.554}{6100}$$

$$= 2.03\ Nm$$

Torque constant,

$$K_t = \frac{Torque}{Current} \tag{2.5}$$

$$= \frac{2.03}{55}$$

$$= 0.04\ Nm/A$$

Electrical torque,

$$K_e = 0.04 \times 0.0605 = 0.0024$$

Mechanical constant,

$$\tau_m = \frac{0.089 \times 0.004 \times 0.22}{0.04 \times 0.0024} = 0.8158$$

BLDC Motor Transfer Function [11],

$$\text{G1}(s) = \frac{\frac{1}{K_e}}{\tau_m\, \tau_e\, s^2 + \tau_m\, s + 1} \tag{2.6}$$

Therefore the transfer function of BLDC motor becomes,

$$\mathrm{G1}(s) = \frac{416.67}{0.38\, s^2 + \; 0.82\, s + 1} \tag{2.7}$$

2.3.2.2 BLDC motor open loop analysis

The open loop step response is shown by using the Simulink tools as shown in figure below.

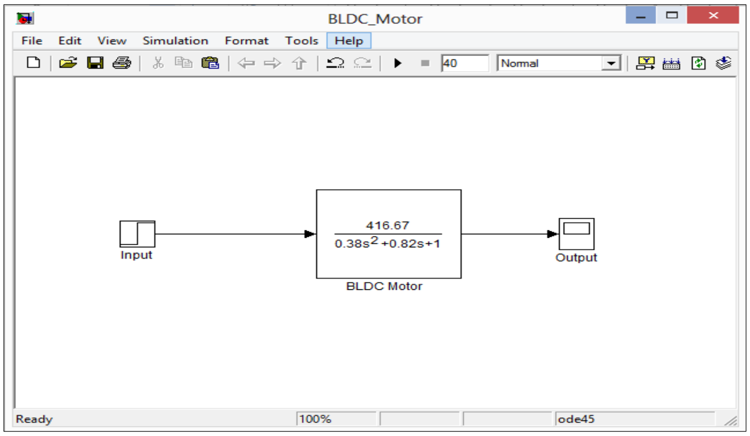


Figure 2.10 – BLDC motor Simulink diagram

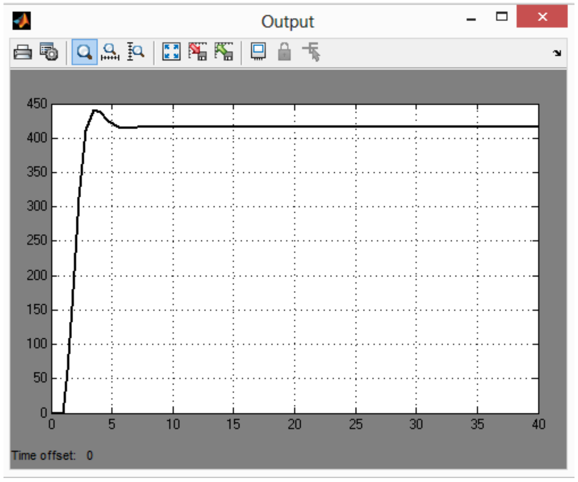


Figure 2.11 – BLDC motor open loop step response

2.3.2.3 DC servo motor

The servo motor we used in this project is Futaba S148. The parameters we used in the modeling are extracted from the datasheet of this motor with corresponding relevant parameters used. Find below in Table 2.1 the major extracted parameters used for the modeling task.

The physical parameters for our example are:

Modulation:	Analog
Torque:	4.8V: 33.3 oz-in (2.40 kg-cm) 6.0V: 41.7 oz-in (3.00 kg-cm)
Speed:	4.8V: 0.28 sec/60° 6.0V: 0.22 sec/60°
Weight:	1.57 oz (44.4 g)
Motor Type:	3-pole
Rotational angle	180^0

Table 2.4 – DC Servo motor parameters

2.3.2.4 DC servo motor transfer function

We have used Futaba S-140 DC servo motor for this experiment. The linear mathematical model (transfer function) for the Futaba S-140 Servo [12] is,

$$\mathrm{G3(s)} = \frac{950}{s^2 + 44s + 950} \tag{1.8}$$

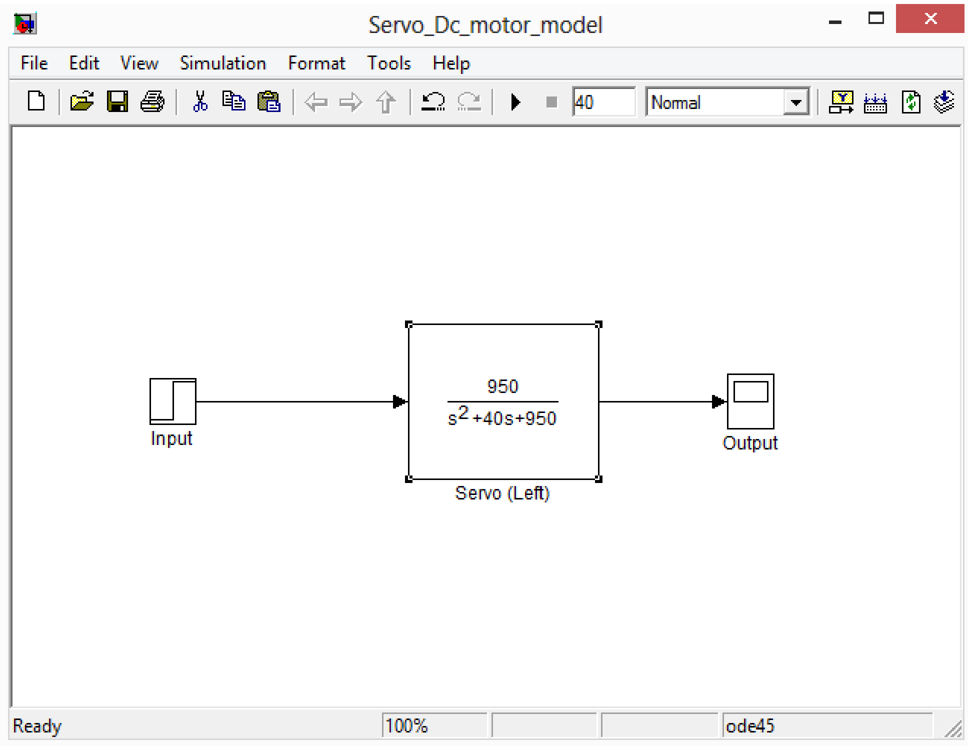


Figure 2.12 – DC Servo motor Simulink model

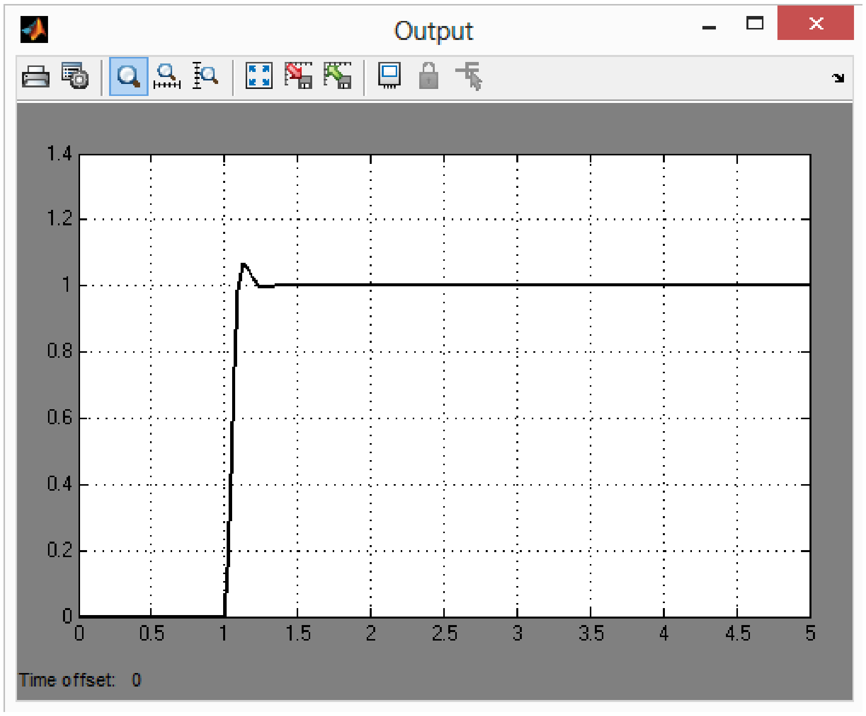


Figure 2.13 – Open loop step response of DC servo motor

2.4 Proportional controller

The mixture of proportional terms is vital to rise the speed of the response and also to remove the steady state error [13]. The proportional controller block is reduced to P only as shown in figure 2.14 By using MATLAB we have determined a suitable value for our proportional controller. Where P = Proportional gain and we set P = 0.5 to get a stable output. In practice, KK2 multirotor controller board is the PID controller for the system we have developed.

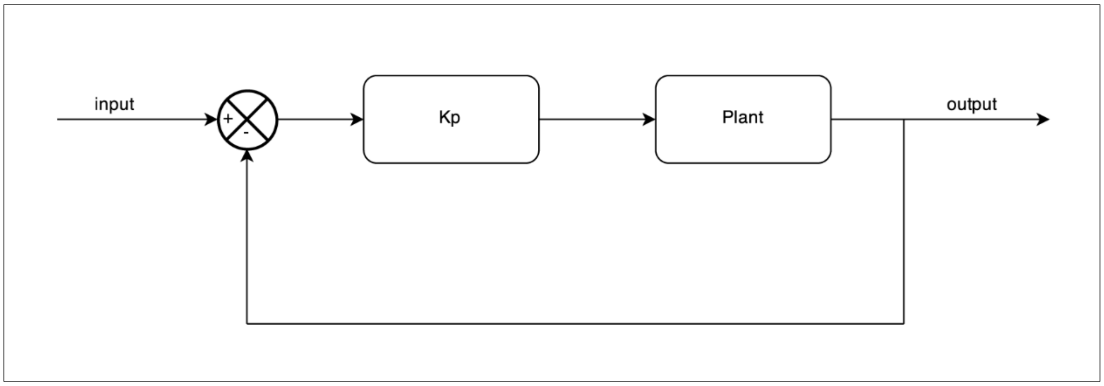


Figure 2.14 – Proportional gain controller

2.5 Control system simulation

From the different outlines required for this trial, a brief steadiness check is required to make the experimentation at the first case. It would be watched that the main plan close to the ideal is figure 2.3.5.

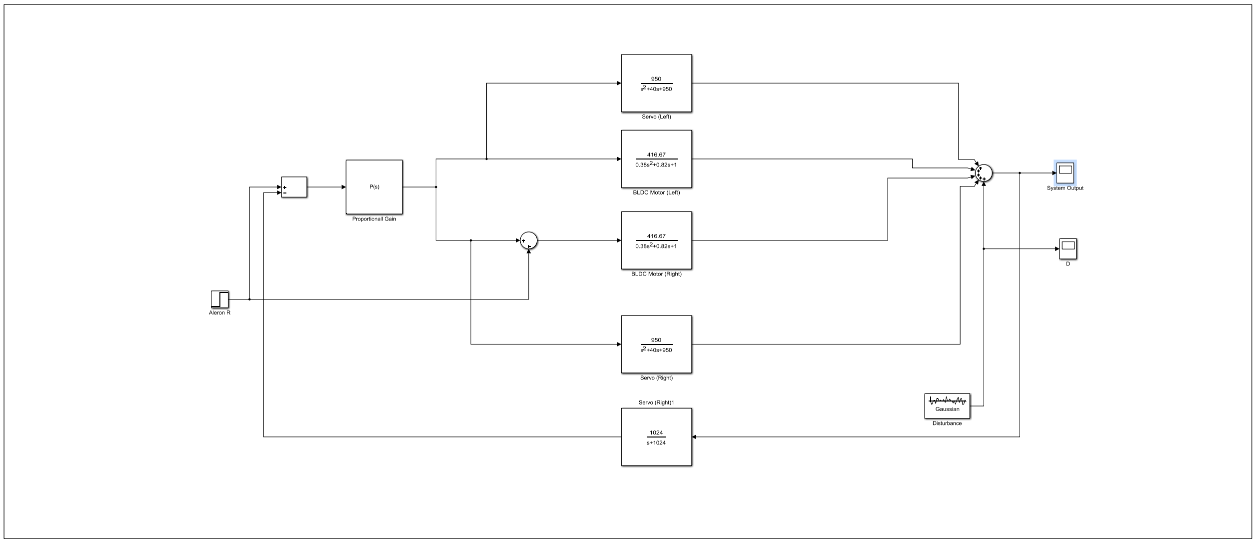


Figure 2.15 – Roll control system Simulink model

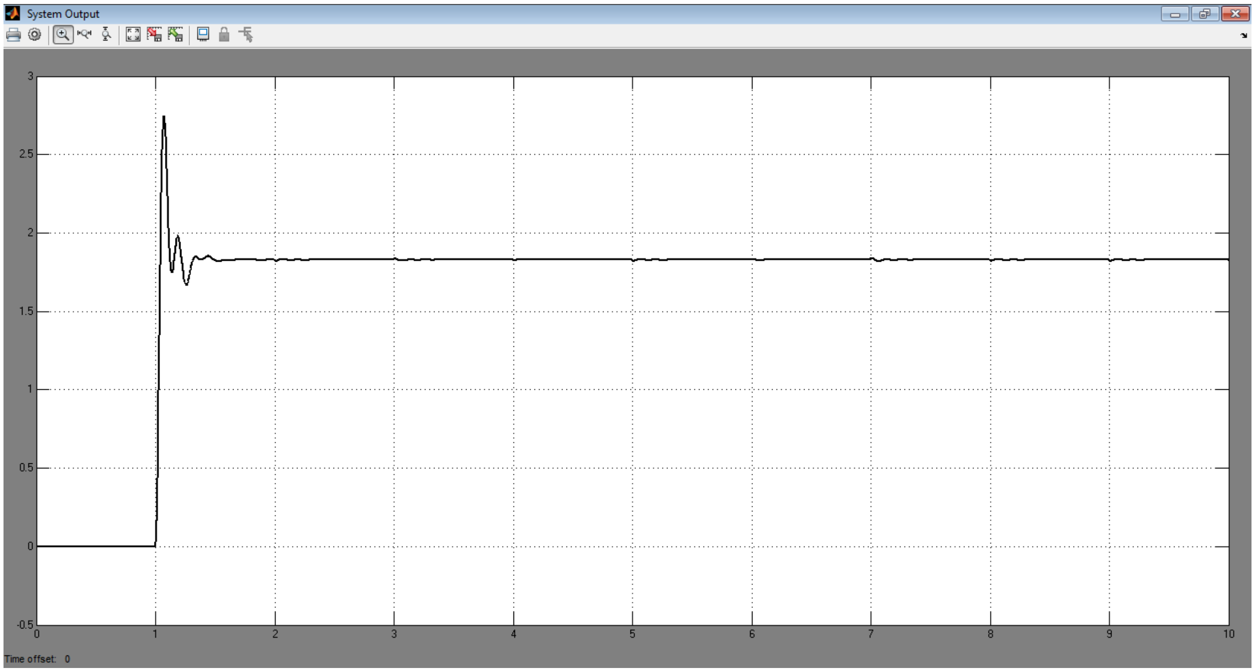


Figure 2.16 – Roll control system Simulink model output

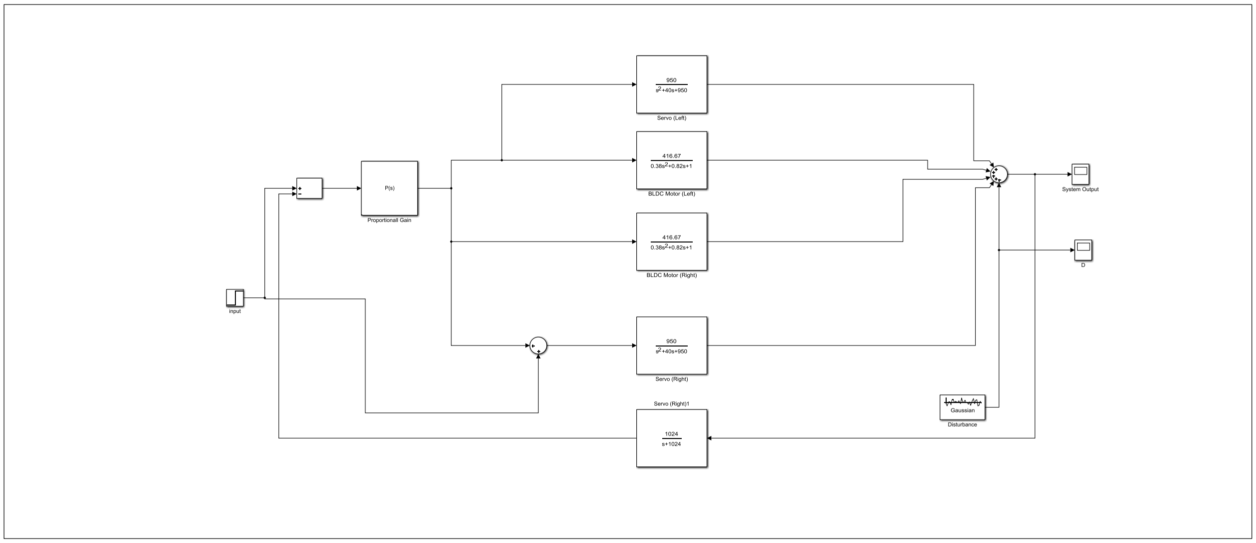


Figure 2.17 – Yaw control system Simulink model

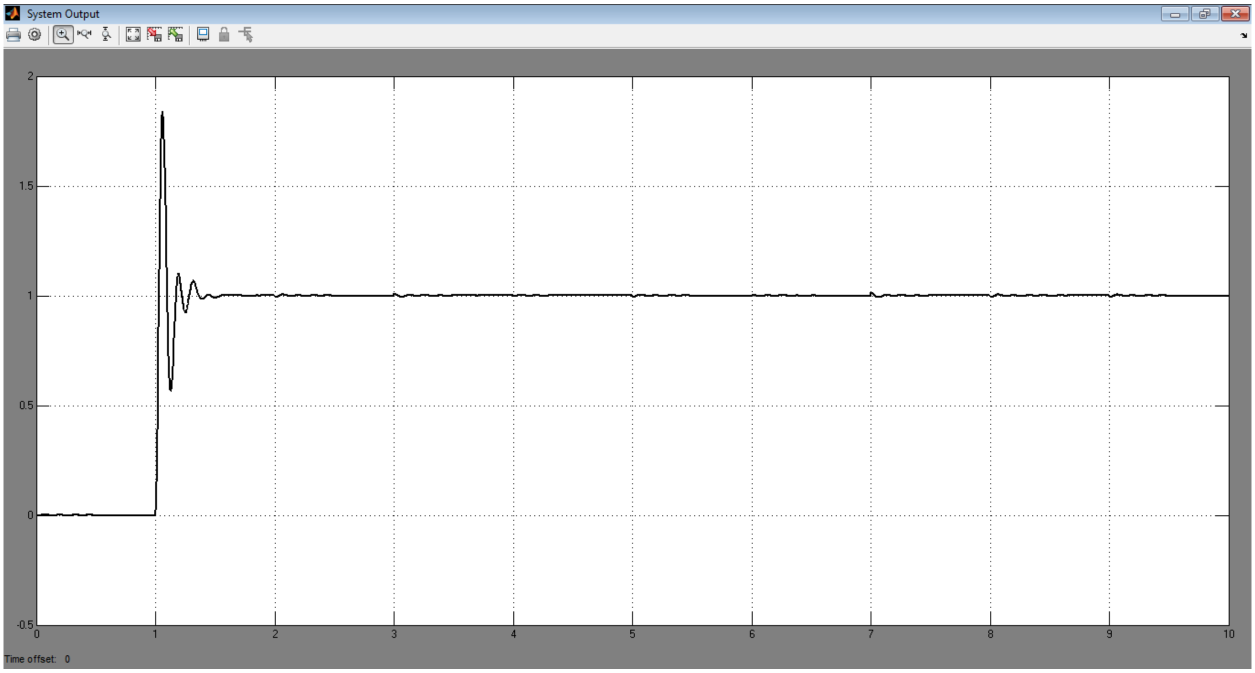


Figure 2.18 – Yaw control system Simulink model output

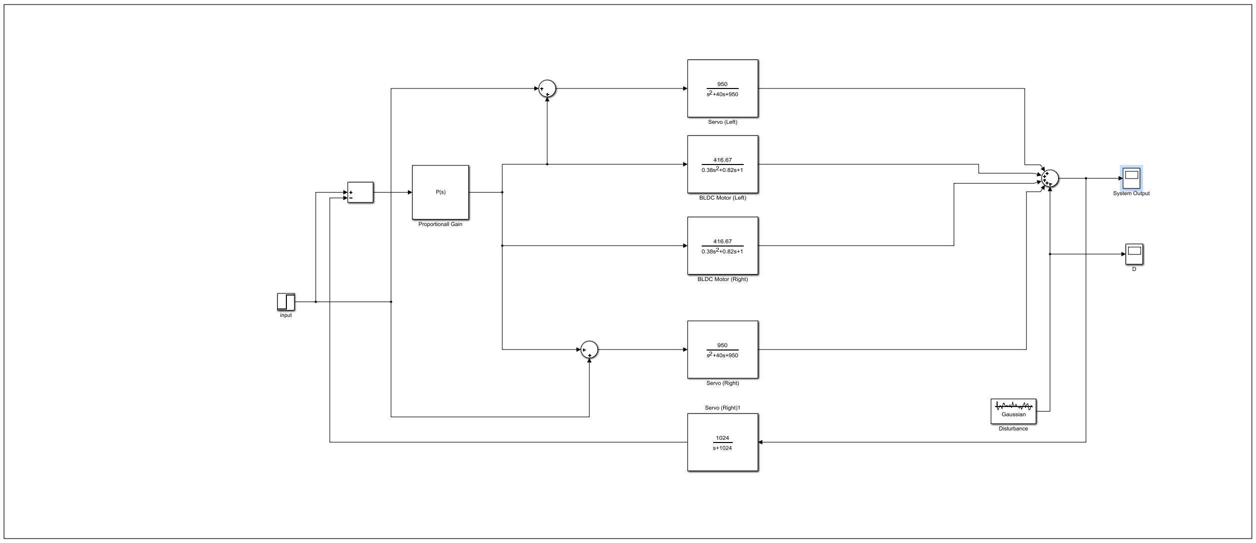


Figure 2.19 – Pitch control system Simulink model

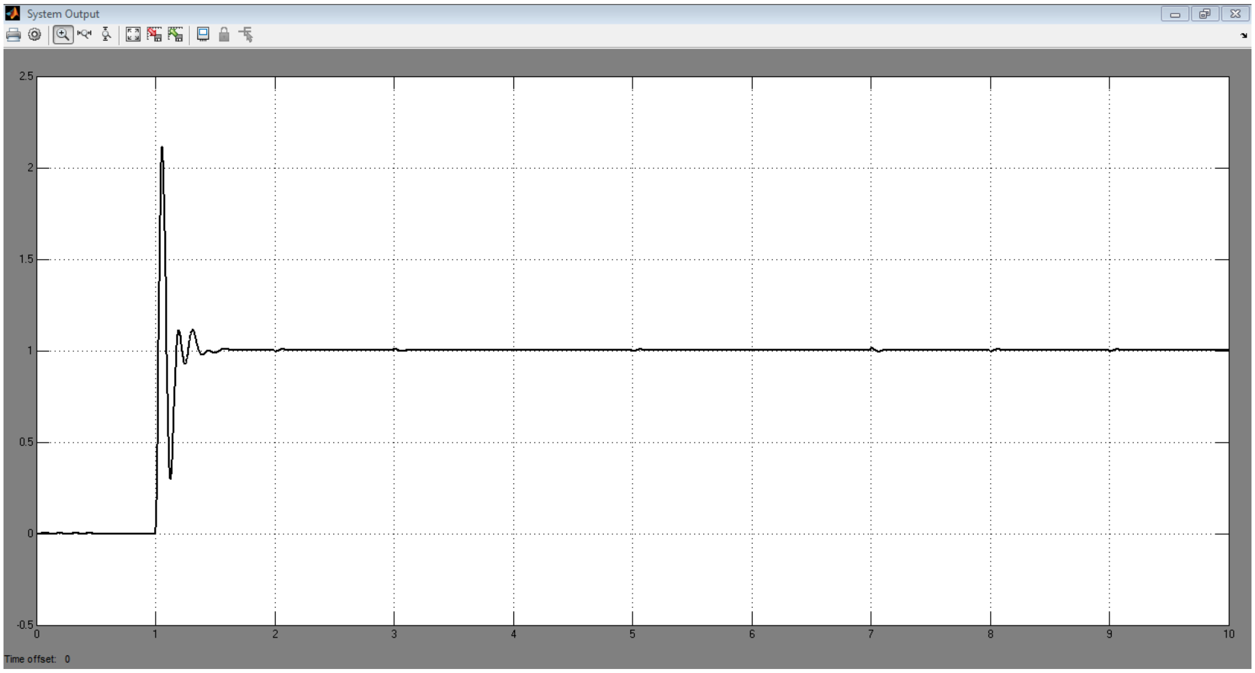


Figure 2.20 – Pitch control system Simulink output

2.5.1 Roll control system transfer function

With the assistance of figure 2.15 and equations 2.7 and 2.8, we have computed roll motion control system's transfer function. Here the plots incorporate the step response, nyquist diagram, and bode plot graph.

For this, different m-file were made.

roll.m

```
clc

s = tf('s');
P = 0.5;
G1 = 416.67/(0.38*s^2+0.82*s+1);
G2 = 416.67/(0.38*s^2+0.82*s+1);
G3 = 950/(s^2+40*s+950);
G4 = 950/(s^2+40*s+950);
D = rand;

systemTransferFunction =
((P*(G1+s*G2+G3+G4))+(P*(G1+s*G2+G3+G4))*D)/(1+(P*(G1+s*G2+G3+
G4))*(1024/(s+1024)));
Drone = zpk(systemTransferFunction); %transfer function

figure;
step(Drone);
figure;
nyquist(Drone), grid;
figure;
bode(Drone), grid;
```

Therefore, roll control system transfer function will be:

$$T_{roll}(\mathrm{s}) = \frac{P \times (G1 + sG2 + G3 + G4) + \ P \times (G1 + sG2 + G3 + G4) \times D}{1 + P \times (G1 + sG2 + G3 + G4) \times \dfrac{1024}{s + 1024}} \tag{2.9}$$

The T(s) derived above in the equation 2.9 is the roll control system's transfer function of the Drone using all necessarily sufficient parameters available.

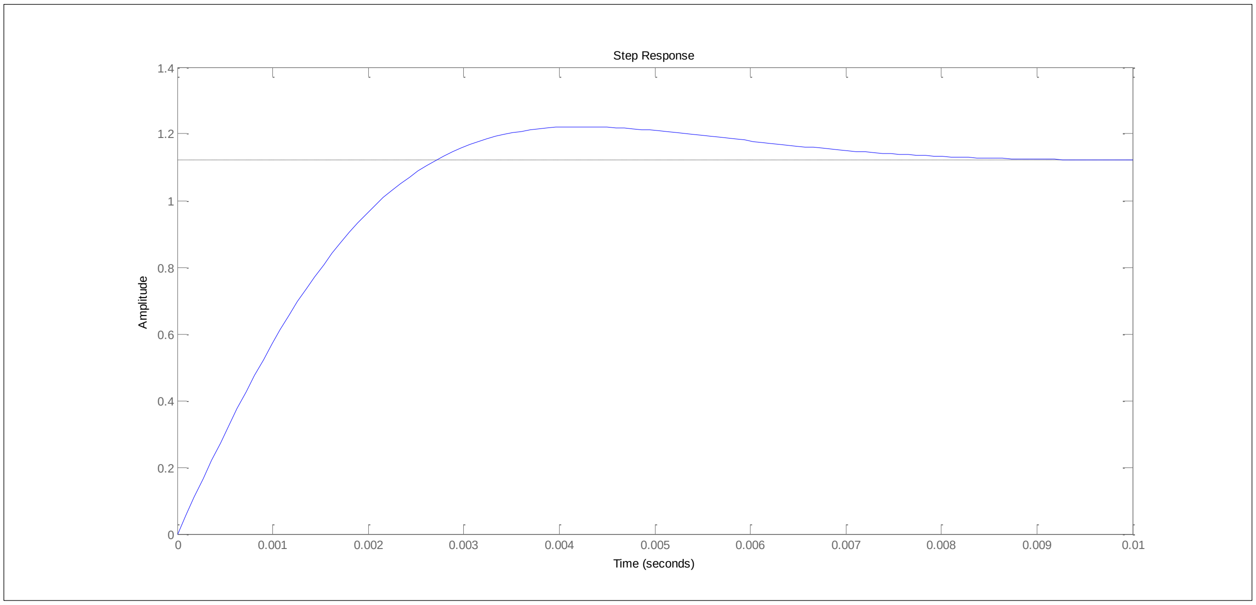
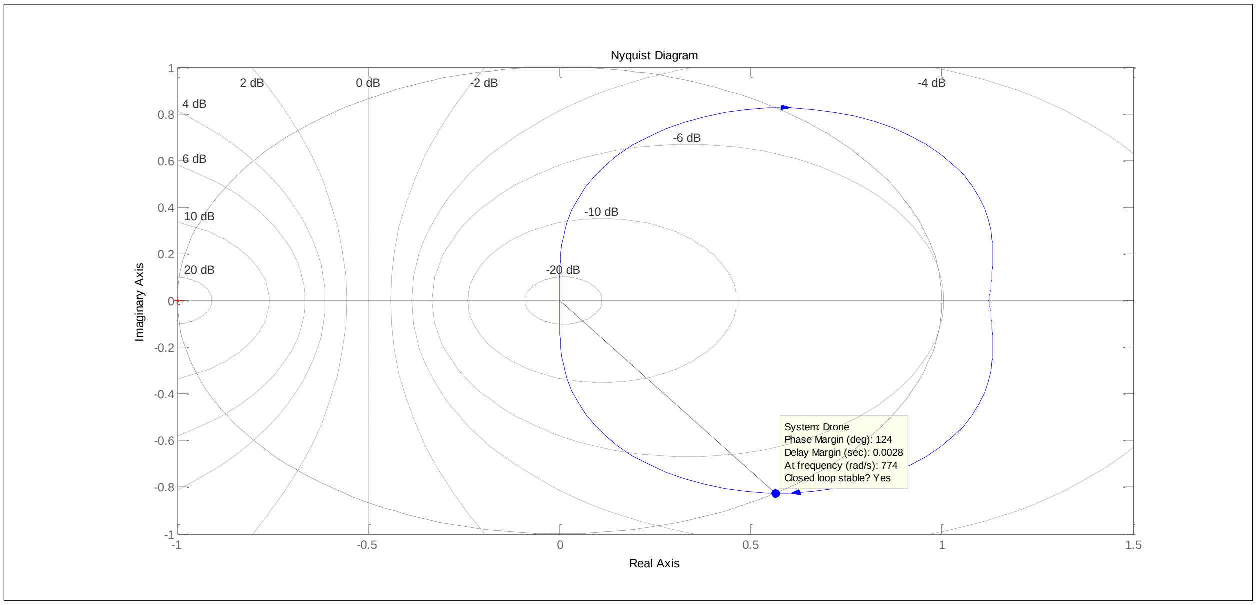


Figure 2.21 – Roll control system step response



System: Drone
Phase Margin (deg): 124
Delay Margin (sec): 0.0028
At frequency (rad/s): 774
Closed loop stable? Yes

Figure 2.22 – Roll control system Nyquist diagram

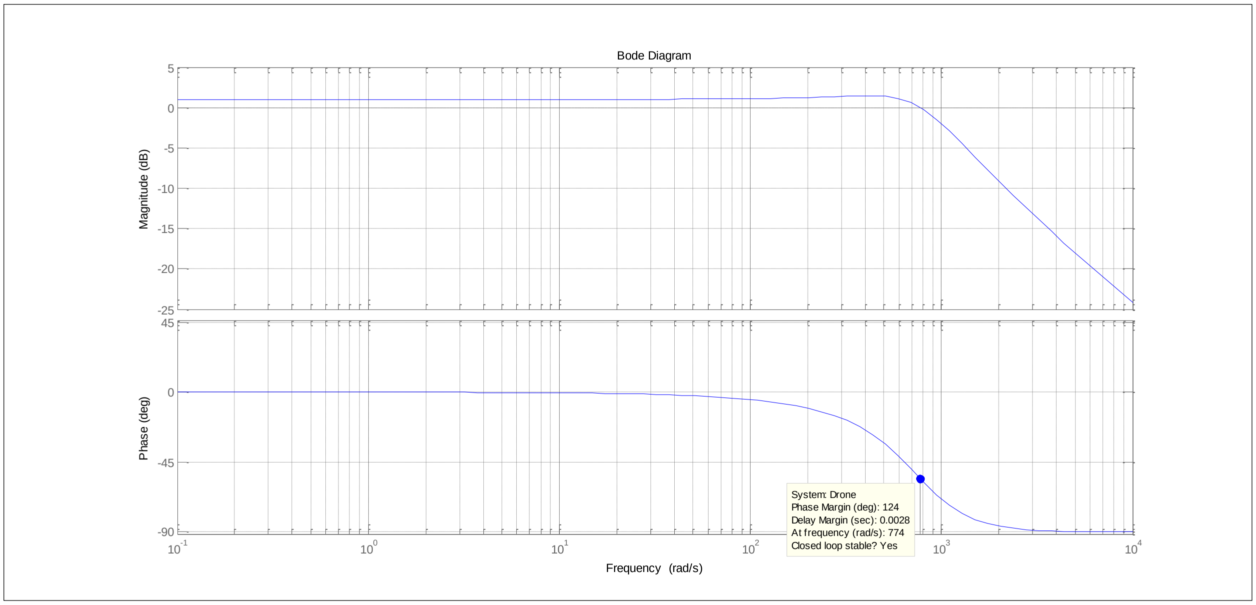


Figure 2.23 – Roll control system Bode Plot

2.5.2 Yaw control system transfer function

With the help of figure 2.17 and equations 2.7 and 2.8, we have measured roll motion control system’s transfer function. Here the plots include the step response, nyquist diagram, and bode plot graph.

For this, different m-file were made.

yaw.m

```
clc

s = tf('s');
P = 0.5;
G1 = 416.67/(0.38*s^2+0.82*s+1);
G2 = 416.67/(0.38*s^2+0.82*s+1);
G3 = 950/(s^2+40*s+950);
G4 = 950/(s^2+40*s+950);
D = rand;

systemTransferFunction =
((P*(G1+s*G2+G3+s*G4))+(P*(G1+s*G2+G3+s*G4))*D)/(1+(P*(G1+s*G2
+G3+s*G4))*(1024/(s+1024)));
Drone = zpk(systemTransferFunction); %transfer function


figure;
step(Drone);
figure;
nyquist(Drone), grid;
figure;
bode(Drone), grid;
```

Therefore, yaw control system transfer function will be:

$$T_{yaw}(\mathrm{s}) = \frac{P \times (G1 + sG2 + G3 + sG4) + \ P \times (G1 + sG2 + G3 + sG4) \times D}{1 + P \times (G1 + sG2 + G3 + sG4) \times \dfrac{1024}{s + 1024}} \tag{2.10}$$

The T(s) derived above in the equation 2.10 is the yaw control system's transfer function of the Drone using all necessarily sufficient parameters available.

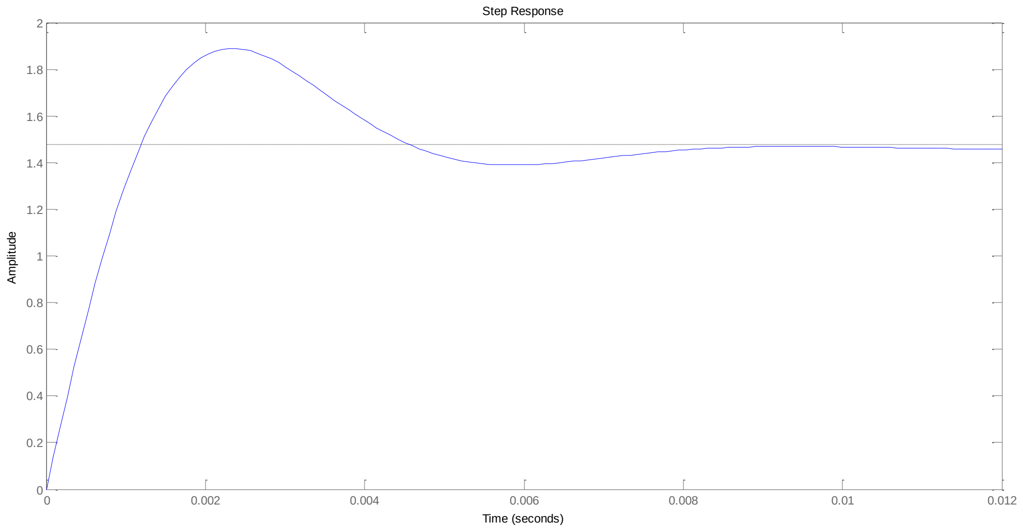


Figure 2.24 – yaw control system step response

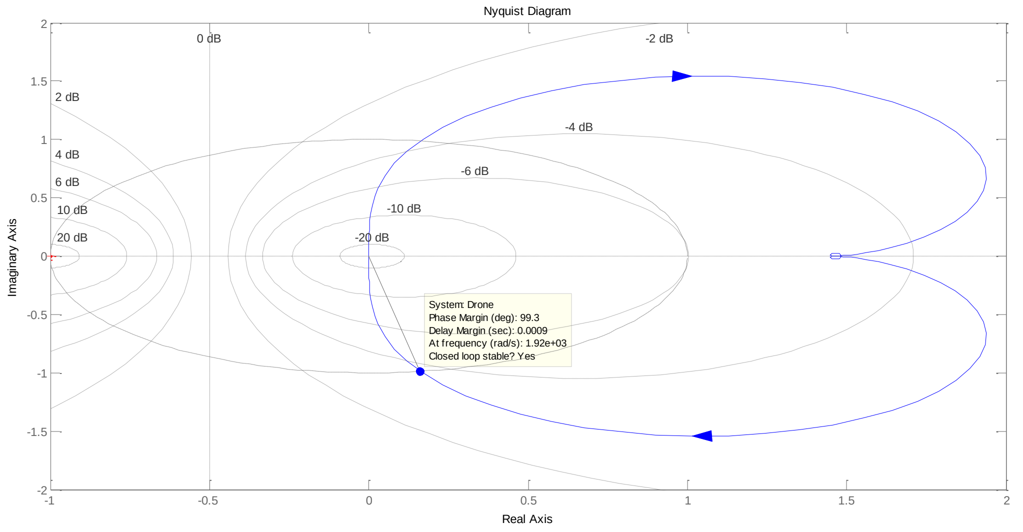


Figure 2.25 – Yaw control system Nyquist diagram

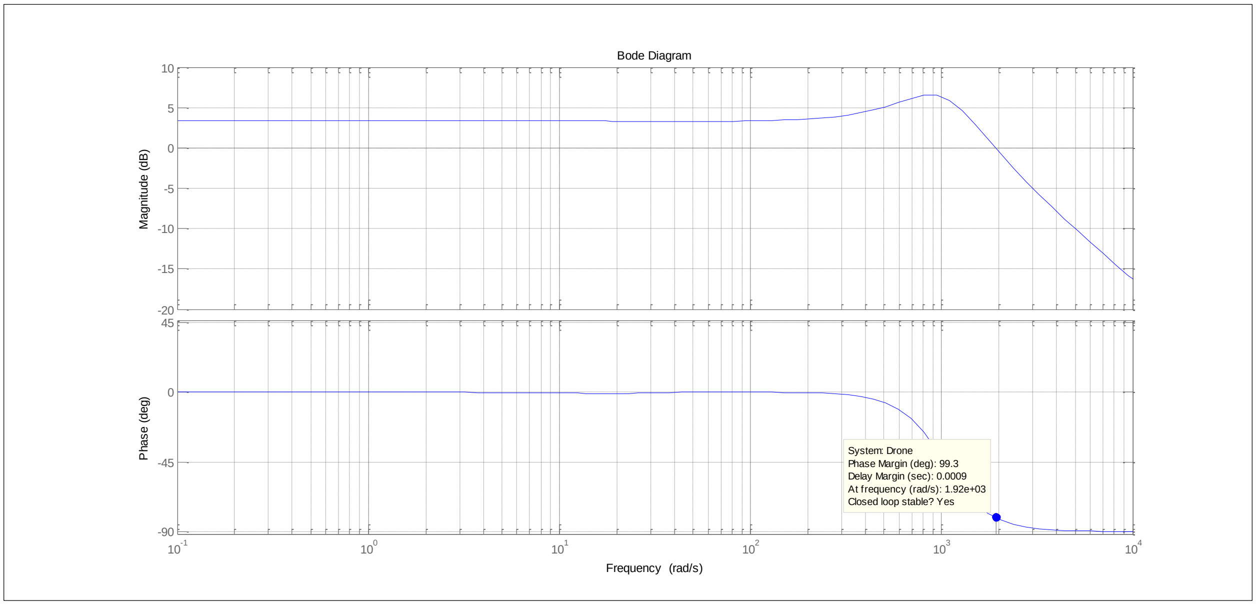


Figure 2.26 – Yaw control system Bode Plot

2.5.3 Pitch control system transfer function

By the aid of figure 2.19 and equations 2.7 and 2.8, we have calculated roll motion control system's transfer function. Here the plots combine the step response, nyquist diagram, and bode plot graph.

For this, different m-file were made.

pitch.m

```
clc

s = tf('s');
P = 0.5;
G1 = 416.67/(0.38*s^2+0.82*s+1);
G2 = 416.67/(0.38*s^2+0.82*s+1);
G3 = 950/(s^2+40*s+950);
G4 = 950/(s^2+40*s+950);
D = rand;

systemTransferFunction =
((P*(G1+G2+s*G3+s*G4))+(P*(G1+G2+s*G3+s*G4))*D)/(1+(P*(G1+G2+s
*G3+s*G4))*(1024/(s+1024)));
Drone = zpk(systemTransferFunction); %transfer function


figure;
step(Drone);
figure;
nyquist(Drone), grid;
figure;
bode(Drone), grid;
```

Therefore, pitch control system transfer function will be:

$$T_{pitch}(\mathrm{s}) = \frac{P \times (G1 + G2 + sG3 + sG4) + \ P \times (G1 + G2 + sG3 + sG4) \times D}{1 + P \times (G1 + G2 + sG3 + sG4) \times \dfrac{1024}{s + 1024}} \tag{2.11}$$

The T(s) derived above in the equation 2.10 is the pitch control system's transfer function of the Drone using all necessarily sufficient parameters available.

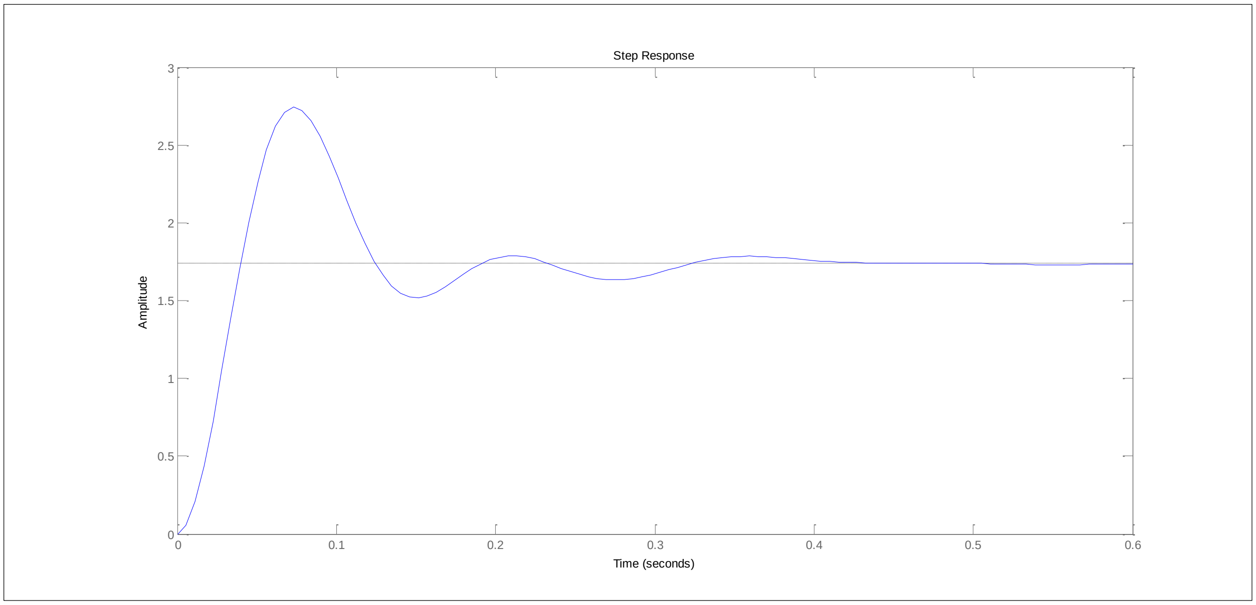


Figure 2.27 – Pitch control system step response

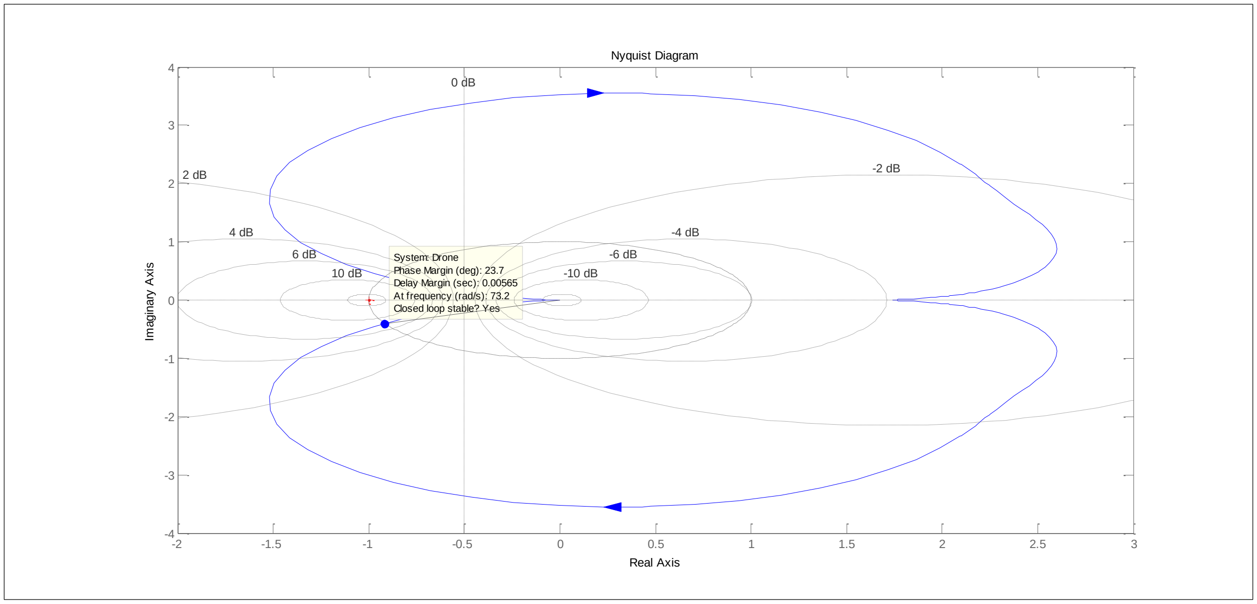


Figure 2.28 – Pitch control system Nyquist diagram

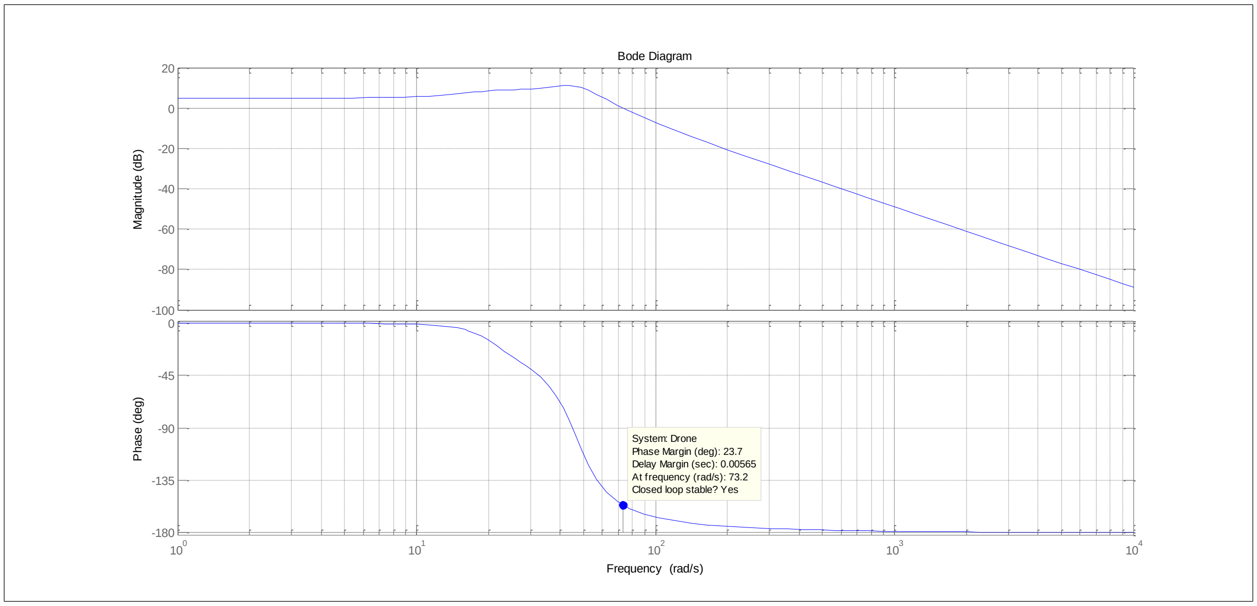


Figure 2.29 – Pitch control system Bode Plot

2.6 Telemetry System

As unmanned aerial vehicle must needs to operate remotely, several communication system used in this project such as radio communication, Wi-Fi communication and 3G communication which are covered in this chapter.

2.6.1 Radio communication

There are many high range radio transmitter and receiver in the market which are expensive. However, as it is prototype and to minimize the cost we used 2.4 GHz FlySky 6 channel transmitter and receiver module. It covers almost 970 meter to 1 kilometer with average obstacle.

Figure 2.30 – FlySky 6 channel radio transmitter and receiver [19]

Over 1200 meter it gets very low signal and completely lost the signal over 1320 meters. To record precise values we used a car to move around and transmits the signal from a stationary point.

Technical Specifications:

- Radio: 2.4 GHz
- Length: 7.4 in (188mm)
- Height: 3.8 in (96.5mm)
- Width/Diameter: 11.6 in (294.6mm)
- Weight: 498.9 g (17.6oz)

By the aid of this device we can control the flight system of our drone. Each channel controls a specific electronic device which in embedded in our system such as brushless DC motors or servo motors, thus we can control forward, backward, right or left motion of the prototype.

2.6.2 Wi-Fi Communication

Wi-Fi communication used in this experiment for the IP webcam software for short range video transmission without internet connection. We have used IP webcam android software for video transmission. It provides live video stream which can be access via local and global computers. For local communication it uses Wi-Fi communication. Mobile device and the on board computer needs to connected in the same Wi-Fi network.

2.6.3 Software

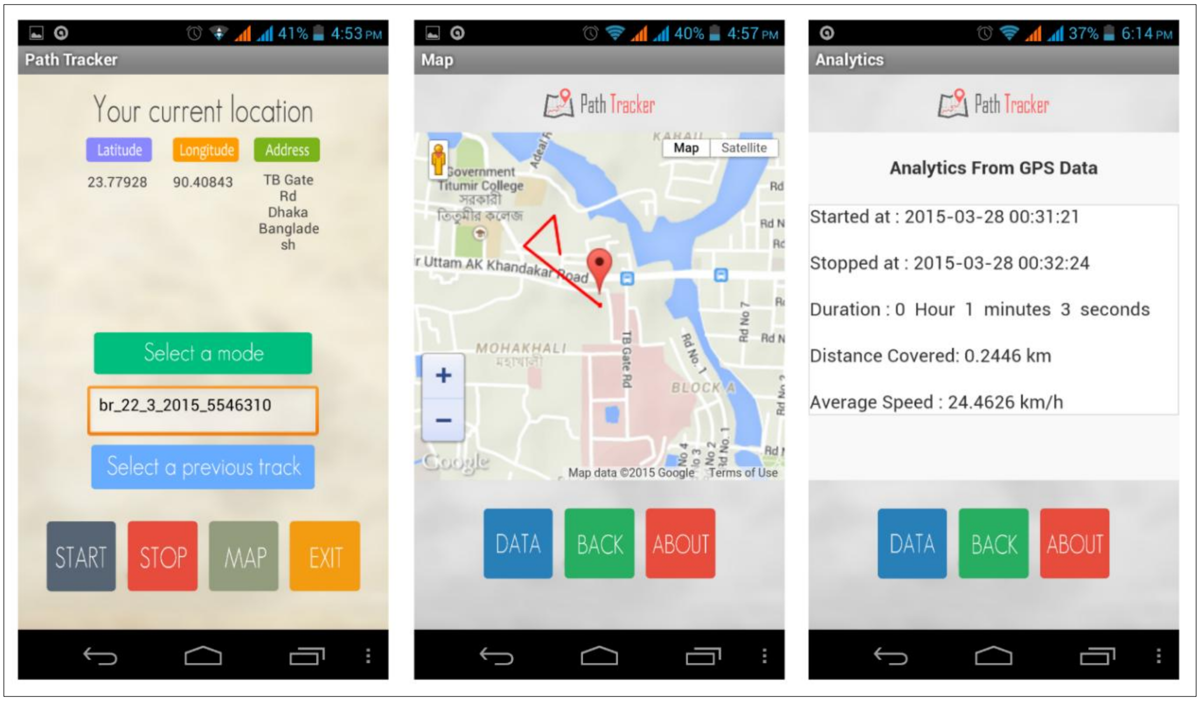
An Android mobile device has been installed in our Drone's payload system for live video stream, live position tracking and real time voice communication. By the aid of two android software we have manipulated audio video transmission and GPS position tracking system.

2.6.3.1 Live location tracking

The software for the android device has been developed using an open source web application which is originally provided by Google and maintained by Massachusetts Institute of Technology (MIT) known as MIT App Inventor. On December 6, 2013 MIT released App Inventor 2 and this web application has been used to develop the app for the embedded system. A person with very basic knowledge of programming can develop any android app through this tool. This is very simple yet effective method to improve any application for android. No substantial software installation is needed for this and this can be completed just over web browser with a Google account.

2.6.3.2 Live location tracking software architecture

By using MIT app inventor we have developed an Android application for live path tracking. We have named it “Path Tracker”. The basic function of this application is, it records GPS coordinates and the current address of the location and sends it to the MySQL web server via PHP. For displaying data using Google Map API v3 it draw a red line through the each points it has travelled. In addition, it records data to when it starts it journey and stops and on the basis of this data it displays the average speed and distance.



Your current location

Latitude	Longitude	Address
23.77928	90.40843	TB Gate Rd Dhaka Bangladesh

br_22_3_2015_5546310

Analytics From GPS Data

Started at : 2015-03-28 00:31:21

Stopped at : 2015-03-28 00:32:24

Duration : 0 Hour 1 minutes 3 seconds

Distance Covered: 0.2446 km

Average Speed : 24.4626 km/h

Figure 2.31 – Live location tracking software

Figure 2.19 shows that a sample hovering data and from that we can see the average speed of our prototype is 24 kilometre per hour.

On the other hand, this data can be also accessed by computer from any place as all the data stored in the server. For the test purpose we have built a website in a free hosting server which can be accessed from both mobile and computer.

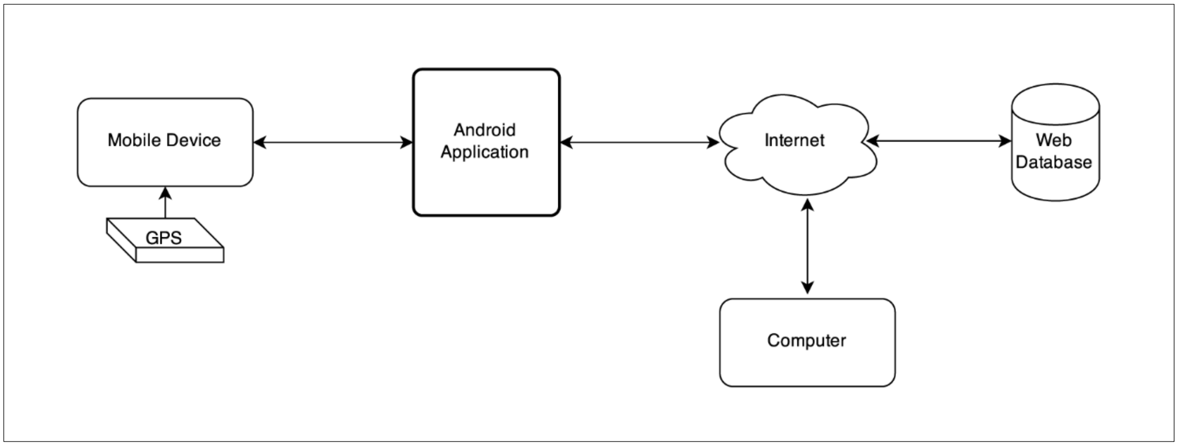


Figure 2.32 – Flow diagram of live location tracking software

2.6.3.3 Live location tracking website architecture

In this experiment, we have built a very simple yet effective website to upload, download and display necessary data. We have used MySQL database to store data and PHP program to upload, download, calculate and display data. In addition, we have used HTML and jQuery to make a interactive display.

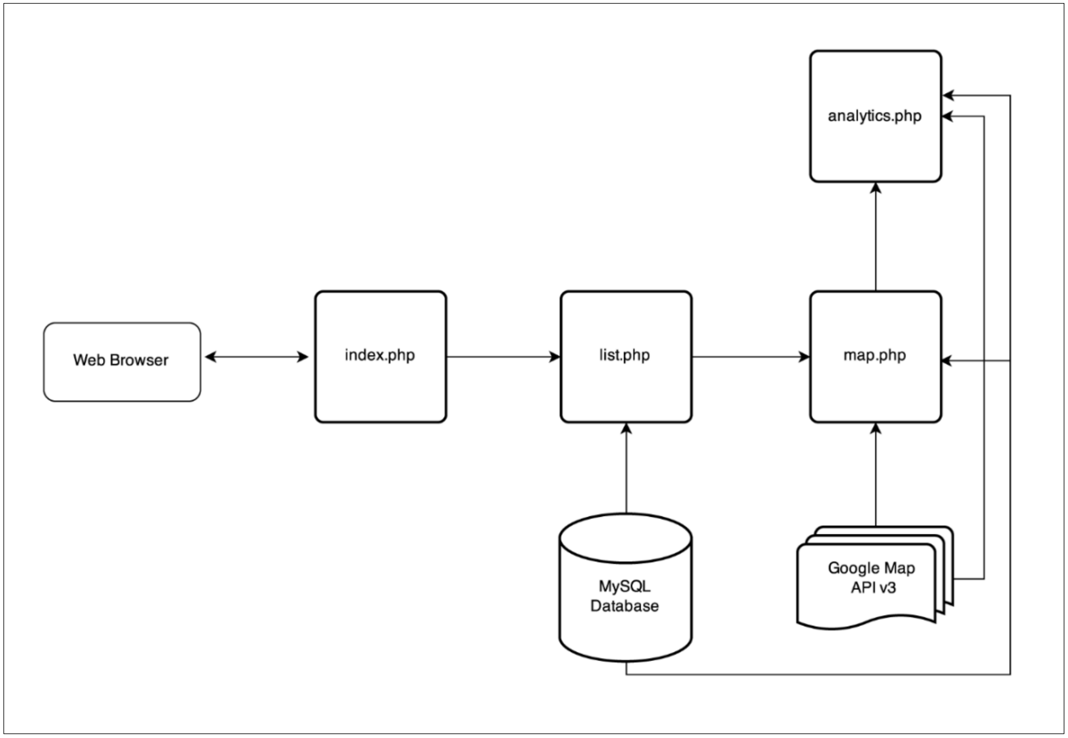


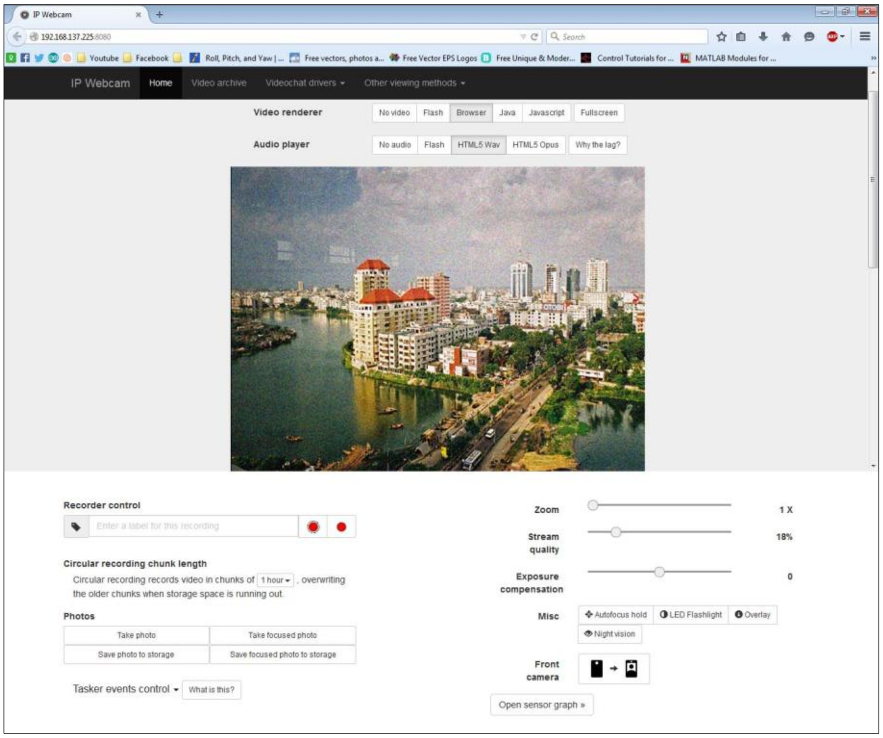
Figure 2.33 – Flow diagram of live location tracking website

At the beginning, “index.php” file takes mobile number of the user and sends a get request to the database by “list.php”. If mobile number exists then it displays all the track lists that are recorded by a user. Then when a user selects an item from the list it will call “map.php” and this file reads all the relevant data that are stored in the database. After that, as it is already connected with Google Map Api V3, it gets the map of the relevant GPS coordinates and draws a red line through all points. In addition, it shows an animated marker at the last point. Finally, “analytics.php” file reads data from the database and calculates average distance by the aid of Google Map Api and we divide that distance value by the duration of flight and get the speed per hour.

2.6.3.4 Live video stream

Live video streaming can be implemented by using 5.4 GHz 500 mw wireless video transmitter and receiver but it is too expensive ($USD 630). To reduce the cost in this experiment we have used an Android mobile phone. In comparison with 5.4 GHz 500 mw wireless video transmitter and receiver mobile phone is much cheaper (USD $86), consumes less power, supports internet connections that enable to communicate globally via internet and more intelligent with GPS and other sensors.

For live video streaming we have used IP-Webcam android application. IP-Webcam turns mobile phones into a network camera with multiple viewing option. Streaming video inside WiFi network without internet access is possible. On the other hand, Ivideon cloud streaming supported for instant global access. In addition, two way audio transmission is also possible in this software.



Video renderer: Browser
Audio player: HTML5 Wav
Circular recording records video in chunks of 1 hour, overwriting the older chunks when storage space is running out.
Zoom: 1 X
Stream quality: 18%
Exposure compensation: 0

Figure 2.34 – IP-Webcam live video stream

2.7 Hardware implementation

We have used aluminium bar instead of carbon fibre bar to minimise cost. A plastic made landing gear is used to land the machine softly and spread the landing force over the body. Two brushless

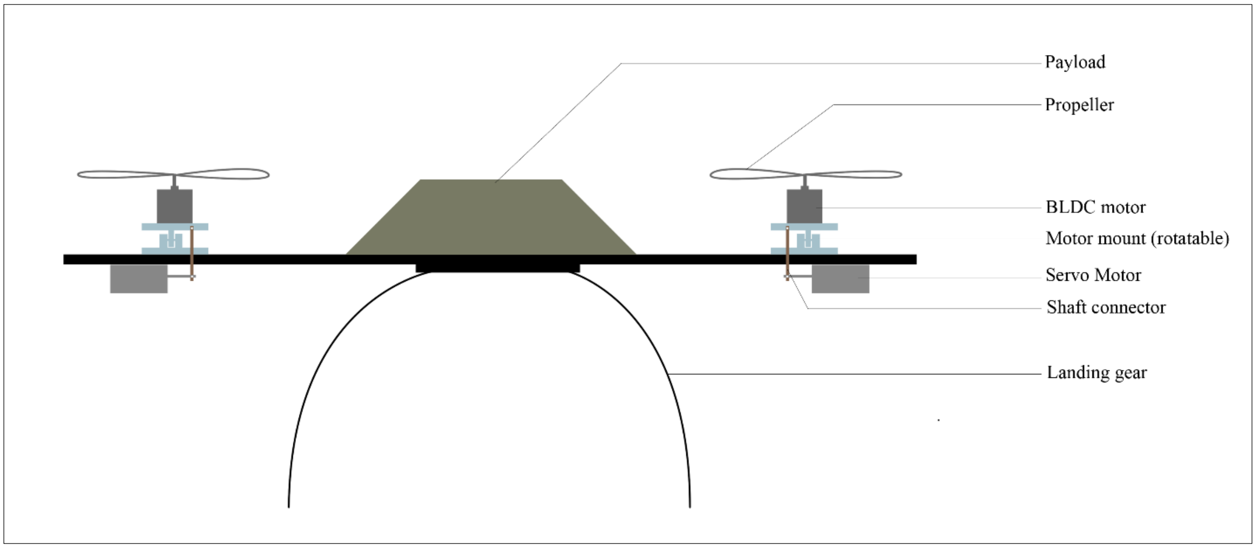


Figure 2.35 – Sketch of the drone

Figure 2.36 – Final product

motors are mounted on the top of the aluminum bar and a servo motor is placed underneath of each brushless motor. Middle part of the body contains all the payloads (ESC, Controller, RF receiver, battery and mobile device). Figure 2.37 shows all the total connections between all electronic components.

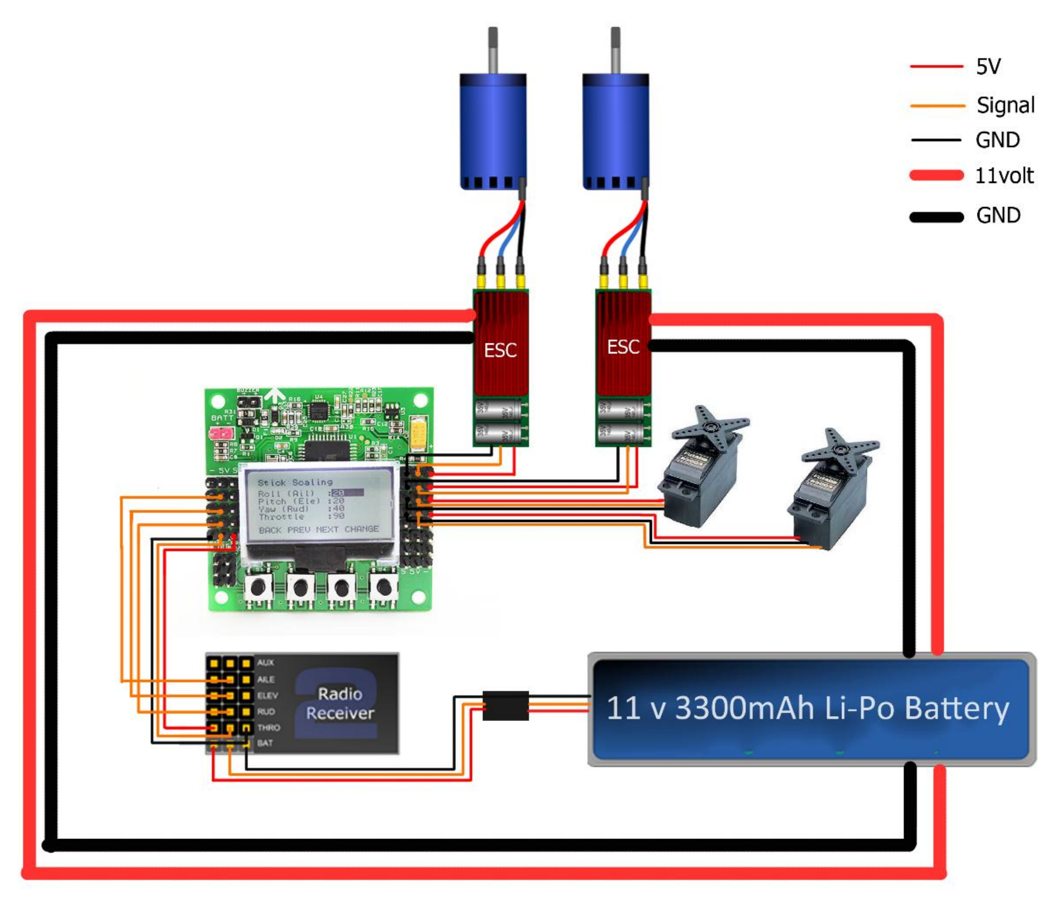


Figure 2.37 – Diagram of connections

In this diagram, thin red, orange and black wires signifies +5V, Signal and GND respectively. Thick red and black connections are 11V and GND line.

Chapter 3

3.1 Introduction

Measurement is one of the important part of this development project. This chapter contains precise measurement of the drone we have developed, application of the developed drone and results.

3.2 Measurements

At the beginning of measurement process we have measured the wait of the drone we have developed. Its wait is 1.7 kg with all the payloads (ESC, battery, controller and mobile device). As every brushless motors with a 12 × 4.5 propeller can produce 1.5 kg of thrust, thus with two propellers we can get almost 3 kg of thrust. Lift equation [14] tells us,

$$\text{Thrust} \geq \text{Weight} \qquad (2.11)$$

So our drone satisfy this equation as we can get 3 kg of thrust and wait of the drone is 1.7 kg.

Table 3.1 contains necessary measurements of the drone we have developed.

Weight	1.7 kg
Motor max tilt angle	35º
Length	0.91 m
Max roll angle	50º

Max pitch angle	30º
Max thrust	3 kg
Max extra payload	1 kg

Table 3.1 – Measurements of the drone

3.3 Application of the developed drone

Application of the drone we have developed has covered a vast area of usage. We can use it in different surveillance purpose. Main applications of this flying machine is given below:

- Firefighting
- Traffic control & surveillance
- Emergency first aid delivery
- Product delivery
- Military surveillance

3.4 Results

Results we have got from this experimental development is slightly different from the theoretical results. For example, from the Simulink diagram we can get a very steady output of the brushless DC motors. However, we have found a lot of unwanted vibration that causes a small oscillation while flying. This vibration is large at low speed and vibration is low at high speed. On the other hand, for vertical takeoff and landing two servo motors needs to keep in same angle and it was supposed to be in same angle as we have tuned the controller circuit board in such a way. However, from the experiment we got a 1º to 3º difference between two servo motors which we need to control manually every time while flying otherwise it gives a slight yaw motion.

From the table 3.1 we can see that maximum pitch and roll angle is 30º and 50º respectively. Beyond this range the aircraft lusts its control thought PID controller is compensating, it gives a large oscillations which causes crash.

Chapter 4

4.1 Conclusion

Main aim of this project was to develop a Drone which can be used in several surveillance purposes and deliver light weight products. For controlling the Drone, 2.4 GHz radio frequency transmitter, receiver, microcontroller, electronic speed controller, brushless DC motor and servo motor have been used. MATLAB®/Simulink® has been used to developed the Drone roll, yaw and pitch control system simulation. The proportional, integral controller action shows the better performance of controlling the roll, pitch and yaw of developed Drone. For live GPS tracking and live video footage feedback is also demonstrated. Demonstration shows the successful operation of Drone tracking and video footage transmission from Drone.

4.2 Limitations

Though we were trying to make it modest, we have some limitations. Firstly, the power issues got priority. Out prototype can fly up to 25-30 minutes with fully charged battery. However, we can overcome such issues by using more powerful batteries and motors but that will increase the cost approximately 52% of the overall cost. Secondly, highest roll angle of the aircraft is 45°. If more than 45° rotation occurs then it lost control. Thirdly, since our radio controller's range is approximately 1 km so we cannot operate this vehicle beyond this range.

4.3 Recommendations

This work could be improved by including the precise mechanical instruments made of carbon fiber. In addition, to have a more precise PID parameters, new methods of PID tuning (the use of genetic algorithms) could be employed for optimal values. Yaw mechanism for tilting rotors can be more improved and well controlled by using gear mechanism. On the other hand, to increase the flight duration 5 cell 5000 mAh Li-Po batteries can be used and it is highly recommended that a vibration absorber needs to be attached to remove vibration effects and get a stable flight.

Appendix

Datasheets of the electronic devices used in this experiment are given below:

ESC:

- Constant Current: 60A
- Burst Current: 80A
- Battery: 2-4S Li-Po
- SBEC: 5.5v / 4A
- Motor Type: Brushless
- Size: 70 x 32 x 17mm
- Battery Wire: 14AWG
- Motor Wire: 14AWG
- Weight: 61g

BLDC Motor:

Model	Battery cell count	RPM/V	Propeller	RPM	MAX Current	Thrust
BL 2815/09	3s	920	11 × 7	8360	30A	1350 gm
			12 × 6	7000	31A	1550 gm

KK2.5.1 multirotor controller board:

- Size: 50.5mm x 50.5mm x 12mm
- Weight: 21 gram
- IC: Atmega644 PA
- Gyro/Acceleration: 6050MPU
- Auto-level: Yes
- Input Voltage: 4.8-6.0V
- AVR interface: standard 6 pin.
- Firmware Version: 2.1.5

Servo Motor:

- Modulation: Analog
- Torque: 4.8V: 122.0 oz-in (8.78 kg-cm)
  6.0V: 153.0 oz-in (11.02 kg-cm)
- Speed: 4.8V: 0.70 sec/60°
  6.0V: 0.56 sec/60°
- Weight: 2.54 oz (72.0 g)
- Dimensions: Length: 1.73 in (43.9 mm)
  Width: 0.91 in (23.1 mm)
  Height: 1.69 in (42.9 mm)

- Motor Type: 3-pole
- Gear Type: Hybrid
- Rotation/Support: Dual Bearings

Li-Po Battery:

- Capacity: 3300mAh
- Voltage: 11.1V
- Max Continuous Discharge: 25C (82.5A)
- Max Burst Discharge: 50C (165A)
- Weight: 284g
- Dimensions: 133*42*23mm
- Charge Rate: 1-3C Recommended, 5C Max

2.4 GHz radio transmitter:

- Radio: 2.4 GHz
- Length: 7.4 in (188mm)
- Height: 3.8 in (96.5mm)
- Width/Diameter: 11.6 in (294.6mm)
- Weight: 498.9 g (17.6oz)

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