A Project Report
On

“TRICOPTER BASED SURVAILANCE SYSTEM”

In partial fulfillment of the requirement for
Award of the

BACHELOR OF SCIENCE
In

ELECTRICAL & ELECTRONICS ENGINEERING

SUBMITTED BY

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DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

CANDIDATE DECLARATION

We hereby certify that the work which is being presented in this dissertation entitled ***"TRICOPTER BASED SURVAILANCE SYSTEM "*** towards partial fulfillment of the requirements for the award of the **Bachelor of Science** in **Electrical & Electronics Engineering,** submitted to the **Department of Electrical & Electronics Engineering, Eritrea Institute of Technology, Mai-Nefhi, Eritrea** is an authentic record of our own work under the supervision of **Mr. Guide Name, Designation,** Electrical & Electronics Engineering Department, Eritrea Institute of Technology, Mai-Nefhi, Eritrea.

The work presented in this dissertation has not been submitted by us for the award of any other degree of this or any other institute.

CERTIFICATE

This is to certify that the above statement made by the students is correct to the best of my knowledge.

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Place: Eritrea Institute of Technology,
Date: May 2016

ERITREA INSTITUTE OF TECHNOLOGY

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BONAFIDE CERTIFICATE

This is to certify that the project report entitled, "***TRICOPTER BASED SURVAILANCE SYSTEM***"Submitted to Eritrea Institute of Technology, Mai-Nefhi is a bonafide record of the project work done by

PITIAS TSEGU 05/1488

In partial fulfillment of the requirement for award of the **Degree in Electrical and Electronic Engineering** during the Academic year 2015-2016

Internal Guide **Head of the Department**

Submitted for the End Semester Examination held on

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Internal Examiner **External Examiner**

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ABBRIVATIONS

Unmanned ground vehicles	UGVs
Unmanned aerial vehicles	UAVs
Radio controlled	RC
Vertical takeoff and landing	VTOL
Systems receiver	RX
Transmitter	TX
RPM	Rotations per minute
Direct Sequence Spread Spectrum	` DSSS
SCL	SCLock
SDA	SDAta
Gyroscope	gyro
Accelerometer	Acc
Field effect transistors	FETs
LiPo	Lithium Polymer
Brushless DC motor	BLDC
Electromotive Force	EMF
Graphical user interface	GUI
Proportional integral and differential	PID

ABSTRACT

The purpose of this research is to design a surveillance system using a tri-copter unmanned aerial vehicle (UAV) with a mounted camera on it. A tri-copter UAV is a flying robot that has three motors and a tail servo motor to carry the third motor and all are located at some distance from the center of gravity, where the controller and the sensors are placed. Each motor is controlled using electronic speed controllers (ESCs) that are supplied with a pulse modulated signal (PWM) from the main controller on board. In addition to these three motors, the servo motor is used to control the reaction torque (commonly known as aerodynamic torque), due to action torque of the propellers, and to produce a yawing motion in the vertical axis. The three motors and the servo allow control of the orientation of the tri-copter roll, pitch and yaw angles with respect to stationary coordinate axes. Thus, we will be able to maneuver the tri-copter in 3-D space using three motors and a servo. The kinematic and dynamic analysis for a tricopter mini-rotorcraft will be conducted. The orientation and control of tricopter according to the parametric equation will be presented. The transformation of all the parameters from one co-ordinate to another co-ordinate will be done for analysis purpose. It includes body frame of reference and earth frame of reference. Hence mathematical modeling of the tricopter will be done.

Fig1.1 Tricopter layout

CHAPTER - 1

INTRODUCTION

1.1 Back Ground

To facilitate missions in hazardous environments, collapsed buildings, filming industry, Power line inspection flying vehicles that are small, agile and are able to take off vertically are of interest. A platform that fulfills those requirements is an UAV (Unmanned Aerial Vehicle) in the form of a multicopter combined with a good control system. Unmanned aerial vehicles (UAVs) can generally be defined as “devices used or intended to be used for flight in the air that has no on-board pilot”. A tri-copter is one such UAV.

Generally, multicopters have more than two rotors (rotorcraft with two rotors is called helicopter). Multicopters have fixed blades with a pitch that are not possible to control, as it does for a helicopter (through the swash plate), to control the direction of the rotor thrust. Instead, the speeds of the rotors are *varied* to achieve motion control of a multicopter. For a tricopter, there is also a servo attached that can tilt one of the motors and by that achieve a change in motion [10]. Multirotor aircrafts are often used in model and radio controlled projects because of the simple construction and control. It includes the ground-station components and also carries some sort of payload, which at a bare minimum includes cameras or other sensors as well as some method to transmit data wirelessly back to a base. Due to the number of rotors, the size of and capacity of the motors does not need to be large in comparison with a helicopter that only has one rotor to induce enough force to lift it up. UAVs are often used in places where it is difficult for a man to operate in such as hazardous environments, steep terrain etc. It is also a suitable and a cheap tool for surveillance. A camera mounted on a multicopter is a very flexible way to survey an area. UAVs can easily be designed for a specific mission and as such it is a very flexible tool.

This project is about stabilizing and control of a tricopter. It is an aircraft with three rotors and a tail servo. Tricopters are considered for use in military or commercial applications and it has the advantage of a helicopter with quick yaw movements, but also the advantage of a quadcopter that is a more robust platform with its four rotor blades, in that the tricopter is more cost efficient in using less components. The control method that will be used in this thesis is based on a dynamical model of the tricopter.

1.2 Problem Statement

A growing problem with robotic unmanned ground vehicles (UGVs) has led to a renewed interest in studies of unmanned aerial vehicles (UAVs). Despite the development of UGVs within the past20 years, navigation in outdoor environments still posses’ significant challenges. Because of the limitations of UGVs, UAVs are becoming increasingly important because they navigate or survey ground-based obstacles and are highly mobile. Applications for UAVs include aerial mapping, meteorology, environmental monitoring, agriculture and forestry, building inspection may be after collapse, disaster and crisis management, firefighting, traffic surveillance, communications, and applications for civil engineering [12].

The tricopter (UAV) that is proposed on this project has to fulfill certain requirements if it is to be used for the intended purpose. It should achieve stability of the orientation. A control strategy that could be used to satisfy this specification will be selected. This controller needs a model of the system to calculate the control signals .That means that the tricopter has to be described by differential, or difference, equations and the model parameters of the tricopter have to be estimated. Hence the tricopter will be described by a dynamic model. The proposed controller has been implemented on an Atmel AtMega 644PA Microcontroller, which has limited computational resources. This means that an online algorithm that solves the selected controller problems in a computationally efficient manner has to be used.

1.3 Significance

The significance of tricopter based surveillance system covers vast application of commercial and military services. It includes applications like transportation of goods between different places, filming industry, help in infantry operations, facilitate missions in hazardous environments, Power line inspection, survey forest wildlife areas, security, assess collapsed buildings, search and Rescue, and also for navigation or survey ground-based obstacles .

1.3.1 Objectives of the study:

The objectives of our project are:

- To model the tricopter flying robot (UAV) and predict a controller so that the orientation is stabilized.
- To use the designed tricopter for surveillance.

1.3.2 Research questions:

It is proposed that the tri-copter can be used for surveillance purposes. But,

- Why the tri-copter is chosen among other multi-copters (like quad and helicopter)?
- How is the flight going to be controlled?

CHAPTER - 2

LITERATURE REVIEW

With advancements in computer processing and reductions in hardware cost it has been possible for the average radio controlled (RC) enthusiast to create their own flying drone. A drone refers to aircraft that have the capability of autonomous flight or autopilot, which means that it, can follow a mission from point to point, typically guided by a transmitter with human control.

Usually drones are also known as unmanned aerial vehicles (UAV) or unmanned aerial systems (UAS), to include the ground-station components and also carry some sort of payload, which at a bare minimum includes cameras or other sensors as well as some method to transmit data wirelessly back to a base. Beginning in the Mid-1990s the US Military invested in the development of UAVs due to their ability to operate in dangerous locations while keeping their human operators at a safe distance. By the year 2000 the US Military had established operational UAV squadrons. The larger UAVs provide a reliable long duration, cost effective, platform for reconnaissance as well as weapons, becoming an indispensable tool for the military. Most of the large military UAVs are fixed wing aircraft. Reducing the size of the UAV will give it greater maneuverability and versatility. The reduction in size comes at the penalty of less payload and endurance time. A rotary aircraft becomes the best alternative to a fixed wing aircraft for minimizing size while maintaining lifting capability. With its ability to hover and perform vertical takeoff and landings (VTOL), a rotary aircraft can maneuver in confined spaces giving it a broader range of applications when compared to a larger or fixed wing aircraft.

Traditional rotary aircraft seen today are helicopters, with a main and tail rotor. On a smaller scale, helicopters are harder to control [MAE586 project work in mechanical engineering] and may not be as stable of a platform for most applications. Complex mechanical control linkages for rotor actuation, increases the possibility of failure and large main rotors can cause damage or injury. A multicopter can alleviate all the problems inherent to a small scaled helicopter design, while maintaining all its benefits.

A multicopter is a rotary aircraft. For this project a tricopter (three rotor rotary aircraft) was selected for design and analysis due to its increased performance and versatility over other popular multicopters, such as quadcopter. Also with one less rotor, motor reliability of the system increases while deign cost decreases, and finally there are few academics papers which research this design. [MAE586 project work in mechanical engineering]

We have already pointed out that an unmanned aerial vehicle (UAV) or automaton is an air ship without a human pilot ready for. Its flight is controlled either independently by machines in the vehicle (autonomous mode) or under the remote control of a pilot on the ground or in an alternative vehicle. There are a wide mixture of UAV shapes, sizes, designs, and aspects. Generally, UAVs were basic remotely guided flying machine, yet self-governing control is progressively being utilized.

Homeland security is one of the main civil UAV applications invested by defense agencies and have been employed in numerous non-hostile areas. So security is another field that UAVs can simplify because law enforcement groups will become more reliant on automated systems in the future to help ensure safety. Besides border patrolling UAVs can also be enrolled in the surveillance of critical infrastructures (power plants, telecommunications, pipelines, etc.), coastal patrol, and other high risk areas [11]and[12].

UAVs can also be useful as tools during or after natural disasters. As a meteorological tool they can provide forewarning to citizens. After a disaster, they can assist with search and rescue teams. Through a systematic exploration of an affected area, UAVs could visually look on to victims to help guide rescue forces. UAVs can also be sent into dangerous weather conditions that would normally prevent search and rescue teams from exploring. [20]

Several recent studies of UAVs have focused on their uses as an alternative to manned aircrafts because of their financial superiority. Because UAVs are typically smaller in size than manned aircrafts, UAVs come with a considerably cheaper price. Factors for cost include the cost to operate the machines, the maintenance costs, the fuel costs, and the housing costs [20].

Progress in sensor technology, data processing and integrated actuators has made the development of miniature flying robots possible Rotorcrafts have witnessed an incredible evolution in the last years. Universities, students and researchers continuously work to introduce more robust controllers and modeling techniques, so that they can provide detailed and accurate representations of real-life tricopters [Quad rotor prototype].

CHAPTER – 3

MAIN BODY

3.1 METHEDOLOGY:

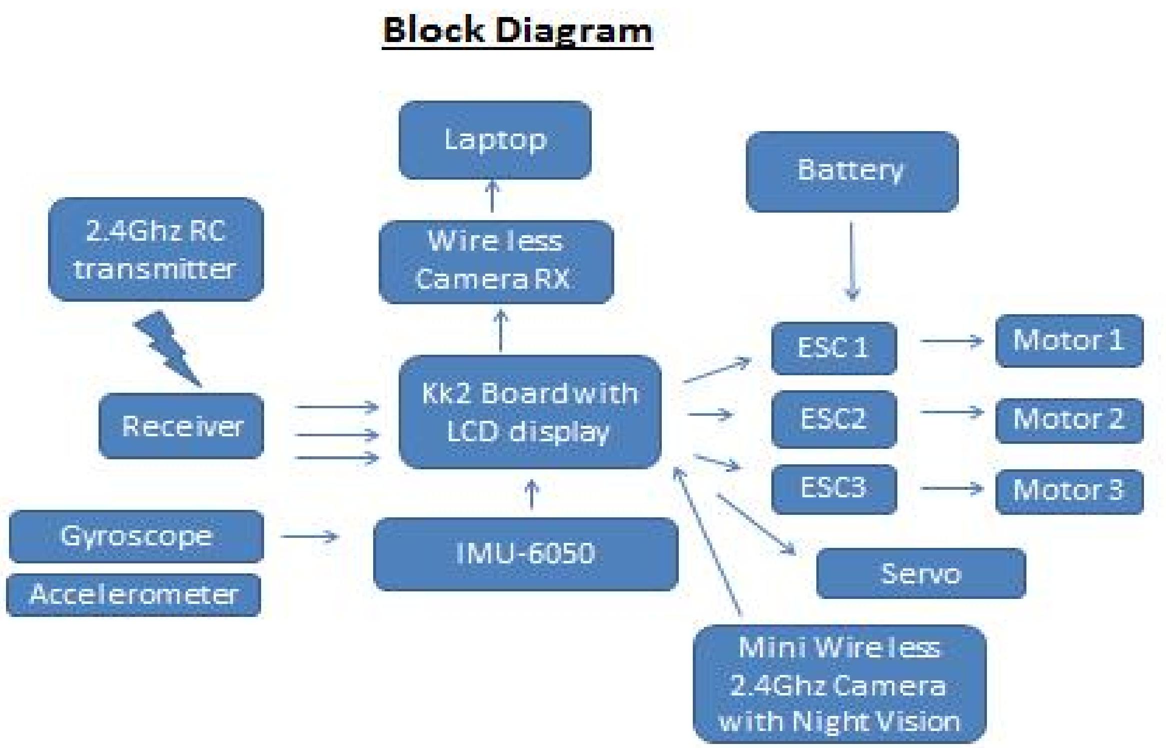
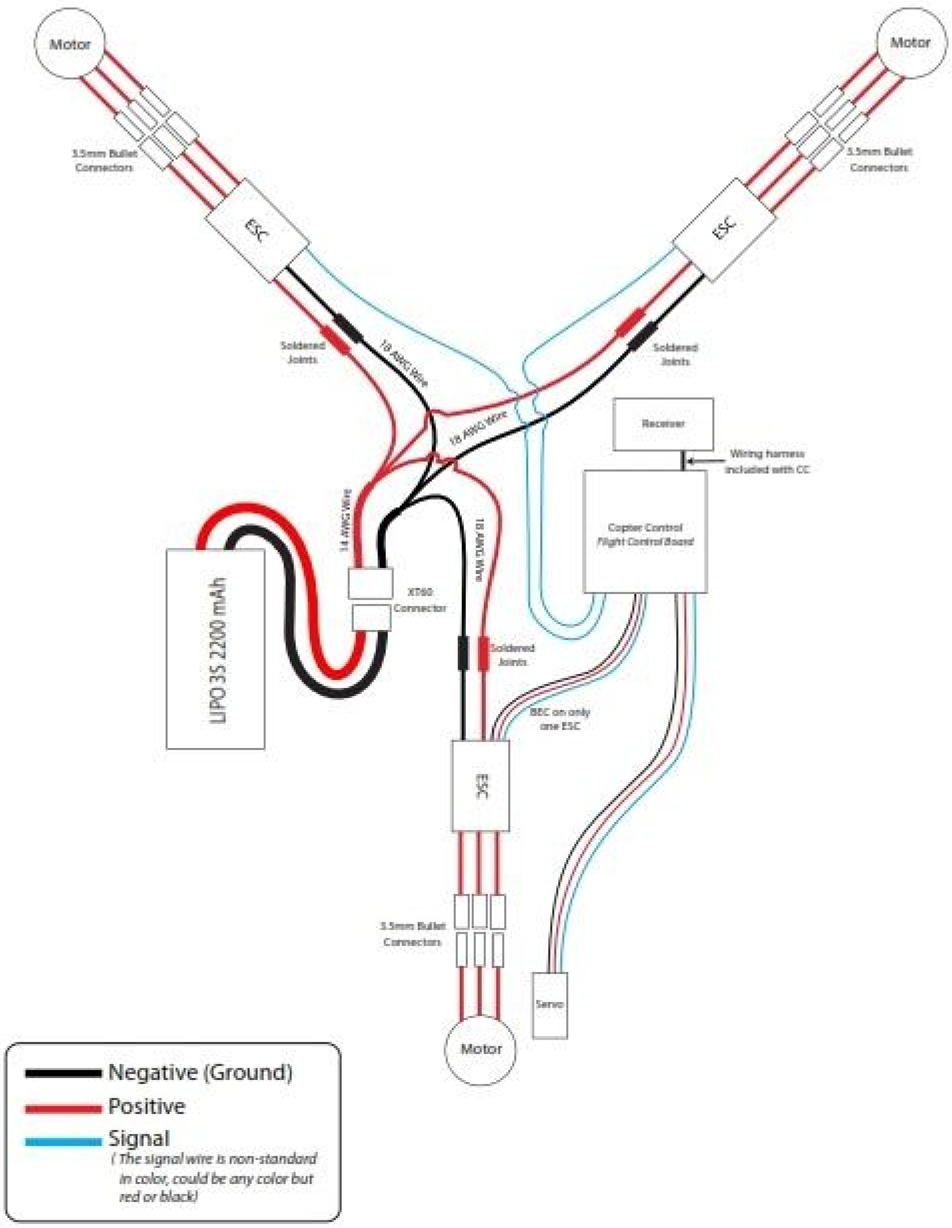


Fig 3.1Block diagram of the Tricopter



Motor
3.5mm Bullet Connectors
ESC
Soldered Joints
18 AWG Wire
Motor
3.5mm Bullet Connectors
ESC
Soldered Joints
18 AWG Wire
Receiver
Wiring harness included with CC
14 AWG Wire
18 AWG Wire
Copter Control
Flight Control Board
LIPO 3S 2200 mAh
XT60 Connector
Soldered Joints
BEC on only one ESC
ESC
3.5mm Bullet Connectors
Servo
Motor
Negative (Ground)
Positive
Signal
(The signal wire is non-standard in color, could be any color but red or black)

Fig 3.2 Wiring diagram of the Tricopter

3.2 COMPONENT DESCRIPTION:

3.2.1 KK2 Board

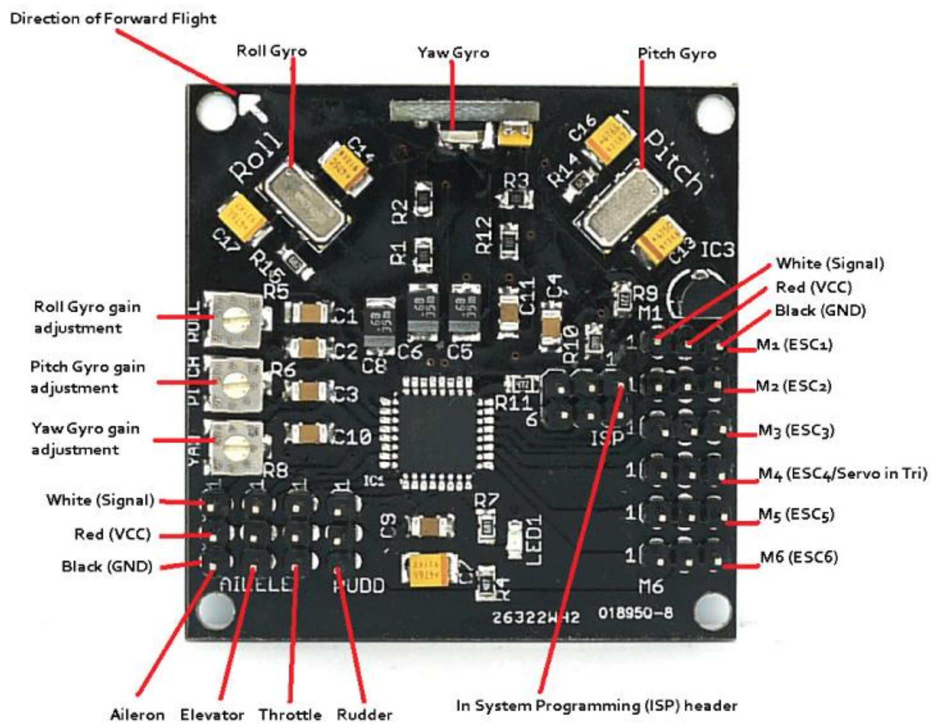


Fig 3.3 KK 2 multi rotor control board

This control board is used for flight control of the Tricopter. Its purpose is to stabilize the aircraft during flight. To do this it takes the signal from the 6050MPU gyro/acc (roll, pitch and yaw) then passes the signal to the Atmega644PA IC. The Atmega644PA IC unit then processes these signals according the program firmware and passes control signals to the installed Electronic Speed Controllers (ESCs). These signals instruct the ESCs to make fine adjustments to the motors rotational speed which in turn stabilizes tricopter craft. The KK2 Multi-Rotor control board also uses signals from your radio systems receiver (Rx) and passes these signals to the AtMega 644PA IC via the aileron, elevator, throttle and rudder inputs. Once this information has been processed the IC will send varying signals. .

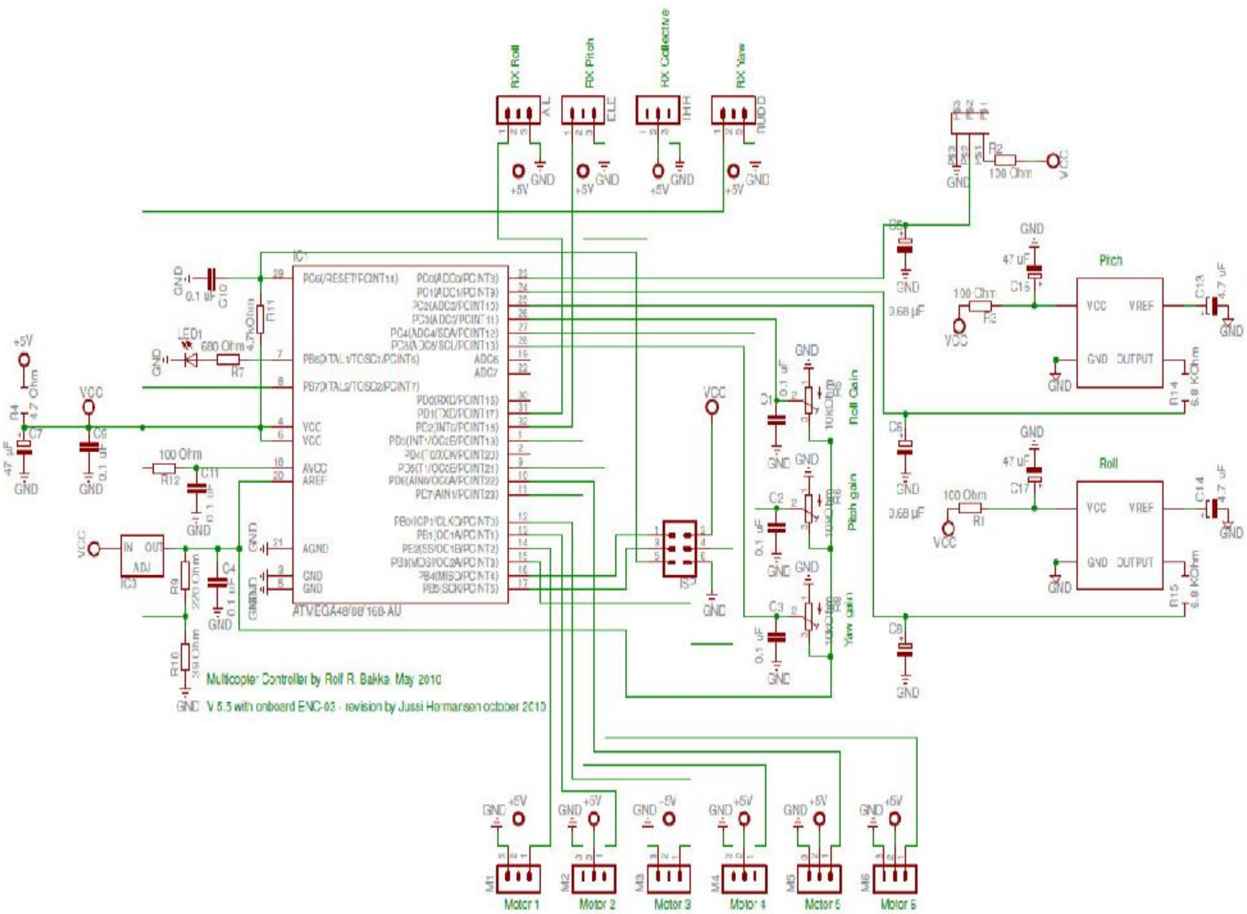


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Fig3.4circuit diagram of the KK2 Board

The kk2 multi-controller uses Murata Piezo gyros that are less sensitive to vibration than SMD type gyros, but it is still a good idea to mount the board on a vibration dampening material. The board must also be mounted with the white arrow facing the direction of forward flight. When connecting your Remote Control Receiver (RX) you must connect the white signal wire of the channels (CH1, CH2, CH3 and CH4) from your RX corresponding to the aileron, elevator, throttle and rudder to the inner pins on the board while the red (VCC) wires are connected to the center pins, and the black (GND) wires are connected to the pins on the outer edge of your board. The pins marked M1 to M6 are connected to the 3 pin BEC plug from your ESCs. They follow the same convention as the RX pins with the white wires connected to the inner pins, the red wires to the center pins and the black wires to the outer pins. The ESCs and the connected servo motor are plugged onto the pins M1 to M4 in the following order depending on flight rotor configuration.

Note also the direction of rotation for each motor. This is achieved by connecting the three ESC wires to the motors and swapping two of the wires to achieve rotation in the opposite direction. The ESCs which in turn adjust the rotational speed of each motor to induce controlled flight (up, down, backwards, forwards, left, right, yaw).

3.2.1.1 POWER SUPPLY AND REQUIRED CALCULATIONS

The power supply that the tricopter will use is a 3 cell lithium polymer battery. Lithium polymer batteries or LiPos are popular in the RC community due to their light weight, power density, and availability in different rating and capacities. LiPos are typically designated by voltage, capacity, and C rating. The voltage of the LiPo is dependent on the amount of cells. Each individual cell maintains a nominal voltage of 3.7 volts and of normally attached with other cells in series or in parallel to achieve their desired rating. The capacity of the LiPo is measure in mAh. This is corresponds to the amount of current, in mA, the battery can discharge in one hour. The C rating is the discharge rate of the battery. It is a multiplication factor of how many times the capacity the battery can safety discharge. For example a 2200mAH 1C can provide a constant 2.2 amps for one hour, while if the same capacity battery was used but as a 40C, then the battery would provide a constant 88 amps for 1.5 minutes. When selecting the proper battery the product of the capacity times the C rating must equal the maximum amp draw. Based on the power requirements of the three motors, it was originally stated that since all the ESCs are wired in parallel, this requires a power supply which can deliver a total of 63 amps in order to achieve 100% throttle. In our project the battery used is 2200mAH capacity, it would be able to support about 2 minutes of 100% throttle for 63 amps. Since the tricopter will normally operate conservatively around an average 30% throttle, as its efficient power setting, the flight time increases closer to 7 minutes. With a nominal voltage of 3.7 volts per cell a full charge places cell voltage at 4.2 volts. In a discharge cycle at a given C rating the LiPo maintains a small change in voltage up to about 80% of its capacity. Normal minimum voltage to maintain the cell without damage or decreased capacity due to over discharge is approximately 3 volts. A typical operating rule is to operate the battery to 80% of its capacity or until a minimum voltage of 3 volts is reached in each cell.

3.2.2 LiPo BATTERY

Lithium Polymer batteries (referred to as “LiPo” batteries), are a newer type of battery now used in many consumer electronics devices. The basic advantage of the LiPo batteries is undoubtedly the capacity to dimensions ratio. They are very small sized while simultaneously being very energy efficient, they have been gaining in popularity in the over the last few years, and are now the most popular choice for anyone looking for long run times and high power.

LiPo batteries offer three main advantages over the common Nickel-Metal Hydride (NiMH) or Nickel Cadmium (NiCd) batteries:

1. LiPo batteries are much lighter weight, and can be made in almost any size or shape.
2. LiPo batteries offer much higher capacities, allowing them to hold much more power.
3. LiPo batteries offer much higher discharge rates, meaning they pack more punch.

But, just as a coin has two sides, there are some drawbacks to LiPo batteries as well.

1. LiPo batteries have a shorter life span than NiMH/NiCd batteries. Their average is only 300 – 400 cycles if treated properly.
2. The sensitive nature and chemistry of the batteries can lead to fire should the battery get punctured and vent into the air.
3. LiPos need specialized care in the way they are charged, discharged, and stored. The equipment can be price-prohibitive.

In short, LiPo batteries offer a wide array of benefits. But each user must decide if the benefits outweigh the drawbacks.

The way we define any battery is through a ratings system. This allows us to compare the properties of a battery and help us determine which battery pack is suitable for the need at hand. There are three main ratings to be aware of on a LiPo battery.

The ratings are:

A. Voltage
B. Capacity
C. Discharge Rating

Fig.3.5 sample LIPO chargeable battery

So what does it all mean? Let's break it down and explain each one.

A. Voltage

A LiPo cell has a standard voltage of 3.7V. For example a7.4V battery means that there are two cells in series (which means the voltage gets added together). If the battery is indicated with "2S" it means that there are 2cells in Series. So a two-cell (2S) pack is 7.4V, as in our case the LiPo battery is a three-cell (3S) pack that indicates the stored voltage is 11.1V.

* The voltage of a battery pack is essentially going to determine how fast your vehicle is going to go. Voltage directly influences the RPM (rotations per minute) of the electric motor (brushless motors are rated by kV, which means 'RPM per Volt'). So if you have a brushless motor with a rating of 3,500kV, that motor will spin 3,500 RPM for every volt you apply to it. On a 2S LiPo battery, that motor will spin around 25,900 RPM. On a 3S, it will spin a whopping 38,850 RPM. So the more voltage you have, the faster you're going to go.

B. Capacity

The capacity of a battery is basically a measure of how much power the battery can hold. Think of it as the size of your fuel tank. The unit of measure here is milliamp hours (mAh). This is saying how much drain can be put on the battery to discharge it in one hour.

Since we usually discuss the drain of a motor system in amps (A), here is the conversion:

Example if the capacity of the battery is 2200mAh. This means that a load of 2200mAh (or 2.2A) would drain the battery completely in one hour. We use this information on charging as well, because it works in the opposite way as well. If we charge the above battery at 2.2Amps, it will be completely charged in about an hour. Physics is a bit fickle, and there is energy lost along the way, so it won't be an hour on the dot, but it's a good ballpark time.

As mentioned above the capacity of the battery is like the fuel tank which means the capacity determines how long you can run before you have to recharge. The higher the number is, the longer the run time. But there are companies that make batteries with larger capacities. The bigger the capacity of the battery means the bigger the physical size and weight of the battery. Another consideration is heat buildup in the motor and speed control over such a long run. Unless periodically checked, you can easily burn up a motor if it isn't given enough time to cool down, and most people don't stop during a run to check their motor temperatures. Keep temperature of the system in mind when picking up a battery with a large capacity.

C. Discharge Rating ("C" Rating)

The last two specifications have a direct impact on certain aspects of the vehicle, whether it's speed or run time. This makes them easy to understand. The Discharge Rating (which will be referred as the C Rating). The C Rating is simply a measure of how fast the battery can be discharged safely and without harming the battery. One of the things that make it complicated is that it's not a stand-alone number; it requires you to also know the capacity of the battery to ultimately figure out the safe amp draw. The "C" in C Rating actually stands for Capacity. Once you know the capacity, it's pretty much a plug and-play math problem. We have a battery with a capacity of 2200mAh and discharging rate of 35C, here's the way we find out the maximum safe continuous amp draw:

2200mAh = 2.2 Amp (1A)

35C = 35 x Capacity (in Amps)

35*2.2A = 77A

The resulting number is the maximum sustained load you can safely put on the battery. Going higher than that will result in the battery becoming, at best, unusable. At worst, it could burst into flames. So our battery can handle a maximum continuous load of 77A.

Most batteries today have two C Ratings: a Continuous Rating (which we've been discussing), and a Burst Rating. The Burst rating works the same way, except it is only applicable in 10-second bursts, not continuously. For example, the Burst Rating would come into play when accelerating a vehicle, but not when at a steady speed on a straightaway. The Burst Rating is almost always higher than the Continuous Rating. Batteries are usually compared using the Continuous Rating, not the Burst Rating.

3.2.2.1 FLIGHT TIME

One of the main considerations in building or buying a drone is the flight time. Yet, although it's such an important factor, it's actually quite hard to calculate. The calculator requires input values for: battery capacity (Ah), discharge (%) and average amp draw (A). In our case the LiPo battery has a capacity of 2200mAh and we have an average current draw of 55 amperes. But this 55A is the current drawn during full throttle (100%), so we take 30% of this current (16.5A) which is the current during average throttle. Taking the discharge for LiPo batteries as 80% the flight time can be calculated as follows.

Flight Time Calculation

Battery Capacity (in Ah)	2.2 Ah
Discharge (80% for LiPo Batteries)	80%
Average Amp Draw	16.5

*Time= (Battery Capacity) * (Discharge)/ (Average Amp Draw)*
=2.2Ah(80/100)/16.5*

Time = 0.106 hour or 6.4 minutes

3.2.2.2 STORAGE

In the old days, we used to run our cars or airplanes until the batteries died, then just set the batteries on the shelf at home, waiting for the next time we could use them. For the longest life of the batteries, LiPo batteries should be stored neither fully charged nor dead and they should be stored at room temperature at 3.8V per cell. Most modern computerized chargers have a LiPo

Storage function that will either charge the batteries up to that voltage, or discharge them down to that voltage, whichever is necessary.

Lithium-Polymer batteries can be damaged by sitting fully charged in as little as a week. So don't forget to put your LiPos at storage voltage when you're done using them.

They should also be stored in a fireproof container of some sort as they are portable and protect your workshop from catching fire.

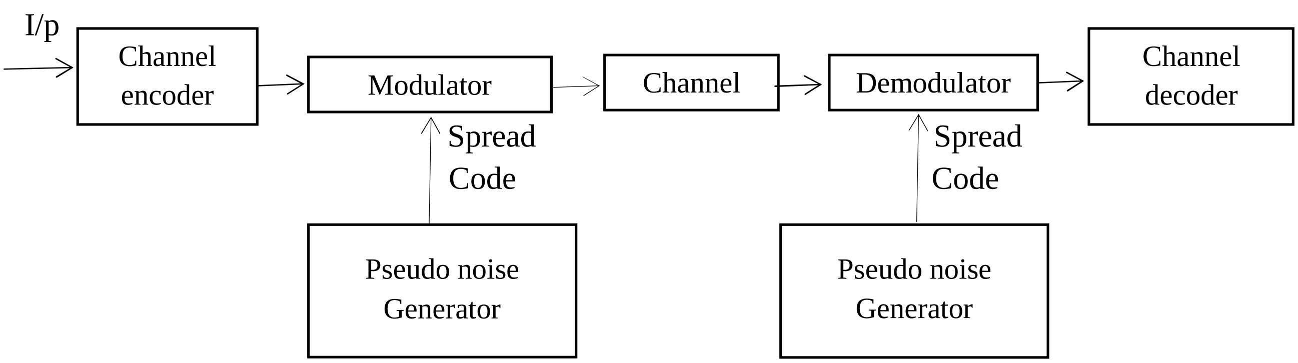
3.2.2.3 OUTFITTING YOUR LIPO WITH A PROPER CONNECTOR

LiPo batteries have all sorts of power just waiting to be unleashed, and we want as much of that power to reach the motor as possible. To do this we need appropriate connectors. Bad connectors increase resistance and prevent all that power from being used efficiently.

3.2.3WIRELESS TRANSMITTER

Transmitter uses 2.4GHz frequency and uses (DSSS) Direct Sequence Spread Spectrum Encryption for transmitting 5channels (thrust, roll, pitch, yaw, AUX) between the Human Pilot and the Receiver attached to the KK2 board controller. The transmitting principle is as follows.

Spread spectrum



Input is fed into a channel encoder that produces an analog signal with a relatively narrow bandwidth around some center frequency. This signal is further modulated using a sequence of digits known as a spreading code or spreading sequence. Typically, but not always, the spreading code is generated by a pseudo noise, or pseudorandom number, generator. The effect of this modulation is to increase significantly the bandwidth (spread the spectrum) of the signal to be transmitted. On the receiving end, the same digit sequence is used to demodulate the spread spectrum signal. Finally, the signal is fed into a channel decoder to recover the data.
Several things can be gained from this apparent waste of spectrum:

- The signals gains immunity from various kinds of noise and multipath distortion. The earliest applications of spread spectrum were military, where it was used for its immunity to jamming.

• It can also be used for hiding and encrypting signals. Only a recipient who knows the spreading code can recover the encoded information.

A comment about pseudorandom numbers is in order. These numbers are generated by an algorithm using some initial value called the seed. The algorithm is deterministic and therefore produces sequences of numbers that are not statistically random. However, if the algorithm is good, the resulting sequences will pass many reasonable tests of randomness. Such numbers are often referred to as pseudorandom numbers.

The important point is that unless you know the algorithm and the seed, it is impractical to predict the sequence. Hence, only a receiver that shares this information with a transmitter will be able to decode the signal successfully.

Direct sequence spread spectrum

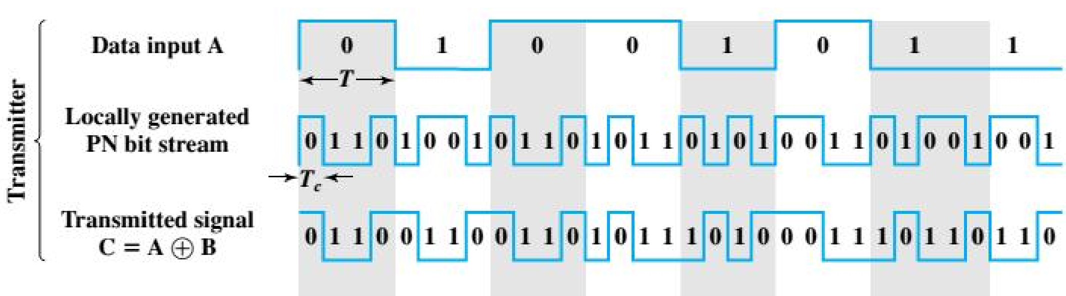
With direct sequence spread spectrum (DSSS), each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code. The spreading code spreads the signal across a wider frequency band indirect proportion to the number of bits used. One technique with direct sequence spread spectrum is to combine the digital information stream with the spreading code bit stream using an exclusive-OR (XOR). The XOR obeys the following rules:

0 XOR 0=0   0 XOR 1=1   1 XOR0=1
1 XOR1=0

Note that an information bit of one inverts the spreading code bits in the combination, while information bit of zero causes the spreading code bits to be transmitted without inversion. The combination bit stream has the data rate of the original spreading code sequence, so it has a wider bandwidth than the information stream.

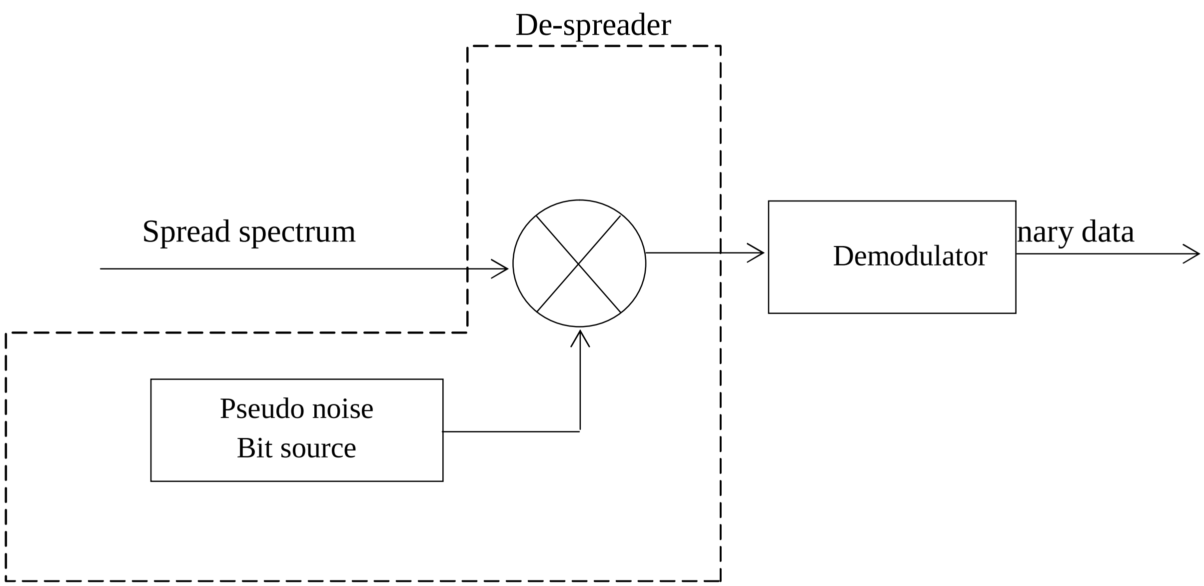
Pseudo noise is generated and then transmitted added with the encoded binary data. The transmitter and the receiver should be synchronized (same pseudo noise should be produced).

The following figure shows an example. Note that an information bit of "one" inverts the spreading code bits in the combination, while information bit of "zero" causes the spreading code bits to be transmitted without inversion. The combination bit stream has the data rate of the original spreading code sequence, so it has a wider bandwidth than the information stream. In this example, the spreading code bit stream is clocked at four times the information rate.



The information carrying signal is multiplied with the generated pseudo noise signal after getting modulated. The pseudo noise is a sequence taking the values 0 and 1. Then the signal gets transmitted.

3.2.4 WIRELESS RECEIVER



The receiver receives command signal at 2.4 GHz and decrypts the 5 channels pulse width modulation (PWM) and passes the signal to the KK2 Tricopter controller board. The generated spread code is eliminated here in the receiver. The pseudo noise at receiver must be aligned properly (synchronized) with the sequence at the transmitter. The input (spread spectrum) is multiplied with the generated pseudo noise. Then this data gets demodulated to obtain the message signal.

As both the transmitter and receiver are synchronized the added and eliminated spread codes are identical. That's why this method of transmission is more secured in which only the desired receiver is able to encode the transmitted data.

Then in this receiver section the message signal is filtered from the incoming signal and then decoded in the decoder.

3.2.5 6050MPU gyroscope/Accelerometer IC

The gyroscope and Accelerometer used in our project is MPU6050 IC in a single chip. It contains 3 axis gyro and accelerometer signals (x, y, z axis). This analog signal is converted to digital with ADC (analog to digital conversion) and passes equivalent 3 axis Acc/Gyro signals (voltages) to the AtMega 644PA chip using I^2C Interfaces.

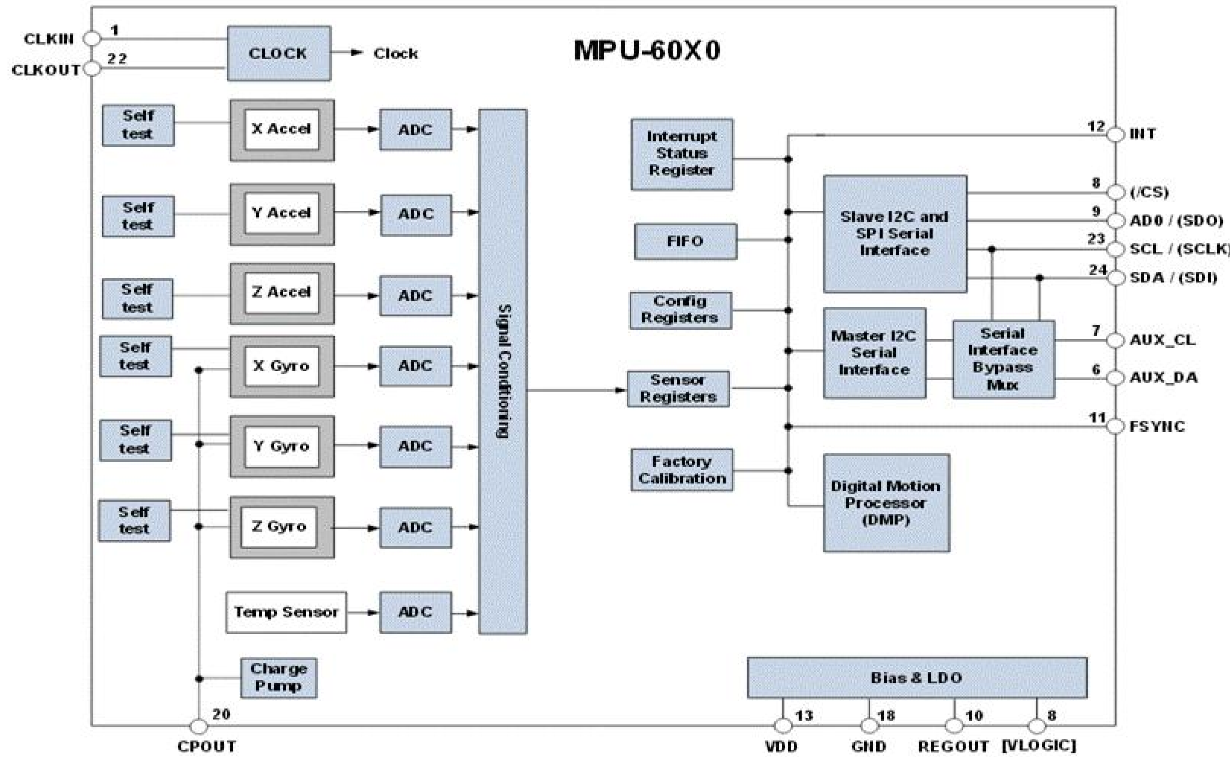


Fig 3.6 block diagram of MPU6050

3.2.5.1 I^2C INTERFACES

The I^2C bus uses only two pins: SCL (SCLock) and SDA (SDAta). SCL is generated by the processor to clock data into and out of the peripheral device. SDA is a bidirectional line that serially transmits all data into and out of the peripheral. The SDA signal is open-collector so several peripherals can share the same 2-wire bus. When sending data, the SDA signal is only allowed to change while SCL is in the low state. Transitions on the SDA line while SCL is high are interpreted as start and stop conditions. If SDA goes low while SCL is high, all peripherals on the bus will interpret this as a START condition. SDA going high while SCL is high is a STOP or END condition. The processor initiates the START condition, and then sends the peripheral address, which is 7 bits long and tells the devices on the bus which one is to be selected. This is followed by a read/write bit (1 for read, 0 for write).After the read/write bit, the processor programs the I/O pin connected to the SDA bit to be an input and clocks an acknowledge bit in. The selected peripheral will drive the SDA line low to indicate that it has received the address and read/write information. After the acknowledge bit, the processor sends another address, which is the internal address within the peripheral that the processor wants to access. The length of this field varies with the peripheral. After this is another acknowledge, then the data is sent. For a write operation, the processor clocks out 8 data bits; for a read operation, the processor treats the SDA pin as an input and clocks in 8 bits. After the data another acknowledgement comes. Some peripherals permit multiple bytes to be read or written in one transfer. The processor repeats the data acknowledge sequence until all the bytes are transferred. The peripheral will increment its internal address after each transfer. One drawback to the I2C bus is speed—the clock rate is limited to about100 KHz. A newer Fast-mode I2C bus that operates to 400 Kbits/sec is also available, and a high-speed mode that goes to 3.4 Mbits/sec is also available. High speed and fast-mode both support a 10-bit address field so up to 1024 locations can be addressed. High-speed and fast-mode devices are capable of operating in the older system, but older peripherals are not useable in a higher-speed system. The faster interfaces have some limitations, such as the need for active pull-ups and limits on bus capacitance. Of course, the faster modes of operation require hardware support and are not suitable for a software-controlled implementation.

The tricopter is equipped with a 3 axis gyroscope (gyro). A gyro measures rate of rotation around a particular axis. When a gyro is used to measure the rate of rotation around the tricopter roll axis, it will measure a non-zero value as long as the tricopter is rolling, but measure zero if the roll stops.

The 3 axis accelerometer has the ability to gauge the orientation of a tricopter relative to the earth’s surface. Why do we need to measure the acceleration?

1. Acceleration is a physical characteristic of a system.
2. The measurement of acceleration is used as an input into some types of control systems.
3. The control systems use the measured acceleration to correct for changing dynamic conditions.

If the tricopter is in free fall, the acceleration will be shown to be zero. If it is only accelerating in a particular direction the acceleration will be indistinguishable from the acceleration being provided by the earth’s gravitational pull. An accelerometer accomplishes this by measuring linear accelerations.

3.2.6 MINI WIRELESS 2.4 GHz CAMERA AND RECEIVER

The Mini wireless camera is mounted on the frame of the tricopter sends wireless video and audio signal both in day/Night at 2.4Ghz signal from the tricopter at an average of 150 meters to the RF receiver attached to the laptop and the video/Image can be saved and Edited in the computer for surveying the required Area.

A. PROPULSION AND POWER SYSTEM

The proper selection of a propulsion and power system, constituting the power train, for any UAV is based on the synchronization of the propeller not over loading the motor, and the combination of the two not exceeding the capability of the battery and the electronic speed controller. Component specifications, manufacture test data, and user field test are used to determine the proper combination for the power train. The flight profile and operational requirements will determine the need for a power system whether it is designed for speed, lift, or a combination of both. Under-propping (too small of a propeller) or over-propping (too large of a propeller) can do irreversible damage to electric motors and ESCs, because an incorrect propeller will force the motor to work harder than it was designed to. Placing an oversize propeller on an electric motor will not cause the motor stall. It will just keep on trying to turn the propeller causing motor to draw higher current. Eventually it will exceed the maximum amperage rating of the motor or ESC and will burn it out. With too small a propeller, the motor can exceed its RPM rating and damage can result from the motor spinning too fast. Since rotary aircraft need to use their rotors to produce thrust and lift, the required thrust to weight ratio is higher. This means that the combined thrust of the three rotors needs to exceed the weight of the tricopter by a certain factor. In RC model airplanes a thrust to weight ratio of 1 is considered aerobatic, but for a tricopter is will only hover an inch off the ground in ground effect? Through prototype testing a ratio of 2 was required to properly fly with light wind, and a ratio of 3 was observed to be ideal for speed and sufficient to carry a payload while operating at higher wind speeds. Based on the objectives of this project the tricopter is designed for taking both lift and speed into its design consideration in achieving a thrust to weight ratio of 3.

3.2.7 ELECTRONIC SPEED CONTROLLERS (ESC'S)

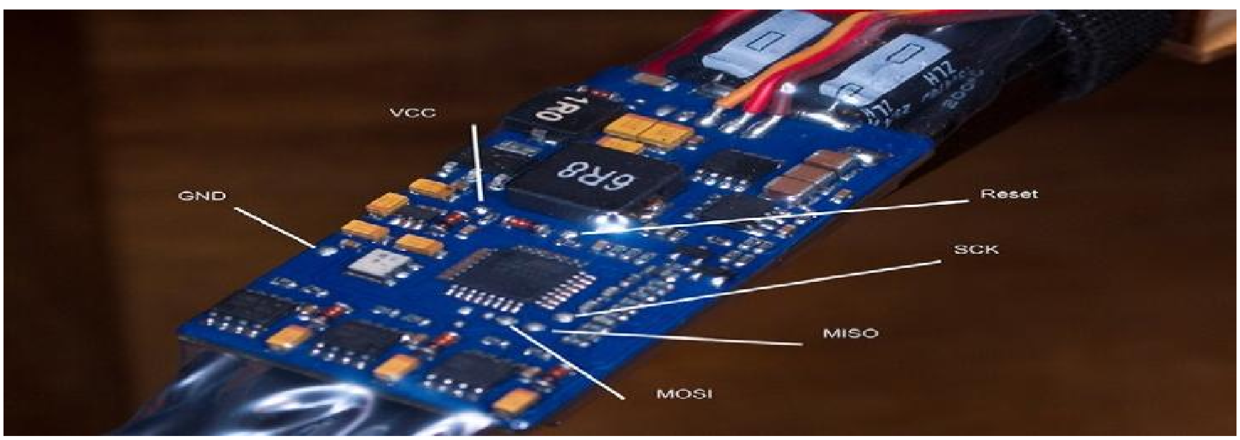


Fig 3.7 F20A electronic speed controller

An electronic speed control or ESC is a circuit with the purpose to control an electric brushless motor's speed, its direction and possibly also to act as a dynamic brake in some cases. In our project we are using 3 ESC's for 3 Brush less DC motors. The ESC board contains Atmega8 MCU that is programmed by the user to take PWM signal from the KK2 controller board and drive the FETs to give appropriate speed to the brushless dc motors. ESCs are often used on electrically powered brushless motors essentially providing an electronically-generated three phase electric power, with a low voltage source and are normally rated according to maximum current. An ESC interprets control information in a way that varies the switching rate of a network of field effect transistors (FETs), not as mechanical motion as would be the case of a servo. The quick switching of the transistors is what causes the motor itself to emanate its characteristic high-pitched whine, which is especially noticeable at lower speeds. It also allows much smoother and more precise variation of motor speeds in a far more efficient manner than the mechanical type with a resistive coil and moving arm once in common use.

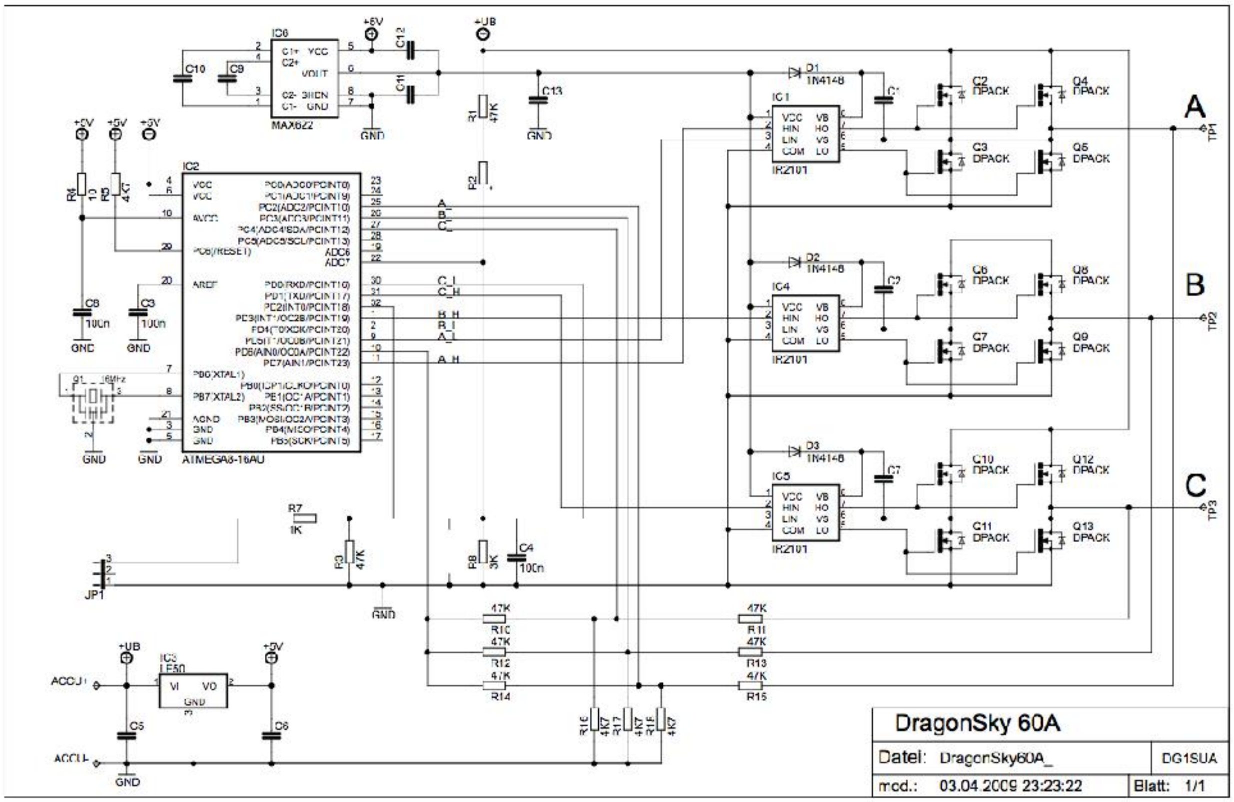


Fig 3.8 Circuit Diagram of electronic speed controller

3.2.7.1 LM7805

The LM7805 series of three terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current.

Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

Features

- Output Current up to 1A
- Output Voltages of 5V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

3.2.7.2 Atmega8L MCU

Features:

- High-performance, Low-power Atmel AVR 8-bit Microcontroller
- Advanced RISC Architecture
  - 130 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 × 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16MIPS Throughput at 16MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory segments
  - 8Kbytes of In-System Self-programmable Flash program memory
  - 512Bytes EEPROM
  - 1Kbyte Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
  - In-System Programming by on-chip Boot Program
  - True Read-While-Write Operation
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Presale, one Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Three PWM Channels
  - 8-channel ADC in TQFP and QFN/MLF package
    Eight Channels 10 - bit Accuracy
  - 6-channel ADC in PDIP package
    Six Channels 10 - bit Accuracy
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources

– Five Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, and Standby
• I/O and Packages
– 23 Programmable I/O Lines
– 28-lead PDIP, 32-lead TQFP, and 32-pad QFN/MLF
• Operating Voltages
– 2.7V - 5.5V (ATmega8L)
– 4.5V - 5.5V (ATmega8)
• Speed Grades
– 0 - 8MHz (ATmega8L)
– 0 - 16MHz (ATmega8)
• Power Consumption at 4 MHz, 3V, 25 C
– Active: 3.6mA
– Idle Mode: 1.0mA
– Power-down Mode: 0.5µA

3.2.7.3 IR2101

- High and Low Side Driver For External N- channel MOSFET or IGBT, up to 600V

The LM7805 accepts 11.1v DC power supply from the battery and regulates an output of 5A and 3A and gives supply to the atmega8L and the IR2101 Driver IC.

The ESC generally accepts a nominal 100 Hz Pulse Width Modulation (PWM) input signal whose pulse width varies from 1ms to 2ms. This input PWM signal is given to the PORT D, pin no 2 of the atmega8L MCU. The atmega8L process the PWM and computes arithmetic and generates 3 phase 120 degree mode VSI for the brushless motors according to the program burned. When supplied with a 1ms width pulse at 100 Hz, the ESC responds by turning off the DC motor attached to its output. A 1.5ms pulse-width input signal results in a 50% duty cycle output signal that drives the motor at approximately 50% speed. When presented with 2.0ms input signal, the motor runs at full speed due to the 100% duty cycle (on constantly) output. Regardless of the pulse width of the signal, the frequency is a limiting factor in the stability of the tricopter. Most of the sensors which aid in controlling stability and the flight control board has processing speeds are well over 500 Hz.

The IR2101 accepts high and low value from the Atmega8L PORTD and Drives the terminals of the motor.

A. Why we choose ESC F20A in our Project:

1. Battery Eliminator Circuit (voltage regulator)

- It takes 11.1Volt from LiPo battery uses switching Regulators through rapid Power cycling by using several (7805 IC) voltage regulators to get 5V, 2A supply and feed Power Supply to the kk2 multi-Rotor board, Servo and Receiver.

2. The main properties of electric speed controller for brushless motor in our Project

1. Use powerful and high-performance MCU processor. The users can set function of use according to their requirements. It fully reflects the smart property of the products as a unique advantage.
2. Support unlimited rotate speed of brushless motor
3. Support the function of fixed speed
4. Delicate circuit design with strong anti-interference
5. The starting mode can be set. The response speed of throttle is very quickly and with very stable linear of speed regulation. It can be used in fixed wing aircraft and helicopter
6. Threshold values of low-voltage protection can be set.
7. With internal SBEC, the operating power to start steering engine is strong and the power dissipation is small.
8. Multi protection function: protection for abnormal input voltage/ protection for low battery/ protection for overheat/protection of lowing power when loss of signals from throttle
9. Good safety performance when energized: the motor will not start at the time of power on regardless of the location of pull rod of throttle in controller.
10. Protection for overheat: the output power will lesson to half when the temperature reaches 100 during the ℃operation of ESC. The output power will automatic recover when the temperature is under 100℃
11. Supports with operation setting for all controller and setting of programming panels
12. Set alarm sound. And judge the working situation after power on.
13. The ESC can be continuingly updated and upgraded (Programed).

3.2.8 DT750 BRUSHLESS MOTOR

The brushless DC motor is electrically commutated by power switches instead of brushes. BLDC motor is widely used in applications including appliances, automotive, aerospace, consumer, medical, automated industrial equipment and instrumentation. Brushless motor are chosen for this project as they offer several advantages over DC motor ,including more torque per weight, efficiency ,reliability reduced noise, longer life (no brush and commutation erosion),elimination of ionizing sparks from the commutator ,more power, and overall reduction of electromagnetic interference. The brushless motor that we have chosen to use for this project are the hex tronik DT 750 brushless out runner 750kv.

The motor are rated highly among the tri copter rotor community and perform very well compared to other brushless motor while still remaining at a very cheap price. The DT 750 draws a maximum of 18 ampere and is capable of producing a trust of approximately 1000 gram. This makes it ideal for use in a medium sized rotor. With three DT 750s operating at ideal conditions we are able to achieve a theoretical maximum thrust of3kg. Compared with a brushed DC motor or an induction motor, the BLDC motor has many advantages.

1. Higher efficiency and reliability
2. Lower acoustic noise
3. Smaller and lighter
4. Greater dynamic response
5. Better speed versus torque characteristics
6. Longer life

3.2.8.1 CONSTRUCTION

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors.

3.2.8.2 STATOR

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles. There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).As their names indicate, the trapezoidal motor gives aback EMF in trapezoidal fashion and the sinusoidal motor’s back EMF is sinusoidal. In addition to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. This makes the torque output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on the stator periphery, thereby increasing the copper intake by the stator windings. Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen. Forty-eight volts, or less voltage rated motors are used in automotive, robotics, small arm movements and so on. Motors with 100 volts, or higher ratings, are used in appliances, automation and in industrial applications.

3.2.8.3 ROTOR

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In con-trust, the alloy material has

high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Neodymium (ND), Samarium Cobalt (Smock) and the alloy of Neodymium, Ferrite and Boron (Node) are some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to compress the rotor further.

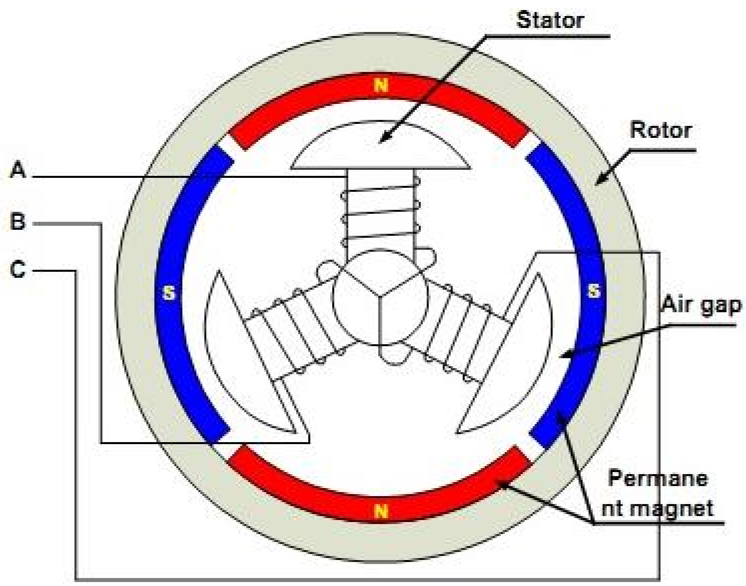


Fig 3.9 Brushless DC motor

3.2.8.4 OPERATING PRINCIPLE

Motor operation is based on the attraction or repulsion between magnetic poles. Using the three-phase motor shown in Figure 7, the process starts when current flows through one of the three stator windings and generates a magnetic pole that attracts the closest permanent magnet of the opposite pole. The rotor will move if the current shifts to an adjacent winding. Sequentially charging each winding will cause the rotor to follow in a rotating field. The torque in this example depends on the current amplitude and the number of turns on the stator windings, the strength and the size of the permanent magnets, the air gap between the rotor and the windings, and the length of the rotating arm.

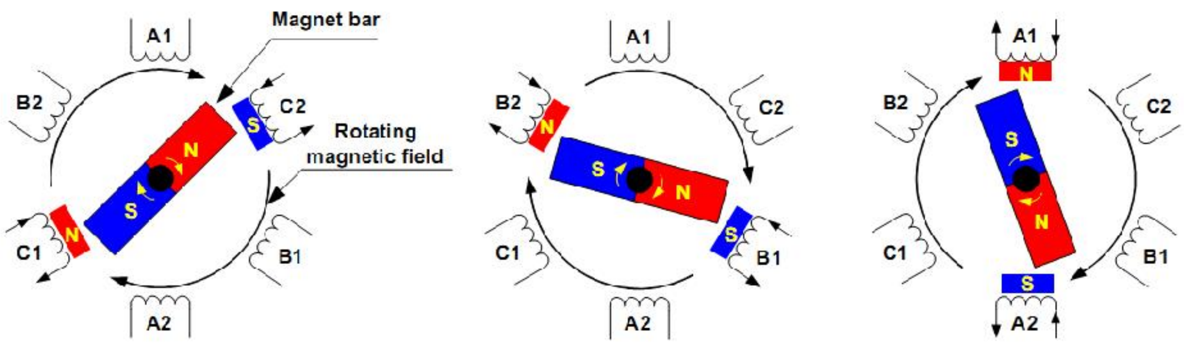


Fig 3.10 the operating principle of BLDC

3.2.8.5 BRUSHLESS DC MOTOR CONTROL

Switch Configuration and PWM

Brushless DC motors use electric switches to realize current commutation, and thus continuously rotate the motor. These electric switches are usually connected in an H-bridge structure for a single-phase BLDC motor, and a three-phase bridge structure for a three-phase BLDC motor shown in Figure 10. Usually the high-side switches are controlled using pulse-width modulation (PWM), which converts a DC voltage into a modulated voltage, which easily and efficiently limits the start-up current, control speed and torque. Generally, raising the switching frequency increases PWM losses, though lowering the switching frequency limits the system's bandwidth and can raise the ripple current pulses to the points where they become destructive or shut down the BLDC motor driver. .

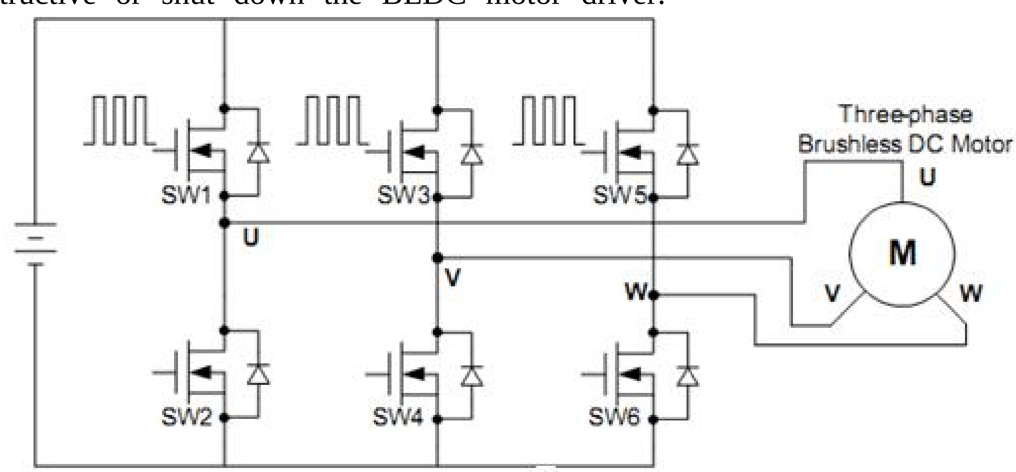


Fig 3.11 switching configuration of BLDC

3.2.8.6 ELECTRONICS COMMUTATION PRINCIPLE

A three-phase BLDC motor requires three Hall sensors to detect the rotor's position. Based on the physical position of the Hall sensors, there are two types of output: a 60° phase shift and a 120° phase shift. Combining these three Hall sensor signals can determine the exact commination sequence. Figure 13 shows the commutation sequence of a three-phase BLDC motor driver circuit for counter-clockwise rotation. Three Hall sensors—"a," "b," and "c"—are mounted on the stator at 120° intervals, while the three phase windings are in a star formation. For every 60° rotation, one of the Hall sensors changes its state; it takes six steps to complete a whole electrical cycle. In synchronous mode, the phase current switching updates every 60°. For each step, there is one motor terminal driven high, another motor terminal driven low, with the third one left floating. Individual drive controls for the high and low drivers permit high drive, low drive, and floating drive at each motor terminal. However, one signal cycle may not correspond to a complete mechanical revolution. The number of signal cycles to complete a mechanical rotation is determined by the number of rotor pole pairs. Every rotor pole pair requires one signal cycle in one mechanical rotation. So, the number of signal cycles is equal to the rotor pole pairs. .

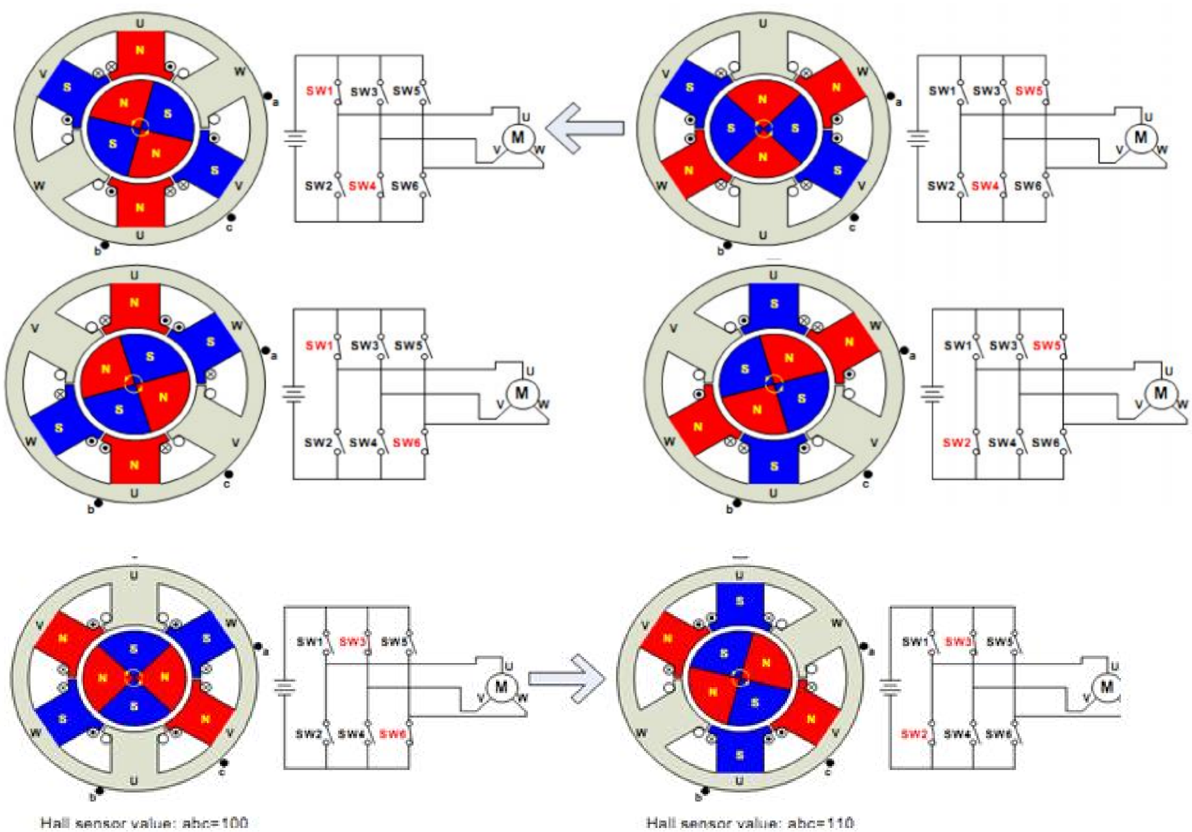


Fig 3.12 Three phase BLDC motor commutation sequence

Figure 3.11 shows the timing diagrams where the phase windings—U, V, and W—are either energized or floated based on the Hall sensor signals a, b, and c. This is an example of Hall sensor signal having a 120° phase shift with respect to each other, where the motor rotates counter-clockwise. Producing a Hall signal with a 60° phase shift or rotating the motor clockwise requires a different timing sequence. To vary the rotation speed, use pulse width modulation signals on the switches at a much higher frequency than the motor rotation frequency. Generally, the PWM frequency should be at least 10 times higher than the maximum motor rotation frequency. Another advantage of PWM is that if the DC bus voltage is much higher than the motor-rated voltage, so limiting the duty cycle of PWM to meet the motor rated voltage controls the motor.

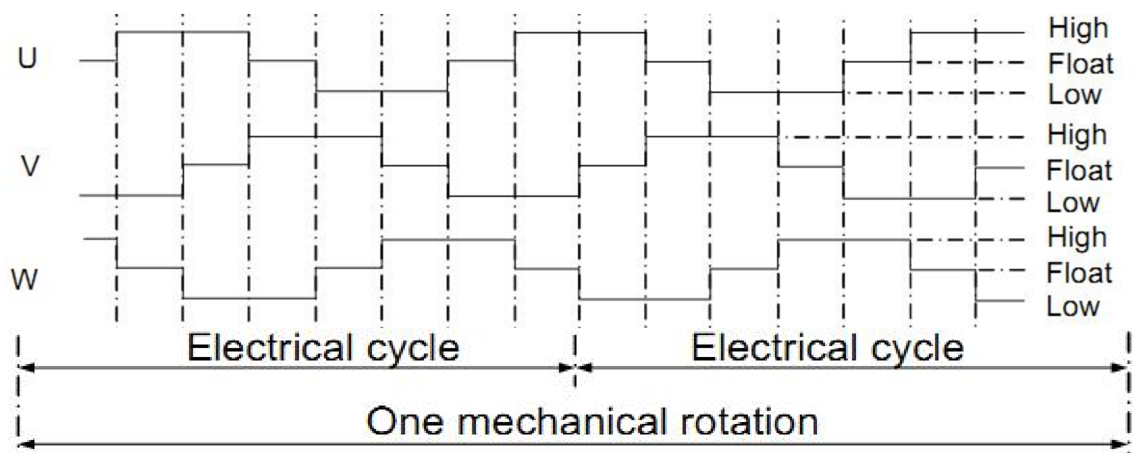


Fig 3.13 three phase electrical signal waveform

3.2.8.7 SENSOR LESS BLDC MOTOR CONTROL

Sensors cannot be used in applications where the rotor is in a closed housing and requires minimal electrical entries, such as a compressor or applications where the motor is immersed in a liquid. Therefore, the BLDC sensor less driver monitors the BEMF signals instead of the position detected by Hall sensors to commutate the signal. The relationship between the sensors' output and the BEMF is shown in Figure 15. The sensor signal changes state when the voltage polarity of the BEMF crosses from positive to negative or from negative to positive. The BEMF zero-crossings provide precise position data for commutation. However, as BEMF is proportional to the speed of rotation, this implies that the motor requires a minimum speed for precise feedback. So under very low speed conditions—such as start-up— additional detectors—such as open loop or BEMF amplifiers—are required to control the motor (This is beyond the scope of this application note). The sensor less commutation can simplify the motor structure and lower the motor cost. Applications in dusty or oily environments that require only occasional cleaning, or where the motor is generally inaccessible, benefit from sensor less commination.

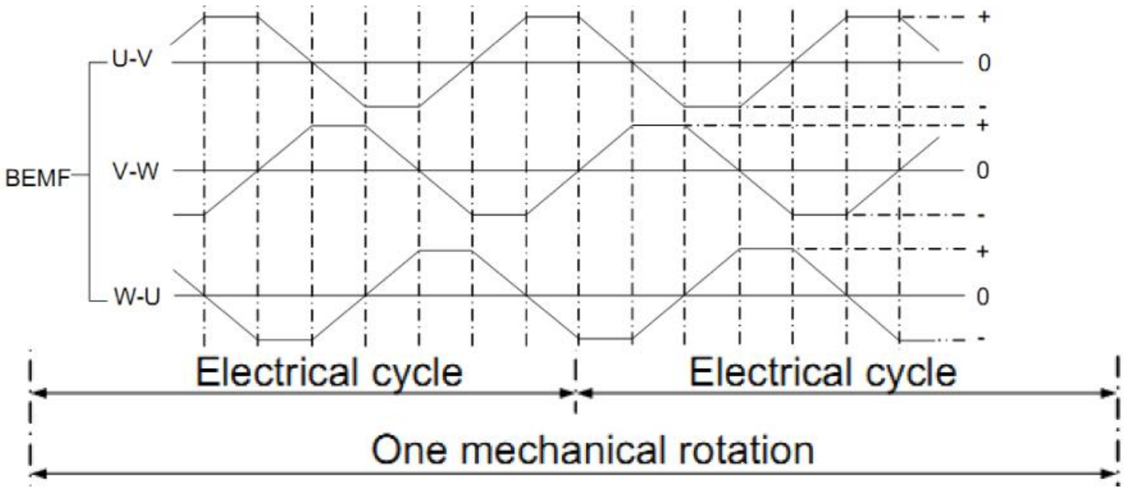


Fig 3.14 Back EMF waveform

3.2.8.7 ROLE OF BRUSHLESS DC MOTOR IN OUR PROJECT

The motor is the first component to select based off of the requirements and size of the tricopter. The tricopter will be comprised of 3 Brushless DC Motor attached to a propeller at the end of each arm. The Brushless motor differs from the conventional Brushed DC Motors in that the commutation of the input voltage applied to the armature's circuit is done electronically, whereas in the latter, by a mechanical brush. In spite of the extra complexity in its electronic switching circuit, the brushless design offers several advantages over its counterpart, to name a few: higher torque/weight ratio, less operational noise, longer lifetime, less generation of electromagnetic interference, low heat generation when properly loaded, and less vibrations. The main advantage of using a brushless DC motor for applications in a tricopter, or in any multicopter design, is that since it is an electronically commutated motor, which are synchronous motors, it is easy to calibrate all 3 motors to synchronously operator at the same RPMs for a given throttle through an electronic speed controller. Field testing with an optical tachometer (device used to measure RPMs) shown that once the three motors were calibrated and synchronized there was less than a 25 RPM variation in each of the motors through the throttle range without excessive correction from the flight controller board. This is further corrected by trimming through the flight controller board to achieve a negligible RPM difference in each of the motors. Brushless motors are normally evaluated by their size, technical performance specifications, and motor constants. Motor size is typically based on industry standards for the required radio controlled aircraft size it is to be used for. Technical performance specifications are the manufactures published analysis of voltage loads, power outputs, max amperages, and recommended propeller sizes. The motor constant, kV, is the rating of the motor in RPMs/Volts in order to give users an indication of the motor speeds for a desired power supply. For tricopter applications the kV constant is chosen based on the arm length. A high kV motor is required for shorter arms and lower kV for longer arms. The reason this is the case has to do with the moment response for each of the arms and the thrust to weight ratio of your design. The shorter the arms of the tricopter give a smaller moment of inertia, making the tricopter more susceptible to changes in its orientation thus making it less stable. The higher kV over the throttle range also gives a greater step increase in RPMs of the motor, which is faster in responding to changes in orientation to maintain stability. As a consequence of high kV motors, the motor also produces less torque therefore only having the capability of turning smaller propellers. Smaller propellers require higher RPMs in high kV motors to generate the required thrust.

For the tricopter design, the main considerations were to lift its required payload, achieve a desired speed, and maintain stability. This was achieved by using a larger propeller; generating more thrust, with larger arms on the frame; higher moments of inertia therefore more stability, and a lower kV motor; higher torque to spin the larger propeller.

3.2.9PROPELLER

The purpose of any aircraft propeller is to convert rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the air foil-shaped blade, and a fluid is accelerated behind the blade. Propeller dynamics can be modeled by both Bernoulli's principle and Newton's third law. The thrust produced depends on the density of the air, the propeller's RPM, diameter, the shape and area of the blades, and pitch. RC propellers are designated by their manufacture, diameter and pitch. There are multiple sites such as the UIUC Propeller Database which provide performance data for commercial RC propellers. From these databases, performance coefficients can be obtained to determine the utility of the selected propeller for the desired application. The diameter is based on the length of propeller from tip to tip measured in inches. The pitch is the distance the propeller should advance in one revolution measured in inches. The pitch speed is the mean geometric pitch times RPM, which is the theoretical speed of the aircraft if there was no slip. The propeller's output power is equal to the thrust times the pitch speed. With a given power, the more thrust you have, the less top speed achieved. Assuming the same power the following thumb rules are made for propeller.

Fig 3.15 Typical model propeller

This figure is picture of a typical model propeller. It is long relative to its width, tapering in thickness from the center hub to the outer tip. The width also varies, flaring slightly outwards from the hub, and then tapering to the tip. The blades are also twisted along their length. There is no simple relationship between all of the propeller parameters. Some normalized relationships will be described, without proof, as a way of introduction to some of the complexities. There are three such normalized relationships. They are the thrust coefficient, Ct, the power coefficient, Cp, and the efficiency coefficient, η, all defined in terms of a variable called the advance ratio, J. Equation 3-1 defines the advance ratio J.

$$J = \frac{V}{nD} \qquad \text{eq.3.1}$$

Where V is the axial or forward velocity of the propeller,
n is the revolution rate
D is the diameter.
A consistent set of units such as ft. /sec, rev/sec and ft. are required.
J is dimensionless. J is an indirect measure of the angle φ at the blade tip.
The thrust is given by

$$T = C_t \times {}^\circ \times n^2 \times D^4 lbf \qquad \text{eq.3.2}$$

Where

P is air density equal to 0.002378slugs/ft^3.
n is the revolution rate in rps
D is the diameter in feet
Ct is the thrust coefficient. It is a function of pitch, diameter, rpm, forward velocity, and blade shape.

Selection:

Larger diameter & less pitch = more thrust, less top speed.

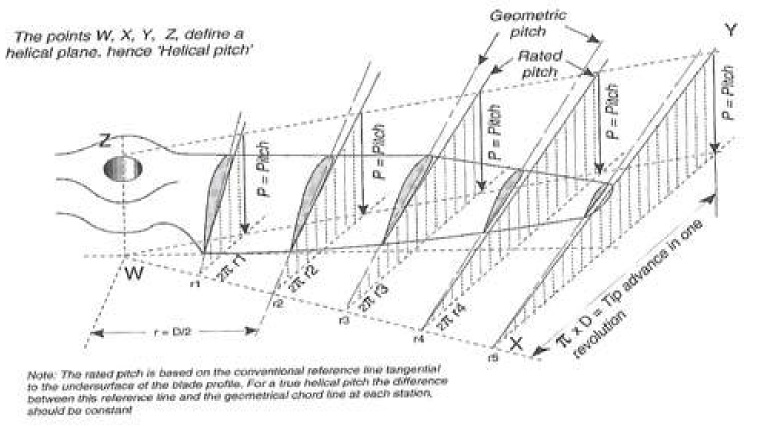
Smaller diameter & more pitch = less thrust, more top speed.

The recommended prop P/D (Pitch/Diameter) ratio for sport RC airplanes is 1:2 to 1:1. With a too large pitch, the prop becomes inefficient at low forward speed and high rpm, as when during the take-off and/or climb. Whereas a propeller designed for greatest efficiency at take-off and climb (with fine pitch & large diameter) will accelerate the plane very quickly from standstill but will give less top speed. In most multicopter designs the desire is typically to have a pitch of around 3 to 5 and maintain a larger diameter propeller. This will naturally achieve the thrust requirement at the cost of speed. The tricopter design for this project does a combination of both. Based on the size and weight of the tricopter it would be typically recommended to be equipped with a 9 X 4.7 (D X P) propeller. Motor test show that this propeller can generate 1100 grams of thrust at 10220 RPMs with a pitch speed of 41 mph. The selected propeller, a 10 X 8, can generate 1100 grams of thrust at 8050 RPMs with a pitch speed of 45.8 mph for the same voltage and slightly higher amps.

3.2.9.1 MODEL PROPELLER

Model air craft propellers are simple looking devices having no adjustable or moving parts. All of the manufacturers produce propellers similar in shape and design. They do vary in minor ways one from another. Given this similarity there must be some underlying reason for it. The purpose of this article is to discuss the 'why' of this similarity and the consequences that flow from it.

This is picture of a typical model airplane propeller. It is long relative to its width, tapering in thickness from the center hub to the outer tip. The width also varies, flaring slightly outwards from the hub, and then tapering to the tip. The blades are also twisted along their length.
In order to understand this shape it is useful to know what the purpose of a propeller is and how it accomplishes that purpose. The primary purpose is to convert engine power to axial thrust via torque transfer (rotational force) to the propeller. Thrust occurs as the rotating propeller captures air, a fluid, and expels it out the back. The more air it expels per unit of time, the more power converted and the greater the thrust. In order to push the air it must be able to capture or grab the air. If the blades were flat (no twist) and oriented perpendicular to the direction of flight they would not capture any air. The flat blades could be tilted so they 'bite' into the air. This works after a fashion but is very inefficient. So the blades are twisted to improve the efficiency. *Fig 3.15*illustrates what happens to a blade when it is twisted and moves forward for one revolution along the Z-axis.



Fi3.16BladeTwist or Pitch Illustration

The objective is to make each piece of the blade along its length advance axially the same distance in one revolution. That way each section produces the maximum amount of thrust at the same time. The pitch is defined as the distance traveled forward in one revolution if there were no slippage; i.e. assuming movement through a solid. Note that the angle of the blade relative to the X-Y plane increases from the tip inward toward the hub. This angle is called the blade angle and is measured on the blades lower surface. The geometric pitch is measured to the airfoil chord line.

The propeller acts like a twisted wing with air pressing on its lower surface and pulling via lower pressure on its upper surface. The blade cross-section thus has an air foil shape to maximize lift and minimize drag. The blade moves slowest in distance around the shaft near the hub and fastest at the tip. Thick airfoil shapes generally perform best at low speeds while thin airfoils perform best at high speeds. The designers then taper the thickness and the width to maximize the lift and drag at each location along the blade. Increasing the width would increase lift but would also increase drag. Designers' have determined that the optimum length to width ratio as defined by the aspect ratio is about 7:1. Hence most model propellers have approximately this aspect ratio and hence the same overall appearance.

Another reason for the thickness and width tapering is mechanical. The greatest stresses occur near the hub so thickness there provides the strength needed. Decreasing the thickness and width with radius also reduces the overall weight and reduces the angular momentum, a desirable property for combating the gyroscopic effects of spinning masses.

While two blades are the most common, three or more blades are sometimes used. Since three blades have more lifting area than two blades of the same size, the blade length can be reduced somewhat while maintaining the same forward speed, rpm and engines haft power. The blade tips move a little slower so they produce less noise and provide greater ground clearance.
Propellers need to be balanced in rotation and aligned symmetrically along the thrust axis. If one blade is heavier than the other vibration may occur that can damage the engine and the airplane. In expensive props, balances are available that can be used to check for imbalance. The author's experience with standard propellers is that most are out of balance when new. If the hub hole is off-center or canted unequal forces will occur on the drive shaft that can damage the engine. Standing behind the plane and looking through the propeller, if the tips appear to produce two overlapping circles the hole is off-center. Standing on the side of the tips from abroad pattern instead of a point-like pattern the hole is canted. In both cases don't use the prop.
Propellers are defined in terms of their diameter and pitch. Diameter is the diameter of the circle swept by the blade tips, measured either in inches or millimeters. In the case of two-bladed propellers it is the tip to tip length. For three-bladed propellers it is twice the length of a blade.

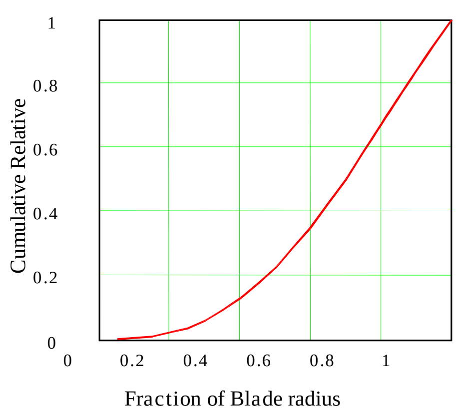


Fig3.17CumulativeThrustversusRelativeBlade Radius

Some propeller designs vary the pitch somewhat over the radius in an effort to improve the performance during some operational regime. By convention the pitch is defined in either

inches or millimeters at 75% of the blade radius. The 75% radius is a fair choice in about half of the thrust of a propeller occurs on each side of this value. In fact, about 80% of the thrust is generated by the outer 50% of a blade,
Since virtually no thrust is generated around the hub**,** the hub area can be designed for strength. Spinners do not appreciably affect the thrust but do reduce drag of the engine area.
Propellers are marked with their nominal diameters and pitches. The pitch values should be viewed with some skepticism. Pitch measurements (ref 4) made about 1996 on nearly200 propellers from four major manufacturers resulted in about 30% of them being off by at least a half-inch, in a few cases by more than an inch.

Although most model propellers have two blades, there are versions with three or more blades. The diameters of these propellers can be reduced relative to two-bladed versions while maintaining the same pitch and engine power. An approximate relationship as a function of the number of blades

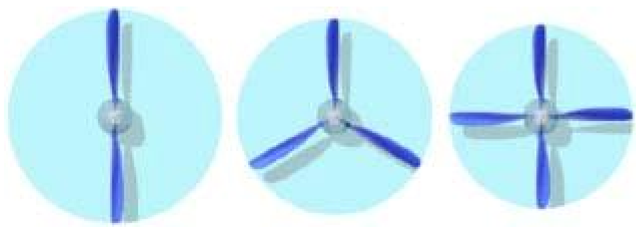


Fig.3.18 types of fixed pitch propeller

This figure shows the resulting relative size for 2, 3 and 4 -bladed propellers having approximately the same performance

These relations are valid only for propellers of the same family having similar blade shapes. You can use the same diameter for different blade numbers if you change the width of the blades. Also the aerodynamic influence of additional blades reduces the power consumption by a small amount, which means, that the replacement 3 blade prop will consume slightly less power than calculated above. On the other hand it will operate at lower Reynolds numbers so that some additional losses can be expected. The formula shown above should get you close to a working solution, though.

3.2.10 SERVO MOTOR

A servo motor is a mechanical motorized device that can be instructed to move the output shaft attached to a wheel or arm to a specified position. Inside the servo box there is a DC motor mechanically linked to a position feedback potentiometer, gearbox, electronic feedback control loop circuitry and motor drive electronic circuit. A typical R/C servo looks like a plastic rectangular box with a rotary shaft coming up and out the top of the box and three electrical wires out of the servo side to a plastic 3 pin connector attached to the output shaft. Out the top of the box there is a servo wheel or Arm. These wheels or arms are usually a plastic part with holes in it for attaching push / pull rods, ball joints or other mechanical linkage devices to the servo. The three electrical connection wires out of the side are V- (Ground), V+ (Plus voltage) and S Control (Signal). The control Signal wire receives Pulse Width Modulation (PWM) signals sent from an external controller and is converted by the servo on board circuitry to operate the servo.

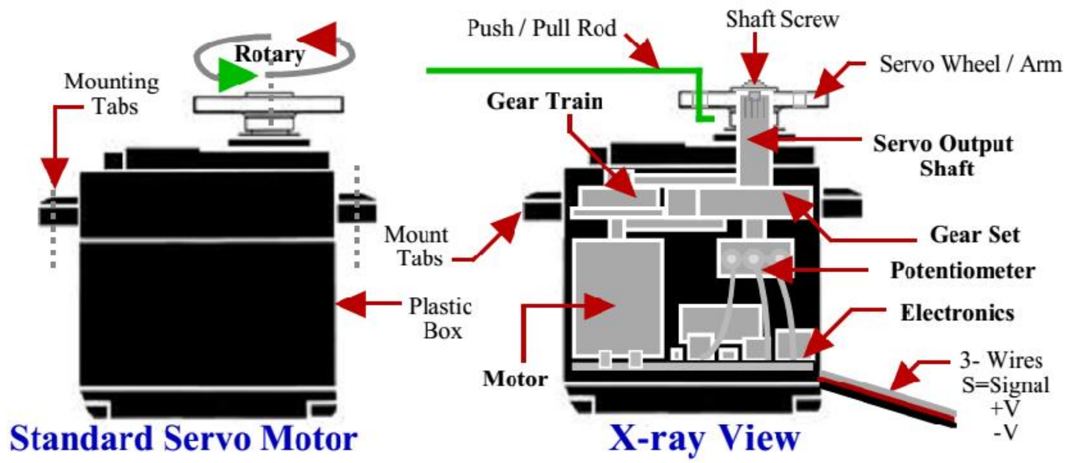


Fig 3.19Digital servo motor

R/C Servos are controlled by sending pulse width signals (PWM) from an external electronic device that generates the PWM signal values, such as a servo controller, servo driver module or R/C transmitter and receiver. Pulse Width Modulation or PWM signals sent to the servo are translated into position values by electronics inside the servo. When the servo is instructed to move (Received a PWM signal) the on board electronics convert the PWM signal to an electrical resistance value and the DC motor is powered on. As the motor moves and rotates the linked potentiometer also rotates. Electrical resistance value from the moving potentiometer are sent back to the servo electronics until the potentiometer value matches the position value sent by the on-board servo electronics that was converted from the PWM signal. Once the potentiometer value and servo electronic signals match, the motor stops and waits for the next PWM signal input signal for conversion.

A pulse width signal (PWM) of approximately 1.5 ms (1500 us) is the "neutral" position for the servo. The servo, neutral is defined to be the point where the servomotor has exactly the same amount of potential rotation in the counter clockwise direction as it does in the clockwise direction. When the pulse width signal (PWM) sent to a servo is less than 1.5 ms the servo moves some number of degrees counterclockwise from the neutral point.

When the pulse is greater than 1.5ms the servo moves some number of degrees clockwise from the neutral point. Generally the minimum pulse will be about 1.0 ms and the maximum pulse will be 2.0 ms with neutral (Stop) movement at 1.5 ms .R/C servos run on 5 volts DC but they often work with voltages V-, V+ between 4 and 6 volts DC power, near1 Amp of current. (Torque load on the servo arm determines amps and can be from 200 mA to 1 Amp depending on moving or holding force the servo needs for position).

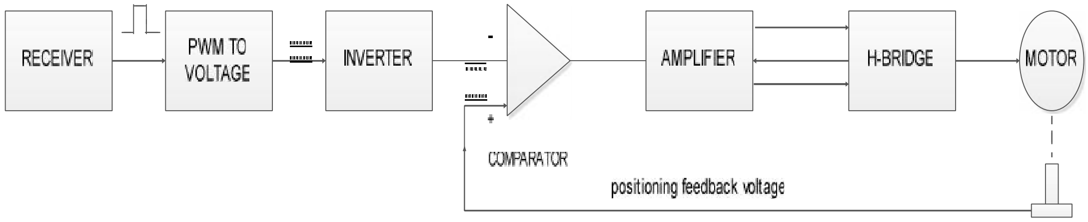


Fig 3.20 General Block diagram of servo motor

3.2.10.1 ROLE OF SERVO MOTOR IN THE TRICOPTER PROJECT

The servo on the tricopter is located on the aft rotor and is responsible for thrust vectoring the aft rotor for yaw control and unbalance torque stabilization. The servo uses for the tricopter project is a metal gear digital servo. A servo receives a signal from the receiver through PWM exactly as the ESC. A traditional analog servo operates at a frequency of 50 Hz, while a digital servo operates about 300 Hz. A small microprocessor inside the digital servo analyzes the receiver signals and processes it in to very high frequency voltage pulses to the servo motor. The pulses are shorter in length, but with many voltage pulses occurring, the servo motor will speed up much quicker and provide constant torque and increase yaw stability.
Components:
(a)Circuit board with a black IC chip (Integrated Circuit) and other components
(b) Variable resistor rotated by the output shaft giving the drums position
(c) Motor
(d) Gearbox

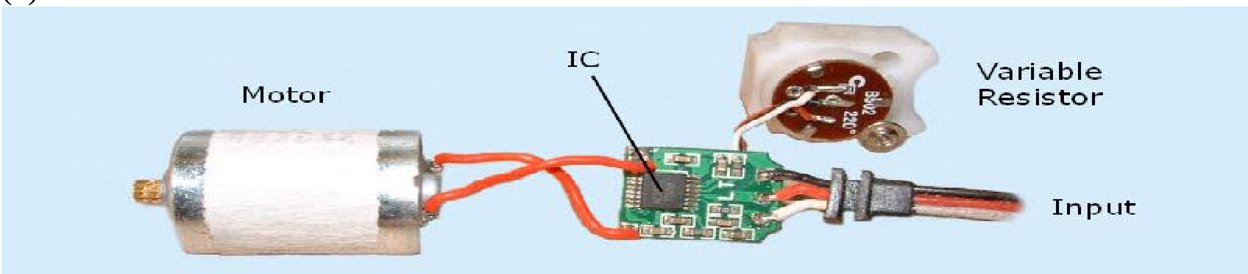


Fig3.21 servo motor components

3.2.10.2 ADVANTAGES AND DISADVANTAGES OF SERVO MOTORS

A. Advantages

(1) If a heavy load is placed on the motor, the driver will increase the current to the motor coil as it attempts to rotate the motor. Basically, there is no out-of-step condition. (However, too heavy a load may cause an error.)

(2) High-speed operation is possible.

B. Disadvantages

(1) Since the servomotor tries to rotate according to the command pulses, but lags behind, it is not suitable for precision control of rotation.

(2) Higher cost.

(3) When stopped, the motor's rotor continues to move back and forth one pulse, so that it is not suitable if you need to prevent vibration. Both motors have advantages and disadvantages. The selection of which type to use requires careful consideration of the application's specifications.

3.3 FLIGHT CONTROL

When all the rotors rotate a thrust will be produced which results in lifting the body of the rotor craft upwards. In addition to this force, according to Newton's second law of motion a reaction torque is produced which will tend to rotate the tri-copter body. This unnecessary torque should be balanced.

The tri-copters motion in flight is similar to any other aircraft, in which the orientation and flight control is a product of roll, pitch, and yaw.The rotation of the tri-copter in the horizontal axis pointed towards the direction of motion is called rolling and the rotation in horizontal axis perpendicular to the direction of motion is called pitching. Both rolling and pitching are controlled by controlling the RPM of the three motors. And the rotation in the vertical axis, called yawing, is controlled by using the servomotor, which is mounted on the rare part of the tricopter. These three angles are called Euler angles. The control strategy is the same as any tradition helicopter. Control strategies of tri-copter are shown in Figure below [Tricopter Design].

Fig 3.22 shows the roll control; varying the rotor speeds of the forward two rotors will generate a roll. By decreasing rotor speed 1 the tri-copter will roll to the left and rotor speed 2 roll to the right.

Fig 3.23 shows the pitch control; varying the rotor speeds from front and aft rotors will generate a pitch. By decreasing rotor speed 1 and 2 and increasing rotor speed 3 the tri-copter will pitch down and sustain forward flight. By increasing rotor speed 1 and 2and decreasing rotor speed 3 the tri-copter will pitch up and fly backwards.

Fig 3.24 shows the yaw control; the yaw is controlled by varying the angle of rotor 3, which is placed on top of the servo motor, to vector the thrust to produce a torque moment which will yaw the tri-copter left or right. In order to maintain lift the rotor speed increases while the thrust angle changes. Figure 3.24 shows the tri-copter yawing right.

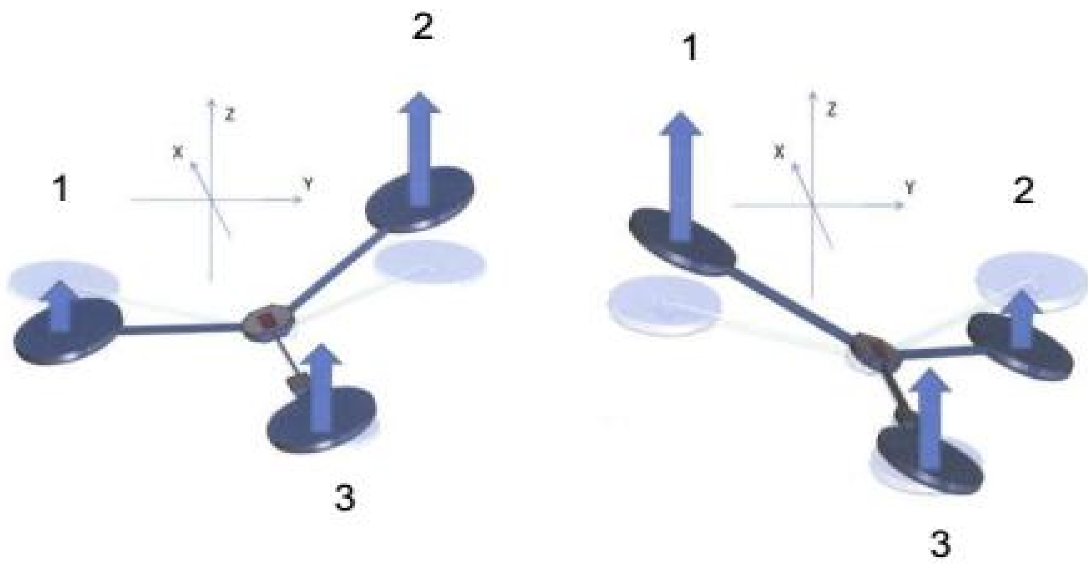


Fig3.22 Roll

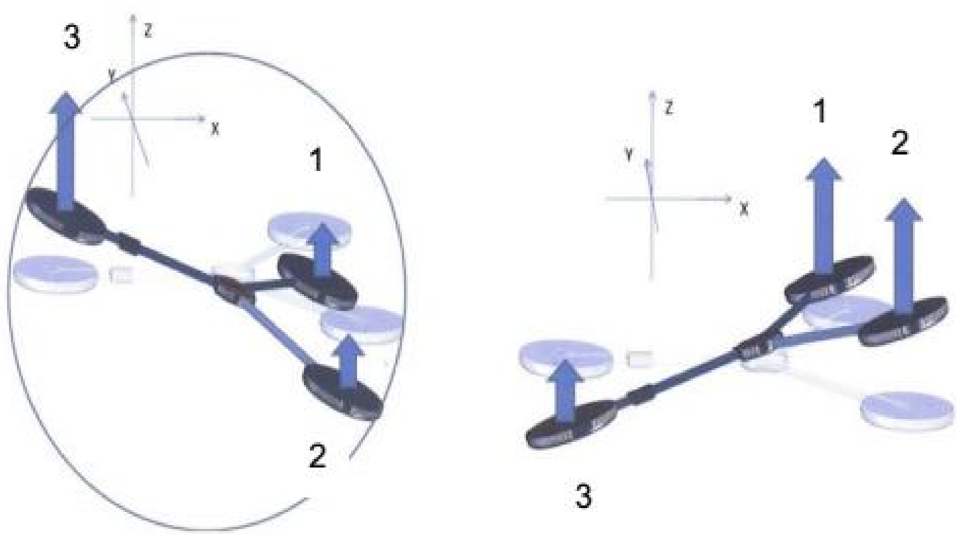


Fig 3.23 Pitch

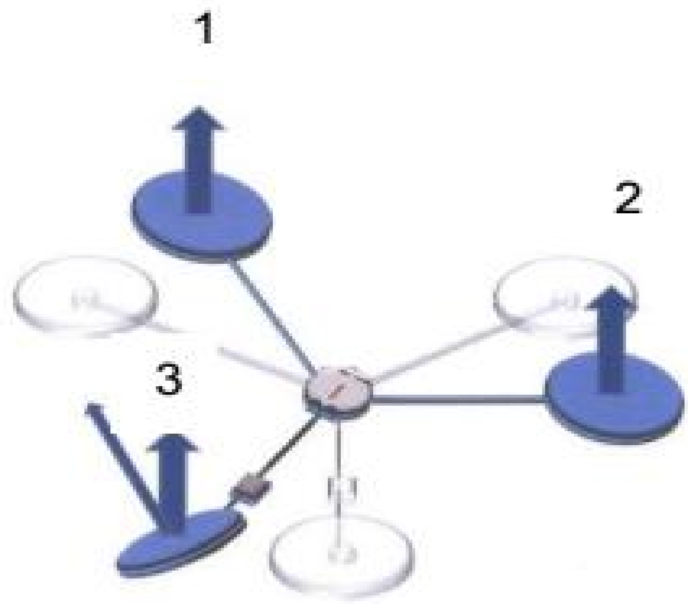


Fig3.24 –Yaw control

In order to change altitude the tri-copter synchronously increases or decreases the speed of all three rotors.

As pointed out earlier, the rotational speed of each of the rotors translates to thrust and torque. The thrust and torque the tri-copter can produce is dependent of the propeller's performance parameters, i.e., thrust and torque coefficients. The thrust and torque is proportional to the thrust coefficient (C_T) times the square of the rotational speed (ω) and torque coefficient (C_Q) times the square of the rotational speed(ω) [17].

$F_r = C_T\ \omega^2$ eq.3.3.1

$F_q = C_Q\ \omega^2$ eq.3.3.2

Where the torque and thrust coefficients are constants related to the propellers that we are using.
In a tri-copter configuration the forward rotors, 2 and 3, turn in opposite directions of each other causing the resultant effect or torque to cancel out or be so small it is negligible. And since we have odd number of rotors the torque produced by rotor 3 will remain unbalanced. For this reason, the aft rotor, is tilted at an angle α by a servo motor as shown in Figure 3.25, in order to compensate the resultant force produced by torque with the resultant force produced by thrust F_r in y axis. In the z axis F_q provides a small contribution for lift.
Here in this case from the geometry we can see that,

$$\Theta = \alpha$$

From this figure, we can see that the tail rotor, which is placed on top of a servo motor, should be tilted by an angle α to balance the torque force; hence the tri-copter will keep stability. For this purpose we will need sensors to make the system a closed feedback so as to keep stability. This is accomplished with the help of the gyroscope and accelerometer sensors. The gyroscope senses angular velocity. And by integrating this orientation is predicted. Hence our controller is a PID controller.

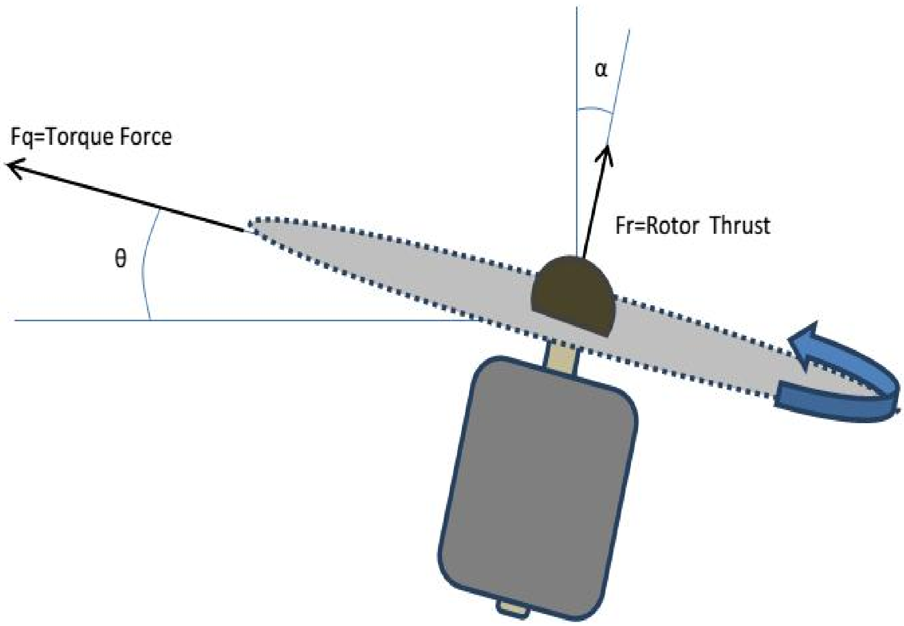


Fig3.25-tail rotor force balance

The accelerometer measures linear acceleration in all the axes. It will help the tricopter to stay in the right orientation. With the help of this to sensors the tricopter stability will be achieved.

As the rotational speed increases so do the resultant forces and therefore a change in the angle α. The yaw gyro working in a closed feedback loop will vary the angle of thrust in order to maintain yaw stability. Therefore the motion of the tricopter to any direction can be achieved by controlling the roll, pitch and yaw angles as the propellers are fixed pitch unlike the giant aerospace vehicles. The forward, backward and turning motion can be explained as below:

Fly forward: When flying forward, motors 1 and 2 must decelerate, while motor 3 on the tail axis must accelerate. As a result, the fuselage of the tricopter is inclined forwards, so part of the trust force has a horizontal component, hence it flies towards the same direction. On the contrary, when flying backwards, motors 1 and 2 must accelerate, while motor 3 must decelerate.

Fly to the right direction: When the tri-rotor flying robot flies to the right direction, motor 1 on the left side must accelerate, while motor 2 on the right side must decelerate, so as to allow the fuselage to incline to the right side and make the tricopter fly to the right direction.

Clockwise yaw: When the tri-rotor flying robot yaws in the clockwise direction, it needs to use the servomotor so that to drive the propeller of the motor 3 inclined in the left side. When the motor 3 rolls, it will generate the clockwise yaw torque, so as to make the tri-rotor flying robot yaw in the clockwise direction.

The reason for choosing a tri-copter among the other UAVs is due to the following reasons:

- Control of a bi-copter is less efficient and less stable as it is prone to aerodynamic torques due to its less number of rotors (particularly in the yawing motion).
- As compared to quad- copters the tri-copter is much less expensive as it have one less of every items including the motors, ESCs, propellers…etc.
- Power consumption in tri-copter is less as compared to the quad-copter, hence the tri-copter is more efficient.

3.4 MATHEMATICAL MODELING OF A TRICOPTER

The first step before the control stage is adequate modeling of the system dynamics. This phase will provide us with the better understanding of the overall system capabilities and limitations.

To be able to derive a mathematical model of a tricopter it has to be defined as a system. Once we have defined a system, input and output to the system should also be defined. In order to make the model as simple as possible, there are some assumptions that we follow. Here we start by the model of the electromagnetic dc motors. We have three dc brushless motors and a servo. The differential equations of a dc motor are according to [19]:-

$$U(t) = R_1 i(t) + L_1 \frac{di(t)}{dt} + k\mu(t)$$

$$J\frac{d\mu(t)}{dt} = ki(t) - f\mu(t)$$

eq.3.4.1

Where, the inductance L_1 of the coil is assumed to be zero. The input voltage to the system is U(t) and the output y (t) is the angle of the motor. The rotational rate of the motor is ω(t) and the current through the motor is i(t). The resistance of the wire is $R_1$and the constant k, with dimension [V.s/rad], is the transformation between the electrical and the mechanical part of the system. The mechanical friction of the motor is f. The system can be written in state space representation as

$$\dot{X}(t) = \begin{pmatrix} 0 & 1 \\ 0 & \frac{-1}{C_1} \end{pmatrix} X(t) + \begin{pmatrix} 0 \\ \frac{C_2}{C_1} \end{pmatrix}$$

$$y(t) = \begin{pmatrix} 1 & 0 \end{pmatrix} X(t)$$

eq.3.4.2

Where

$$C_1 = \frac{JR_1}{fR_1 + k^2}$$

$$C_2 = \frac{k}{fR_1 + k^2}$$

$$X = (\bar{\ } \quad \mu)^T \text{ and}$$

$$Y = \bar{\ }$$

This gives the transfer function between input voltage and output angle as

$$G(s)_{servo} = \frac{C_2}{s(1+sC_1)} \qquad \text{eq3.4.3}$$

The output of the system is the angle of the motor. As the transfer function above shows there are two poles. The servo controls the angle of the motor and therefore it can be described with this transfer function. And the angular velocity is controlled by the dc motor not by the servo, and the transfer function is

$$G(s)_{rotor} = s\frac{C_2}{s(1+sC_1)} = \frac{C_2}{1+sC_1} \qquad \text{eq.3.4.3}$$

And the system has only one stable pole. If we assume the constant C_1 is very large, each poles of the motor will be located near the origin. this gives a short rise time for a step response[19] and therefore the relation between the input signal and the rotational rates is seen to be static i.e., $u(t) \approx \omega(t)$, This gives that the output angular rate, ω, is constant if the input voltage is constant. Hence the five extra poles from the three motors and the servo can be neglected, only for the simplification of the model.

Therefore the input signals to the system are, $[\omega_1\ \omega_2\ \omega_3\ \alpha]$, where this are the rotational rates of the three motors and the tilt angle of the servo motor.

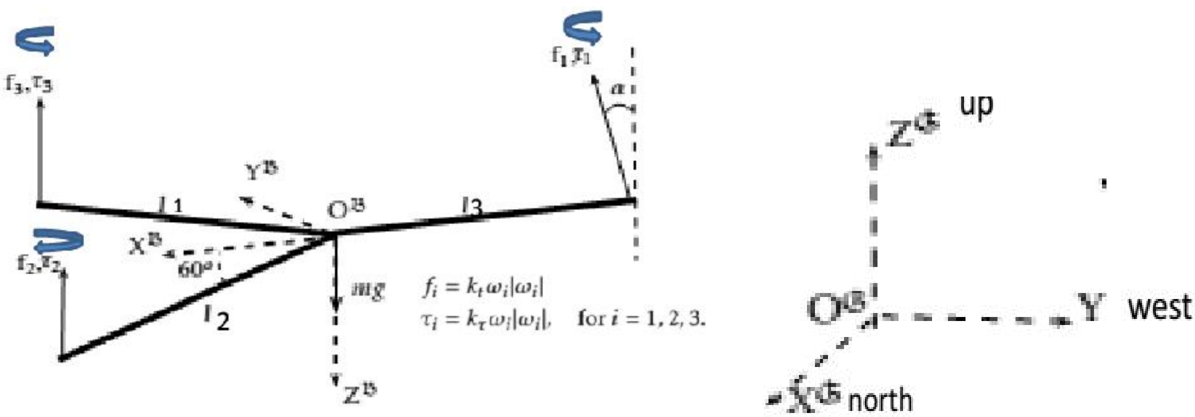
The output of the system is described by those states that are measurable by the sensors. Our sensors are gyroscope and accelerometer and the states that are measured by these sensors are those that describe the orientation of the tricopter. These states are rotational rates about each axes, $[p\ q\ r]^\beta$. So, we have defined the system, input and output signals.

3.4.1. COORDINATE SYSTEM

Before deriving the dynamical model of the tricopter the coordinate systems has to be defined such that output signals can be defined. There are two coordinates of interest that has to be defined. The local that is seen as the body fixed coordinates of the tricopter (β) and global which is coordinate system of the earth (G). The reason for having multiple coordinate systems is:-

- Newton's laws of motion are derived relative to a fixed, inertial reference frame; however motion is easily described in a body fixed frame.

- Aerodynamic torques and forces act on the aircraft body and are most easily described in a body fixed reference frame.
- Most onboard sensors like accelerometer and gyros measure information with respect to the body reference frame.
- Most mission requirements are specified in inertial reference frame.



a) local coordinate system *b)earth(global) coordinate system*

Fig3.26

In the local coordinate system X^β points towards the direction of motion and Y^β points to the right of the direction of motion and Z^β points downwards from the center of mass of the tricopter.

In the earth coordinate system X^G points towards north Y^G points towards west and Z^G points upwards. The relationship between these coordinate systems can be described mathematically by rotational matrix denoted by $Q_{xyz}^{\phi\Theta\psi}$. This will map local coordinates to the global coordinates. Where ϕ, Θ, ψ are roll, pitch and yaw angles about x^β, y^β, z^β axes respectively and are called Euler angles. The rotational matrix $Q_{xyz}^{\phi\Theta\psi}$ is given by [15]:-

$$Q_{xyz}^{\phi\theta\psi} = \begin{pmatrix} C_\theta C_\psi & C_\theta S_\psi & -S_\theta \\ S_\phi S_\theta C_\psi - C_\psi S_\psi & S_\phi S_\theta S_\psi - C_\phi C_\psi & S_\phi C_\theta \\ C_\phi C_\theta C_\psi + S_\phi S_\psi & C_\phi S_\theta S_\psi - S_\theta C_\psi & C_\psi C_\theta \end{pmatrix} \qquad 3.4.4$$

Where C=cos, S=sin and T=tan

The tricopter is rigid body with 6 degree of freedom (DOF), [21] and the states that describe the motion are

$X= [(x, y, z)^{G}, (u, v, w)^{G}, (\phi, \Theta, \psi)^{\beta}, (p, q, r)^{\beta}]^{T}$

$U= [\omega_1, \omega_2, \omega_3, \alpha]^{T}$ and

$Y= [(p, q, r)^{\beta}]^{T}$

Free body diagram:-

With the free body diagram shown in fig.3.26 and the tricopter geometry fig.3.27 which form an angle of 120^0 between the arms the force and torque are defined as:-

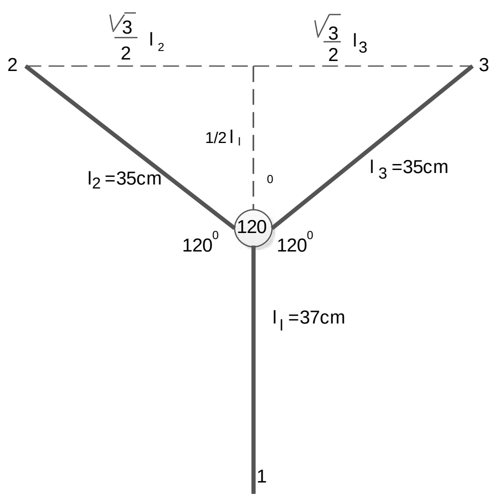


Fig.3.27:- geometry of a tricopter. Numbers 1, 2, 3 correspond to motors 1, 2, 3 respectively

FORCES:-

$$F_{ext} = \begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} = \begin{pmatrix} 0 \\ k_t \mu_1 |\mu_1| \sin\sim \\ -k_t (\mu_1 |\mu_1| \cos\sim + \mu_2 |\mu_2| + \mu_3 |\mu_3|) \end{pmatrix} \qquad \text{eq.3.4.5}$$

TORQUES:-

$$M_{F_{ext}}=\begin{pmatrix}M_x\\M_y\\M_z\end{pmatrix}=\begin{pmatrix}\frac{\sqrt{3}}{2}l_2k_t(\mu_2|\mu_2|-\mu_3|\mu_3|)\\ \frac{1}{2}l_2k_t(\mu_2|\mu_2|+\mu_3|\mu_3|)-l_1k_t\mu_1|\mu_1|\cos\sim+k_2\mu_1|\mu_1|\sin\sim\\ -l_1k_t\mu_1|\mu_1|\sin\sim-k_2(\mu_1|\mu_1|\cos\sim+\mu_2|\mu_2|+\mu_3|\mu_3|)\end{pmatrix}$$ eq.3.4.6

Where ℓ_1=37cm,ℓ_2=ℓ_3=35cm

These equations of torque and force are given on the body coordinate system, however position and translational velocity are given in the global (earth) coordinate system G hence the transformation is done by the rotational matrix $Q_{xyz}^{\phi\theta\psi}$ and is given by[1]:-

$$F_{ext}^{G}=Q_{xyz}^{¤-.}\ F_{ext}$$ eq.3.4.7

3.4.2 TRANSLATION

Now the next step is to derive the differential equations of the system based on basic laws of physics. From Newton's second law of motion we have

$$m\dot{V}^{G}=\sum F=F^{G}+F_g=Q_{xyz}^{¤-.}\ F_{ext}+\begin{pmatrix}0\\0\\-mg\end{pmatrix}$$

Separating into each axes,

$$\dot{u}^{G}=\frac{1}{m}(F_{x,ext}C_{-}C_{.}+F_{y,ext}C_{-}S_{.}-F_{z,ext}S_{-})$$

$$\dot{v}^{G}=\frac{1}{m}(F_{x,ext}(S_{¤}S_{-}C_{.}-C_{¤}S_{.})+F_{y,ext}(S_{¤}S_{-}S_{.}+C_{-}C_{.})+F_{z,ext}S_{¤}C_{-})$$

$$\dot{w}^{G}=\frac{1}{m}(F_{x,ext}(C_{¤}S_{-}C_{.}+S_{¤}S_{.})+F_{y,ext}(C_{¤}S_{-}S_{.}-S_{¤}C_{.})+F_{z,ext}C_{¤}C_{-})-g$$

eq3.4.8

And the trelationship between position and transalational velocity is given by

$$x^G = u^G$$
$$y^G = v^G$$
$$z^G = w^G$$
eq3.4.9

3.4.3 ROTATION

The differential equations of the angular rates can be found from torque equations, by assuming that the tricopter is a rigid body, again from Newton's second law of motion for rotation[18] we have,

$$\frac{dh}{dt_i} = m_F$$
eq3.4.10

Where h is angular momentum given by h=J$\Omega_{b/I}$ and $\Omega_{b/I}$ = [(p, q, r) β] ^{T}, and

$$J = inertial \quad matrix = \begin{pmatrix} J_{XX} & 0 & 0 \\ 0 & J_{yy} & 0 \\ 0 & 0 & J_{zz} \end{pmatrix}$$
eq.3.4.11

Where $J_{XX}=\int (y^2+z^2)\, dm$, $J_{YY}=\int(x^2+z^2)\, dm$ and $J_{ZZ}=\int(x^2+y^2)\, dm$

From equation of corolis [15] we have

$$\frac{dh}{dt_i} = \frac{dh}{dt_b} + \Omega_{b/i} \times h = m$$
eq.3.4.12

Before calculating by using the above equation let's calculate the inertial matrix using the mass of the components and some assumptions.

Components	**Quantity**	**Mass**	**symbol**
Motor	3	78g	m_m
Servo	1	55g	m_s
Propeller	3	26g	m_p
Battery	1	450g	m_b

Central structure	1	Frame(2x36.7g)+kk2board(21g)+bolts(14g)+ Battery holder(75g)=183.4g	m_c
Arm	2+1	2x26.4g+31.3g+ESCs(3x30)=174.1g	m_a
Total mass		1.1745kg	M

- Concentrated masses at the two front ends(35cm length of each)=

$M_{c1}=M_m+m_p+1/2(m_a+m_{ESC})$ =132.2g=0.1322kg

Distance from Z^β axis=35cm=0.35cm=λ_1
Distance from X^β axis=35cos60^0=17.5cm=λ_{c1}
Distance from Y^β axis=17.5cm

- Concentrated mass at the third end=
$M_{c2}=m_m+m_s+1/2(m_a+m_{ESC})+m_p$=78+26+55+1/2(26.4+30) =187.2g=0.187.2kg

Distance from Zβ axis =37cm=0.37m=λ_{c2}
Distance from Xβ axis=0=λ_{c2x}
Distance from Yβ=0.37cm=λ_{c2}

For simplicity let's assume that the central part is concentrated in a sphere of radius of 6cm=0.06m=σ, and mass $m_s=m_c+m_b+1/2m_a$=675.3g=0.6753kg

Then,

$$J_{XX}=2m_{c1}\lambda_{c1}^2+m_{c2}\lambda_{c2x}^2+2/5m_s\sigma^2$$

Upon inserting the numbers we get

$$J_{XX}=0.00907kgm^2,$$

$$J_{YY}=2m_{c1}\lambda_{c1}^2+m_{c2}\lambda_{c2}^2+2/5m_s\sigma^2$$

After substituting the numbers;

$$J_{YY}=0.0347kgm^2, \text{ and}$$
$$J_{ZZ}=2m_{c1}\lambda_1^2+m_{c2}\lambda_2^2+2/5m_s\sigma^2=0.059kgm^2$$

Hence our inertial matrix will be

$$J=\begin{pmatrix} 0.00907 & 0 & 0 \\ 0 & 0.0347 & 0 \\ 0 & 0 & 0.059 \end{pmatrix}$$

By using eq.3.4.12 above and the force and torque equations given by eq.3.4.6 the differential equations of the rotational rates can be written as:-

$$\dot{p} = \frac{1}{J_{xx}}[(J_{yy} - J_{zz})r\ q\ + \frac{\sqrt{3}}{2} l_2 (f_2 - f_3)]$$

$$\dot{q} = \frac{1}{J_{yy}}\{(J_{zz} - J_{xx})p\ r\ + [\frac{l_2}{2}(f_2 + f_3) - l_1 f_1 \cos\text{~} + \text{²}_1 \sin\text{~}]\}$$

$$\dot{r} = \frac{1}{J_{zz}}\{(J_{xx} - J_{yy})p\ q\ + [-l_1 f_1 \sin\text{~} - \text{²}_1 \cos\text{~} - \text{²}_2 - \text{²}_3]\} \qquad \text{eq. 3.4.13}$$

By studying the above equation it can be seen that the tricopter is a cross coupled system. That is the time derivative of the states depends on another states. In addition each input signal changes several of the states. For example induced thrust of rotor 2, (see fig.3.27) changes both the states p and q.

The orientation of the tricopter is described by Euler angles. The rotational angle velocities of the tricopter with respect to(x, y, z)$^{\beta}$ has to be transferred to the global coordinate system. This transformation is given by:-

$$\begin{pmatrix} \dot{\text{¤}} \\ \dot{-} \\ \dot{\cdot} \end{pmatrix}^G = \begin{pmatrix} 1 & \sin(\text{¤}^G)\tan(\text{¯}^G) & \cos(\text{¤}^G)\tan(\text{¯}^G) \\ 0 & \cos(\text{¤}^G) & -\sin(\text{¤}^G) \\ 0 & \frac{\sin(\text{¤}^G)}{\cos(\text{¯}^G)} & \frac{\cos(\text{¤}^G)}{\cos(\text{¯}^G)} \end{pmatrix} \begin{pmatrix} p \\ q \\ r \end{pmatrix} \qquad \text{eq.3.4.14}$$

This matrix is derived by taking the time derivative of the rotational matrix and then inverting [1].

3.4.4 NONLINEAR MODEL

The system is a 6 DOF (degree of freedom) rigid body and is described by the nonlinear differential equations derived above. These include translational velocity, translational position, rotational velocity and rotational position. The nonlinear model of the system is summarized as below:-

$$x^G = u^G$$
$$y^G = v^G$$
$$z^G = w^G \qquad \text{eq.3.4.9}$$

$$\dot{u}^G = \frac{1}{m}(F_{x,ext} C_{\text{–}} C_{.} + F_{y,ext} C_{\text{–}} S_{.} - F_{z,ext} S_{\text{–}})$$
$$\dot{v}^G = \frac{1}{m}(F_{x,ext}(S_{\text{¤}} S_{\text{–}} C_{.} - C_{\text{¤}} S_{.}) + F_{y,ext}(S_{\text{¤}} S_{\text{–}} S_{.} + C_{\text{–}} C_{.}) + F_{z,ext} S_{\text{¤}} C_{\text{–}})$$
$$\dot{w}^G = \frac{1}{m}(F_{x,ext}(C_{\text{¤}} S_{\text{–}} C_{.} + S_{\text{¤}} S_{.}) + F_{y,ext}(C_{\text{¤}} S_{\text{–}} S_{.} - S_{\text{¤}} C_{.}) + F_{z,ext} C_{\text{¤}} C_{\text{–}}) - g \qquad \text{eq3.4.8}$$

$$\dot{\text{¤}}^G = p + \sin(\text{¤}^G)\tan(\text{¯}^G)q + \cos(\text{¤}^G)\tan(\text{¯}^G)r$$
$$\dot{\text{–}}^G = \cos(\text{¤}^G)q - \sin(\text{¤}^G)r$$
$$\dot{\cdot}^G = \frac{\sin(\text{¤}^G)}{\cos(\text{¯}^G)}q + \frac{\cos(\text{¤}^G)}{\cos(\text{¯}^G)}r \qquad \text{eq.3.4.14}$$

$$\dot{p} = \frac{1}{J_{xx}}[(J_{yy} - J_{zz})r\ q + \frac{\sqrt{3}}{2} l_2 (f_2 - f_3)]$$
$$\dot{q} = \frac{1}{J_{yy}}\{(J_{zz} - J_{xx})p\ r + [\frac{l_2}{2}(f_2 + f_3) - l_1 f_1 \cos\sim + \text{²}_1 \sin\sim]\}$$
$$\dot{r} = \frac{1}{J_{zz}}\{(J_{xx} - J_{yy})p\ q + [-l_1 f_1 \sin\sim - \text{²}_1 \cos\sim - \text{²}_2 - \text{²}_3]\} \qquad \text{eq3.4.13}$$

The output signals are defined by those signals measurable by the sensors.these are

$$[(p,q,r)^{\beta}]^T = Y \qquad \text{eq.3.4.15}$$

3.4.5 LINEARIZATION

The above derived equations are nonlinear and should be linearized. The reason for linearizing a nonlinear differential equation is that linear approximmations simplify the analysis and design of a system and are used as long as the results yield a good approximation to reality [19].

When we linearize a system we linearize it for a small signal about the steady state solution. The steady state solution is called equilibrium[19]. the equilibrium point of the tricopter is when it attains a predefined position and orientation. This means that the tricpter can be linearized around this equilibrium point $\mathbf{X}_o$,$\mathbf{U}_o$. With this we have

$$\dot{\mathbf{X}}_o=0$$

$$f(\mathbf{X}_o,\mathbf{U}_o)=0$$

In [16] the linearization of the dynamics will result in A, B, C matrices where the elements in the A, B, C matrices are given by $a_{i,j}$, $b_{i,j}$, $c_{i,j}$ respectively as

$$a_{i.j} = \frac{\partial f_i(X_0,U_0)}{\partial X_j}, \quad b_{i,j} = \frac{\partial f_i(X_0,U_0)}{\partial U_j}, \quad c_{i,j} = \frac{\partial h_i(X_0)}{\partial X_j} \qquad \text{eq.3.4.16}$$

Where i denotes the row and j denotes the column.

Linearizing the nonlinear model of the tricopter using the above equations results in the following description of the dynamics.

$$Z = AZ + BV$$
$$X_0 = [x_0^G, y_0^G, z_0^G, u_0^G, v_0^G, w_0^G, ¤_0^G, \bar{}_0^G, \cdot_0^G, p_0, q_0, r_0]^T$$
$$U_0 = (\mu_{1,0}, \mu_{2,0}, \mu_{3,0}, \sim_0)^T$$

Where

$Z=X-X_0$

$V=U-U_0$

and

$X_o=[X_o,Y_o,Z_o,0,0,0,\pi,0,\psi_o,0,0,0]^T$

Which corresponds to the condition when the tricopter is hovering in the air, i.e.,the position and orientation are constant but the rotational and translational velocities are zero. Since the coordinate system G has Z axis upward and the coordinate system β has Z axis downwards the rotation between this systems is$[\pi,0,\psi_o]$. by using eq.3.4.16 this will result in the following matrices.

$$A = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a4,8 & a4,9 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a5,7 & a5,8 & a5,9 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a6,7 & a6,8 & a6,9 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a7,7 & a7,8 & 0 & a7,10 & a7,11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a8,7 & 0 & 0 & 0 & a8,11 & a8,12 \\ 0 & 0 & 0 & 0 & 0 & 0 & a9,7 & a9,8 & 0 & 0 & a9,11 & a9,12 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a10,11 & a10,12 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a11,10 & 0 & a11,12 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a12,10 & a12,11 & 0 \end{pmatrix}$$

$$B = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & b4,2 & b4,3 & b4,4 \\ b5,1 & b5,2 & b5,3 & b5,4 \\ b6,1 & b6,2 & b6,3 & b6,4 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & b10,2 & b10,3 & 0 \\ b11,1 & b11,2 & b11,3 & b11,4 \\ b12,1 & b12,2 & b12,3 & b12,4 \end{pmatrix}$$

And, $C=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$

Where for A matrix

$$a_{9,11}=\frac{\partial\cdot}{\partial\text{¤}}=q_0\frac{C_{\text{¤}0}}{C_{\text{–}0}}-r_0\frac{S_{\text{¤}0}}{C_{\text{–}0}},\qquad a_{9,12}=\frac{\partial\cdot}{\partial r}=\frac{C_{\text{¤}0}}{C_{\text{–}0}}$$

$$a_{10,11}=\frac{\partial p}{\partial q}=\frac{J_{yy}-J_{zz}}{J_{xx}}r_{0,}\qquad a_{10,12}=\frac{\partial p}{\partial r}=\frac{J_{xx}-J_{zz}}{J_{xx}}q_0$$

$$a_{11,10}=\frac{\partial q}{\partial p}=\frac{J_{zz}-J_{xx}}{J_{yy}}r_{0,}\qquad a_{11,12}=\frac{\partial q}{\partial r}=\frac{J_{zz}-J_{xx}}{J_{yy}}p_0$$

$$a_{12,10}=\frac{\partial r}{\partial p}=\frac{J_{xx}-J_{yy}}{J_{xx}}q_0,\qquad a_{12,11}=\frac{\partial r}{\partial q}=\frac{J_{xx}-J_{yy}}{J_{zz}}p_0$$

$$a_{4,8}=\frac{\partial \dot{u}}{\partial \theta}=-\frac{1}{m}(F_{x,0}S_{\theta 0}+F_{y,0}S_{\theta 0}S_{\psi 0}+F_{z,0}C_{\theta 0})$$

$$a_{4,9}=\frac{\partial \dot{u}}{\partial \psi}=-\frac{1}{m}(F_{X,0}C_{\theta 0}S_{\psi 0}+F_{y,0}C_{\theta 0}C_{\psi 0})$$

$$a_{5,7}=\frac{\partial \dot{v}}{\partial \varphi}=-\frac{1}{m}(F_{X,0}(C_{\varphi 0}S_{\theta 0}C_{\psi 0}+S_{\varphi 0}S_{\psi 0})+F_{y,0}(C_{\varphi 0}S_{\theta 0}S_{\psi 0}-S_{\varphi 0}C_{\psi 0})+F_{z,0}C_{\varphi 0}C_{\theta 0})$$

$$a_{5,8}=\frac{\partial \dot{v}}{\partial \theta}=\frac{1}{m}(F_{X,0}S_{\varphi 0}C_{\theta 0}C_{\psi 0}+F_{y.0}S_{\varphi 0}C_{\theta 0}S_{\psi 0}-F_{z,0}S_{\varphi 0}S_{\theta 0})$$

$$a_{5,9}=\frac{\partial v}{\partial \psi}=\frac{1}{m}(-F_{X,0}(S_{\varphi 0}S_{\theta 0}S_{\psi 0}+C_{\varphi 0}C_{\psi 0})+F_{y,0}(S_{\varphi 0}S_{\theta 0}C_{\psi 0}-C_{\varphi 0}S_{\psi 0}))$$

$$a_{6,7}=\frac{\partial \mu}{\partial \varphi}=-\frac{1}{m}(F_{X,0}(S_{\varphi 0}S_{\theta 0}C_{\psi 0}+C_{\varphi 0}S_{\psi 0})+F_{y,0}(S_{\varphi 0}S_{\theta 0}S_{\psi 0}+C_{\varphi 0}C_{\psi 0})+F_{z,0}S_{\varphi 0}C_{\theta 0})$$

$$a_{6,8}=\frac{\partial \mu}{\partial \theta}=\frac{1}{m}(F_{x,o}C_{\varphi 0}C_{\theta 0}C_{\psi 0}+F_{y,o}C_{\varphi 0}C_{\theta 0}S_{\psi 0}-F_{z,0}C_{\varphi 0}S_{\theta 0})$$

$$a_{6,9}=\frac{\partial v}{\partial \psi}=\frac{1}{m}(-F_{x,0}(C_{\varphi 0}S_{\theta 0}S_{\psi 0}+S_{\varphi 0}C_{\psi 0})+F_{y,0}(C_{\varphi 0}S_{\theta 0}C_{\psi 0}+S_{\varphi 0}S_{\psi 0}))$$

$$a_{7,7}=\frac{\partial \varphi}{\partial \varphi}=q_0C_{\varphi 0}T_{\theta 0}-r_0S_{\varphi 0}T_{\theta 0}, \qquad a_{7,8}=\frac{\partial \varphi}{\partial \theta}=-gS_{\varphi 0}S_{\theta 0}$$

$$a_{7,10}=\frac{\partial \varphi}{\partial p}=1, \qquad a_{7,11}=\frac{\partial \varphi}{\partial q}=S_{\varphi 0}T_{\theta 0}, \qquad a_{7,12}=C_{\varphi 0}T_{\theta 0}$$

$$a_{8,7}=\frac{\partial \theta}{\partial \varphi}=q_0S_{\varphi 0}-r_0C_{\varphi 0}, \qquad a_{8,11}=\frac{\partial \theta}{\partial q}=C_{\varphi 0}, \qquad a_{8,12}=-S_{\varphi 0}$$

For B matrix,

$$b_{4,1} = \frac{\partial \dot{u}}{\partial μ_1} = \frac{1}{m} 2k_t μ_{1,0} (S_{\sim 0} C_{-0} S_{\cdot\ 0} + C_{\sim 0} S_{-0})$$

$$b_{4,2} = \frac{\partial \dot{u}}{\partial μ_2} = \frac{1}{m} (2k_t μ_{2,0} S_{-0})$$

$$b_{4,3} = \frac{\partial \dot{u}}{\partial μ_3} = \frac{1}{m} (2k_t μ_{3,0} S_{-0})$$

$$b_{4,4} = \frac{\partial \dot{u}}{\partial \sim} = \frac{1}{m} k_t μ_{1,0} \left| μ_{1,0} \right| (C_{\sim 0} C_{-0} S_{\cdot\ 0} - S_{\sim 0} S_{-0})$$

$$b_{5,1} = \frac{\partial \dot{v}}{\partial μ_1} = \frac{1}{m} 2k_t μ_{1,0} (S_{\sim 0} (S_{¤0} S_{-0} S_{\cdot\ 0} - C_{-0} C_{\cdot\ 0}) - C_{\sim 0} S_{¤0} C_{-0})$$

$$b_{5,2} = \frac{\partial \dot{v}}{\partial μ_2} = \frac{-1}{m} (2k_t μ_{2,0} S_{¤0} C_{-0})$$

$$b_{5,3} = \frac{\partial \dot{v}}{\partial μ_3} = \frac{-1}{m} (2k_t μ_{3,0} S_{¤0} C_{-0})$$

$$b_{5,4} = \frac{\partial \dot{v}}{\partial \sim} = \frac{1}{m} k_t μ_{1,0} \left| μ_{1,0} \right| (C_{\sim 0} (S_{¤0} S_{-0} S_{\cdot\ 0} + C_{-0} C_{\cdot\ 0}) + S_{\sim 0} S_{¤0} C_{-0})$$

$$b_{6,1} = \frac{\partial \dot{\mu}}{\partial \mu_1} = \frac{1}{m} 2k_t \mu_{1,0} (S_{\sim 0}(C_{\text{¤}0} S_{\text{–}0} S_{\cdot\ 0} - S_{\text{–}0} C_{\cdot\ 0}) - C_{\sim 0} C_{\text{¤}0} C_{\text{–}0})$$

$$b_{6,2} = \frac{\partial \dot{\mu}}{\partial \mu_2} = \frac{1}{m} 2k_t \mu_{2,0} C_{\text{¤}0} C_{\text{–}0}$$

$$b_{6,3} = \frac{\partial \dot{\mu}}{\partial \mu_3} = \frac{1}{m} 2k_t \mu_{3,0} C_{\text{¤}0} C_{\text{–}0}$$

$$b_{6,4} = \frac{\partial \dot{\mu}}{\partial \sim} = \frac{1}{m} 2k_t \mu_{1,0} \left|\mu_{1,0}\right| (C_{\sim 0}(C_{\text{¤}0} S_{\text{–}0} S_{\cdot\ 0} + S_{\text{¤}0} C_{\cdot\ 0}) + S_{\sim 0} C_{\text{¤}0} C_{\text{–}0})$$

$$b_{10,2} = \frac{\partial \dot{p}}{\partial \mu_2} = \frac{-1}{J_{xx}} \sqrt{3} l k_t \mu_{2,0}$$

$$b_{10,3} = \frac{\partial \dot{p}}{\partial \mu_3} = \frac{-1}{J_{xx}} \sqrt{3} l k_t \mu_{3,0}$$

$$b_{11,1} = \frac{\partial \dot{q}}{\partial \mu_1} = \frac{1}{J_{yy}} 2\mu_{1,0} (k_{\text{₂}} S_{\sim 0} - l k_{\text{₂}} C_{\sim 0})$$

$$b_{11,2} = \frac{\partial \dot{q}}{\partial \mu_2} = \frac{1}{J_{yy}} l k_{\text{₂}} \mu_{2,0}$$

$$b_{11,3} = \frac{\partial \dot{q}}{\partial \mu_3} = \frac{1}{J_{yy}} l k_{\text{₂}} \mu_{3,0}$$

$$b_{11,4} = \frac{\partial \dot{q}}{\partial \sim} = \frac{1}{J_{yy}} \mu_{1,0} \left|\mu_{1,0}\right| (k k_{\text{₂}} S_{\sim 0} + k_{\text{₂}} C_{\sim 0})$$

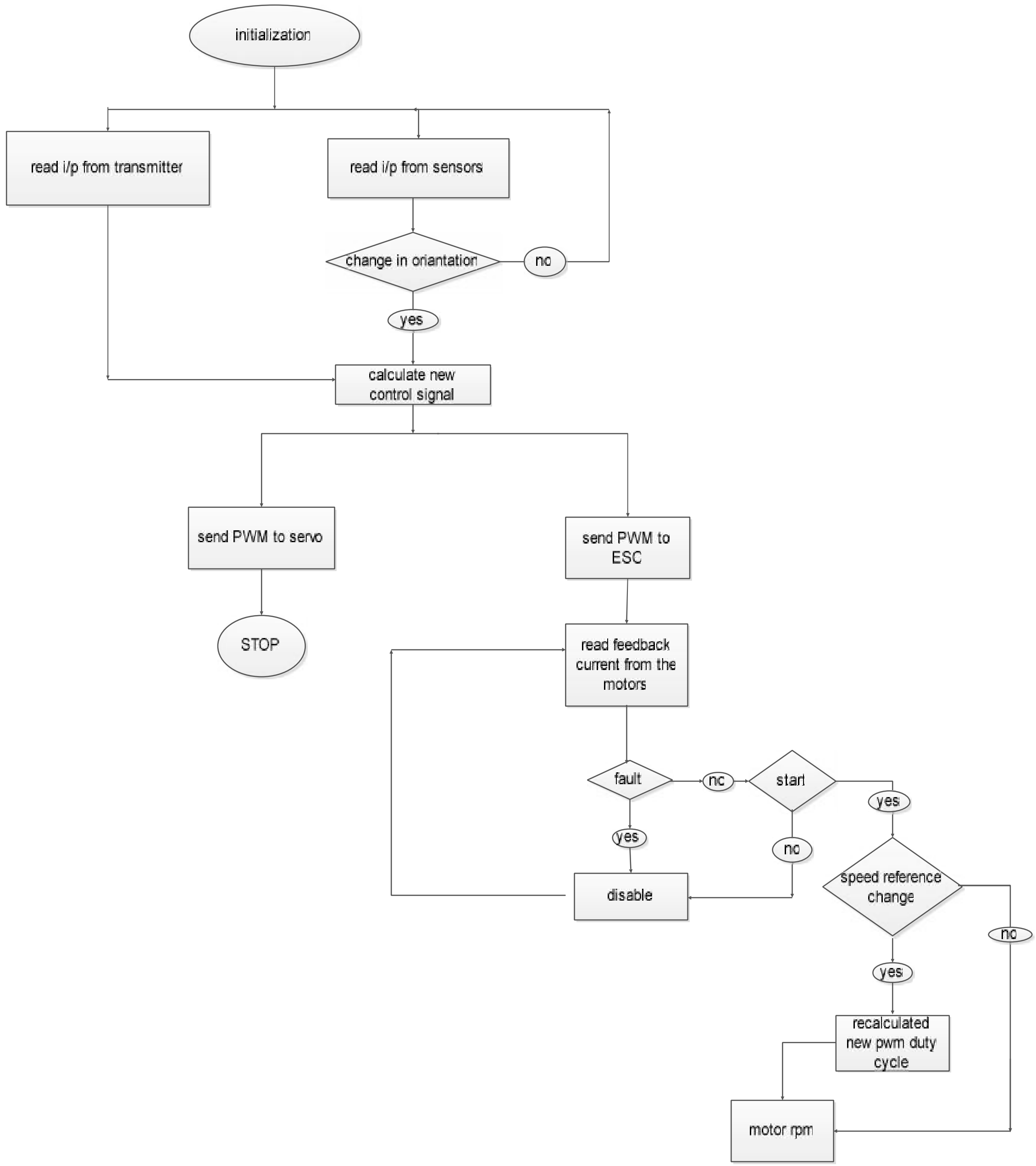
$$b_{12,1} = \frac{\partial \dot{r}}{\partial \mu_1} = \frac{-1}{J_{zz}} 2\mu_{1,0} (l k_{\text{₂}} S_{\sim 0} + k_{\text{₂}} C_{\sim 0})$$

$$b_{12,2} = \frac{\partial \dot{r}}{\partial \mu_2} = \frac{-1}{J_{zz}} 2k_{\text{₂}} \mu_{2,0}$$

$$b_{12,3} = \frac{\partial \dot{r}}{\partial \mu_3} = \frac{-1}{J_{zz}} 2k_{\text{₂}} \mu_{3,0}$$

$$b_{12,4} = \frac{\partial \dot{r}}{\partial \sim} = \frac{1}{J_{zz}} \mu_{1,0} \left|\mu_{1,0}\right| (k_{\text{₂}} S_{\sim 0} - l k_{\text{₂}} C_{\sim 0})$$

3.5 FLOW CHART



The overview of the program that is going to be installed in the Atmega644PA and the ESC can be summarized using the following flowchart. The program has to solve complicated mathematical equations to calculate the control signals so that the system is stabilized.

3.6 MATERIAL SELECTION:

The components selected for the Tricopter is based on project mission goals. The required mission goals for this project are for the tricopter be designed to be agile in flight while maintaining stable orientation, reduced vibrations, and have the ability to carry a payload. The tricopter that we are designing consists of the following main components:

- Frame which consists of aluminum and wooden booms
- Kk2.15 flight board consisting of AtMega 644PA microcontroller, sensors(accelerometer and gyroscope combined in a single IC called MPU-6050) and LCD screen
- Three brushless motors with their props to produce the necessary thrust.
- Three ESCs(electronic speed controllers) to control each motor
- A servo motor to produce yawing motion and control the reaction torque.
- Power supply …

Frame design considers the following specifications

- *Weight*-weight is the most important constraint that should be taken under consideration while designing the frame. We have selected aluminum for this purpose and wooden booms to support each motor due to its resistivity to the transfer of vibration to the flight board
- *Robustness*
- *Ability to easily adjust and mount new devices*

The combination of the selected power train, to include the motor, propellers, electronic speed controller (ESC), and power supply, will determine the tricopters agility and payload carrying ability. The motors that we are using are selected based on their high torque capacity, less noise, and less electromagnetic interference so that the wireless connection will be easier with the ground station. The onboard flight controller and sensors will aid in the tricopters handling characteristic and the ability to operate without losing stability. The frame construction and material selection will alleviate excess vibrations in the tricopter caused by the motors rotation.

BRUSHLESS DC MOTOR

In our project we are using 3 (Three) DT-750 brushless motors. These motors are perfect for small planes, and particularly multirotors such as tricopter, quadcopter, hexacopter, or octacopter.

Specifications

Required Voltage: 11.1v
Suggested Battery Capacity: 1300mAh +
Suggested Prop: 11x3.8 or 11x4.7
Max current draw: 18A (with 11x4.7 prop)

Max thrust: 1000g+
No Load Current: 1.4A
Shaft: 4M (perfectly suited to Towerpor/GWS SF Slow Fly props)
Weight: 78g
Diameter: 41mm
Overall length: 77mm
KV: 750rpm/v

LiPo (LITHIUM POLYMER) BATTERY

In our project we are using the TURNIGY 2.2A LiPo Battery

Specifications

LiPo 11,1V 2200mAh 35C battery
Type of cells: LiPo
Plug: Tamiya small
Dimensions: 107x34x18mm
Weight: 150g

SERVO MOTOR

[MG995 High Speed Digital Metal Gear 2BB Torque RC Servo for HPI Savage XL FUTABA]

Specifications

Power Supply: Through External Adapter.
Stable and Shock Proof
Connector Wire Length 300mm
Operating Speed : 0.17sec / 60 degrees (4.8V no load)
Operating Speed : 0.13sec / 60 degrees (6.0V no load)
Stall Torque : 9 kg-cm (180.5 oz-in) at 4.8V
Stall Torque : 12 kg-cm (208.3 oz-in) at 6V
Operation Voltage : 4.8 - 7.2Volts
Gear Type: All Metal Gears
Original box: NO
Color: Black
Item size: 40 * 19 * 43mm
Servo weight: 55g
Net weight: 66g (with accessories)
Package weight: 75g

KK2.15 MULTI-ROTOR LCD FLIGHT CONTROL BOARD

Specifications

Size: 50.5mm x 50.5mm x 12mm
Weight: 21 gram (Include Piezo buzzer)
IC: Atmega644 PA
Gyro/Acc: 6050MPU Invent Sense Inc.
Auto-level: Yes
Input Voltage: 4.8-6.0V
AVR interface: standard 6 pin.
Signal from Receiver: 1520us (5 channels)
Signal to ESC: 1520us

ELECTRONIC SPEED CONTROLLER ESC F20A

The **Hobby King F-20A** has a **100% N-FET** design and a **Crystal Oscillator** for PWM range accuracy in all temperatures.

Specifications

Max cont. current: 20A
Peak current: 40A (10s)
Voltage: 2-4S LiPo, 5-12 NiCad
BEC: 5V/3A
Size: 54x26x11mm
Weight: ~30g

MINI 2.4G 4CH WIRELESS AUDIO DVR KIT SPY NANNY CAMERA CCTV CAMCORDER CAM

Features

- Wireless USB DVR
- 4-channel 2.4GHz wireless video/audio
- Capture images 30 frames per second
- Record file format AVI and play with Windows Media Player
- USB 2.0 interface, transmission rate up to 480Mpit/s,48times
- Fluency video display,720*576 image up to 30 frames/s

- Moving image display up to 1440*1152
- Sharp and nature image with true color
- Auto brightness, white balance, color saturation, contrast, Gamma
- Advanced digital video control function

Products description

- Send e-mails attachment with image.
- Save image on Hard Disk.
- Sound alarm.
- Video signal filter, for filtrate Active and Invalid channel.
- Signal lost alarm.
- Motion Detection.
- Adjustable sensitivity.
- Automatically lock, while not any operate.
- Schedule Monitoring, for timer snap.
- Record video/audio (with usb 2.0 audio interface),snap shot.
- Automatic Space Management. Stop recorder or capture still automatically on disk full.
- Support 4 Channel video inputting on one computer.
- Support on Screen Display. Display data and time, or channel description on video.
- Supports manual open/close Invalid channel, or add/delete channel description.
- Supports login and logout, by User Name and Password.
- Supports running background stealthy.
- One video/audio input
- Receiving Frequency:
  channel 1: 2.414GHZ channel 2: 2.432GHZ
  channel 3: 2.450GHZ channel 4: 2.468GHZ

System Requirement

- CPU speed: 1.8GHZ or higher
- RAM: 256 EMS memory or more
- Hard disk space 10GB
- Operating system: win2000, winXP,win8 (not support win 7 64bit and vista 64bit ,MAC)
- USB2.0 port
- 64bit color display card

Camera Specifications

- Images sensor: 1/3" cmos
- Validity Pixel: PAL: 628 X 582/NTSC: 510 X492;

- Horizontal Definition: 380 Line;
- Minimum illumination: 1.5 Lux
- Frequency: CH1:2.414GHZ CH2: 2.432GHZ
- CH3:2.450GHZ CH4: 2.468GHZ

- Transmission power: 10mW
- Open Transmission Distance: 50M
- Power: DC 8V/500mA
- Work Temperature: -10 ~+50 degree Celsius

Figure1 Buttons introduction:

- Viewer Mode - Select viewer mode, such as Four Viewer, Big & Four Viewer and Single viewer.
- Viewer Window - Show video image.
- Audio Play - For audio remote listening, with USB2.0 Audio interface.
- Login & Logout - Login and Logout the Multi viewer, by Username and Password.
- Camera/Channel Selection - Click the button, select Camera/Channel.
- Auto turning focus - Click the "ON" button to enable, and click the "OFF" button to disable.
- Channel Settings -Such as channel description, channel active/inactive etc. H. System Settings - Adjust video recorder settings, such as Save AVI File Path etc.
- Record -Start and end video record
- Property - Advanced Settings video picture settings and fine tuning.
- Show Stamp -Show Multi viewer's system information, such as channel description, etc.
- Timer Snap - Captures and saves a bitmap picture after Schedule end. Timer adjustable by clicking on have file options button. Ref. N)
- Snap Shot -Capture and saves an instant bitmap picture.
- Save File - Settings Schedule for timer snaps displays and allows capture of destination path and filename of bitmap capture file.
- Security & Surveillance - Include E-Mail Sever Setup, Motion Detection Setup, Signal Lost Setup, Sensitivity Setup, and Auto Logout Setup.

Package Includes:

- 1 x Wireless USB DVR
- 1 x AV Cable
- 1 x User manual CD
- 1 x Wireless camera

Carbon Fiber Propeller Set 9 X 4.7 CW/CCW

Specifications

9x4.7 Carbon Fiber Propeller Set CW/CCW

Size: 9 x 4.7 inches

Applicable to 8MM shaft diameter brushless motor

Carbon content 100% TORAY 3K carbon fiber applied

Optimized propeller efficiency and loading stability

WALKERA 2.4GHZ 6CH WIRELESS RECIEVER

Specifications

Size: 33 X 20 X 13mm
Sensitivity: -105dmb
Frequency Interval: ¡Ý 4M
Receiver Battery: 4.8-6V1300mAh (not included)
Weight: 5g

Features

Walkera 6CH DEVO RX601 2.4GHZ Receiver for DEVO 6S, 7, 8S, 10 and 12S Transmitter

Small and light, best use for planes or 6-channel helicopters.

Package Included:

1 x Walkera RX601 Receiver

DEVO 7E 2.4GHZ 6CH TRANSMITTER

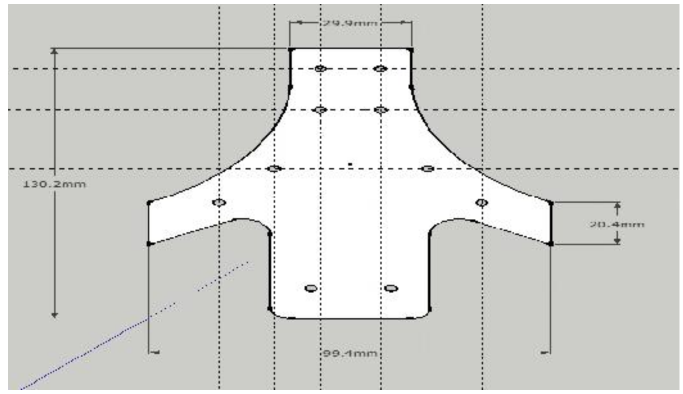
Specifications

- The DEVO 7E uses 2.4 GHZ DSSS technology and supported fixed and automatic ID binding and ID assignments

- USB online firmware updates permit use of the latest transmitter features
- Adjustable radio power output to improve battery life
- Wireless data transmission between two DEVO 7E simplifies the use of training mode
- 30 model memory data slots available
- DEVO 7E adjusting the gyro sensitivity makes hovering flight and fancy in an easy way. AUX2 gyro variable gain control makes adjustment for hovering or 3D flight simple
- Ergonomic design provide comfortable and straight forward operations
- DEVO 7E supports software switching between control modes 1 2 3 and 4
- DEVO 7E is suitable for both helicopter and airplane control

ENCODER……….7 channel micro computer system
FREQUENCY……2.4 GHZ DSSS
OUTPUT POWER…less than or equal to 100mW
POWER SUPPLY….battery 4X1.5V or NiMH 4X1.2V 1600-2000mah
OUTPUT PULSE….1000-2000 ms (1500ms Neutral)
CURRENT DRAIN…less than or equal to 200mA (100mW)

TRICOPTER FRAME DESIGN:



- FRAME TYPE : FIBER GLASS
- QUANTITY 2: CUT AND DRILLES FOR 3MM SCREW NUTS.

USB ASP (ISP) PROGRAMMER CABLE FOR KK2 MULTICOPTER BOARD AND ESC

Z

- USB AVR CABLE FOR PROGRAMMING THE KK BOARD AND ELECTRONIC SPEED CONTROLLER
- COMPILER WINAVR
- INTEGRATED DEVELOPMENT BOARD AVR STUDIO.

3.7 RESULT

So far we have done so many experiments on our project. This is because, so many experiments should be done to select the suitable P, I and D gains that enables our system to be stable and achieve the required characteristic performance. After a lot of trial we come up with values which can keep our tricopter somehow stable. Considering the wind and other external disturbances we filled up the required PID (proportional, integral and differential) gain in to the controller board. And now it is flying to a certain expected range. So, at this point we have done the electronics part, the programming part, and every material collection and implementing it. The flight videos that are approached so far are included in our documentation. The videos in the documentation show the stability along with the movement (back ward, forward, upward and downward) of the Tricopter. Also the video recorded by the camera which is installed on the Tricopter is included in the documentation. The video in our documentation includes:-

1. Tricopter stability
2. Tricopter movements and
3. Video recorded by the Tricopter

3.8 SIMULATION

The simulation part consists of the following steps:

1. Data collection and data analysis
2. Modeling and loading initial conditions
3. Simulating in Simulink

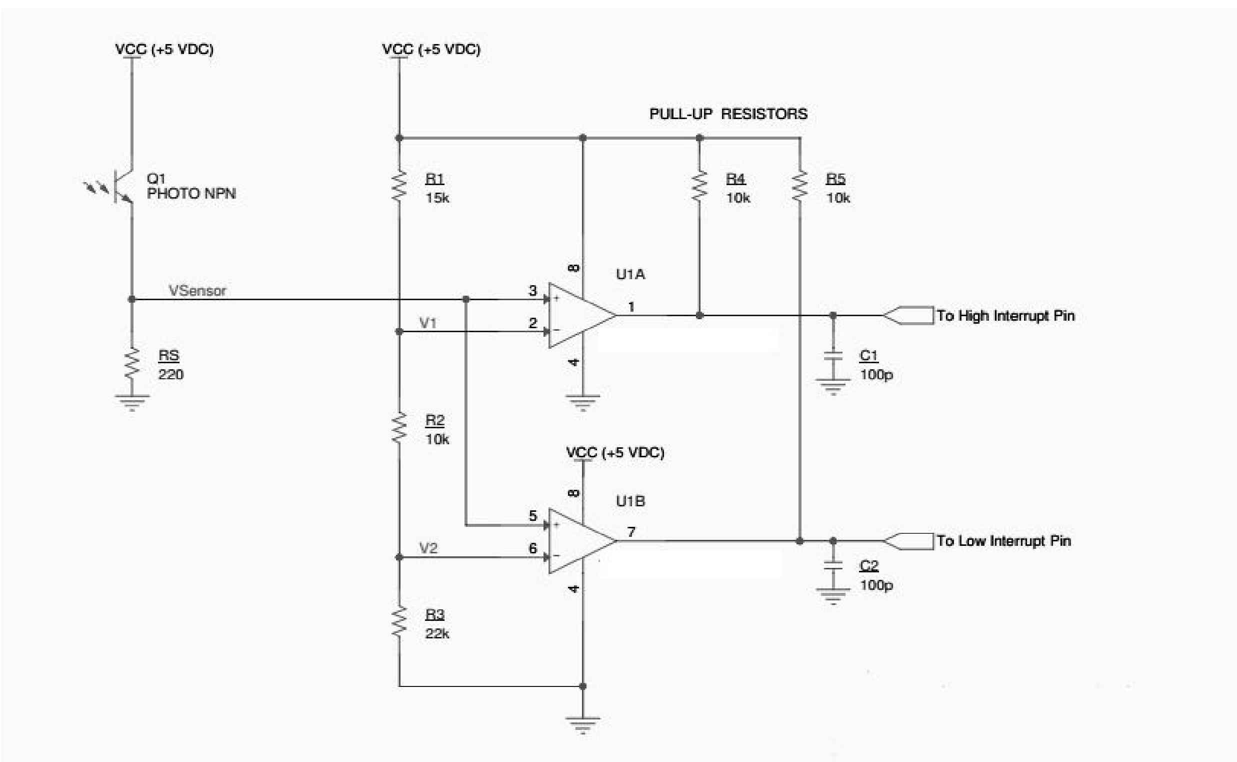
3.8.1 DATA COLLECTION AND DATA ANALYSIS:

We have used MATLAB Simulink environment to simulate the control system of our project. Before actually performing the simulation we have conducted some experiments for calculating some performance parameters of the system. To obtain these parameters we measure RPM, thrust and torque. This requires designing a simple circuit, an arduino UNO program that facilitates easy data collection, and a MATLAB data analysis program that makes data analysis simple and fast.

The actual work of the entire setup will consist of:

- A single motor with its prop, battery and ESC
- An arduino UNO microcontroller which handles the program that generates PWM signal to the ESC for driving the motor and serial communication with PC.
- A comparator circuit with photo transistor.

Fig. 3.8.1 motor test setup for data collection



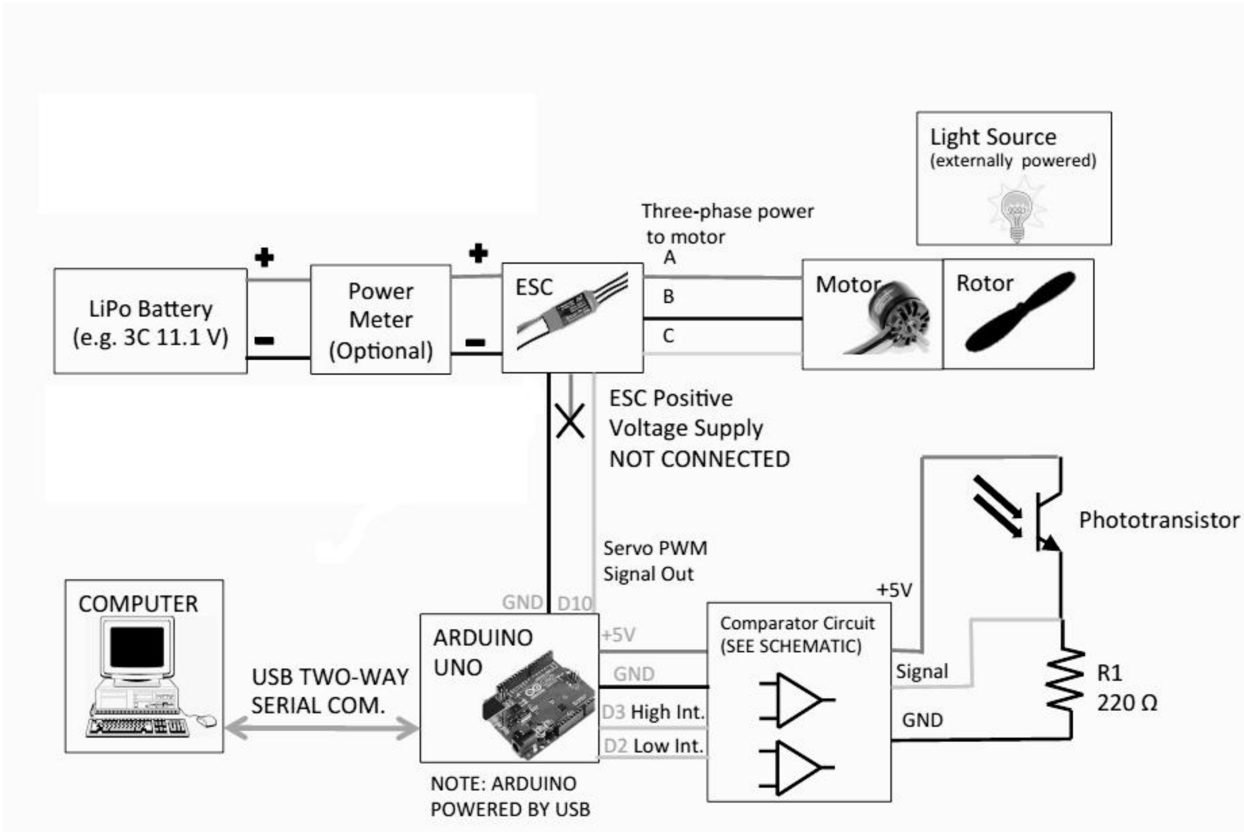


Fig. 3.8.2 comparator circuits

As the props rotate the light source that faces the phototransistor will get interrupted and this is given to the comparator and the comparator accordingly produces two types of signals (high and low). This square waves are given to the arduino and it counts the waves which are equivalent to the RPM of the motor.

The reason for going to arduino is that it makes serial communication simple by just selecting the baud rate and some few codes. The arduino prints the RPM, time in seconds and the throttle command that we type on the serial COM monitor. The serial data looks like something like this.

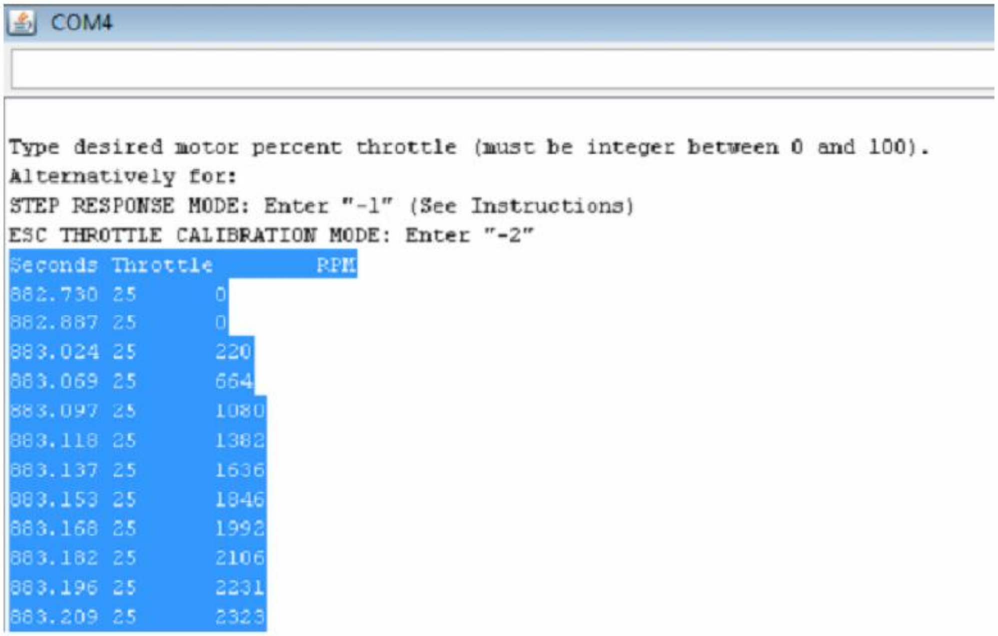


Fig.3.8.3 arduino serial monitor

These data are imported in to MATLAB workspace and saved in a single file which is loaded during the data analysis.

Other types of data that we should import to MATLAB are the mass measurements that correspond to the torque and thrust. During both the thrust and torque measurement, as the motor rotates the reading on the digital balance will increase and hence correspond to the thrust as well as torque of the motors they apply.

After sending the desired throttle percentage through the serial monitor, the mass is read in grams and are manually copied to excel from where it is imported to MATLAB workspace with the name gramsMeas.

Name	Value	Min	Max
gramsMeas	<20x1double>	154	467
Throttle	<799x1 double>	25	95
Seconds	<799x1 double>	849.90...	2.3294...
RPM	<799x1 double>	0	7909

Fig.3.8.4. loaded data

For data analysis we have prepared a GUI (graphical user interface) using MATLAB.

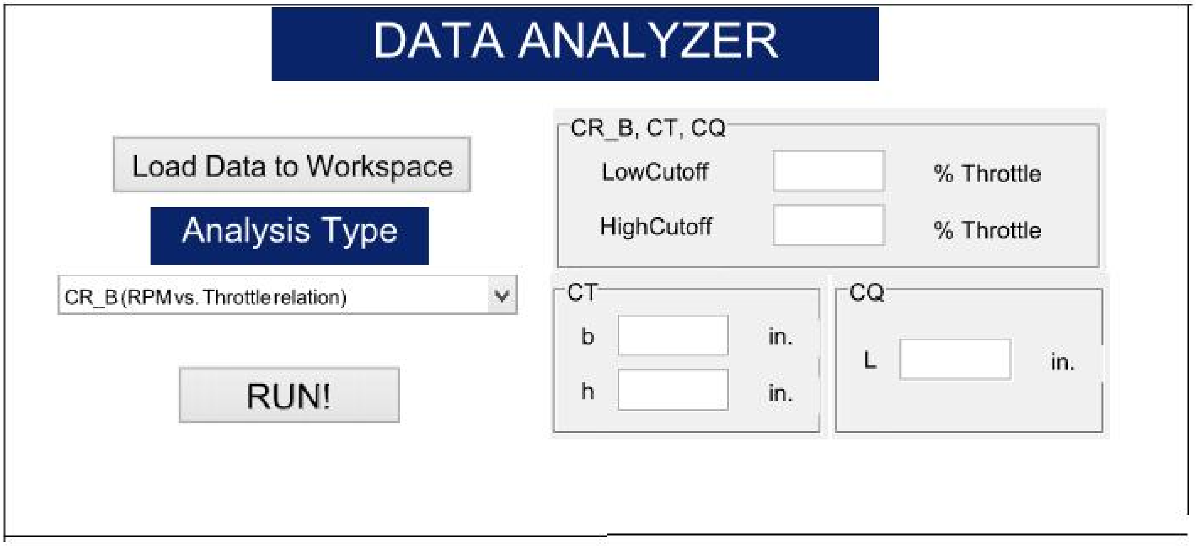


Fig. 3.8.5 data analyzer GUI

In the data analyzer there are three types of analysis

1. Rpm vs. throttle relation

In this mode, the data saved should be loaded by the load button and the required inputs are given. This consists of low and high cutoff throttles and the dimensions of the setup we have prepared for measuring torque and thrust where “h” is height, ”L ”is the horizontal length at the bottom and “b” is the horizontal length at the top (this is only for torque measurement as can be seen in the GUI).

This type of analysis is done by linear regression method and helps finding constants CR and b which helps to linearly fit the throttle commands with the RPM according to

$$\mu = (throttle\%)c_R + b \qquad \text{eq.3.8.1}$$

Where

ω is the expected RPM, throttle% is the throttle command, C_R is the throttle to RPM conversion coefficient and b is the y-intercept.

Once the data is loaded and the user inputs are given after pressing the run button we get the output of figure 3.8.6.

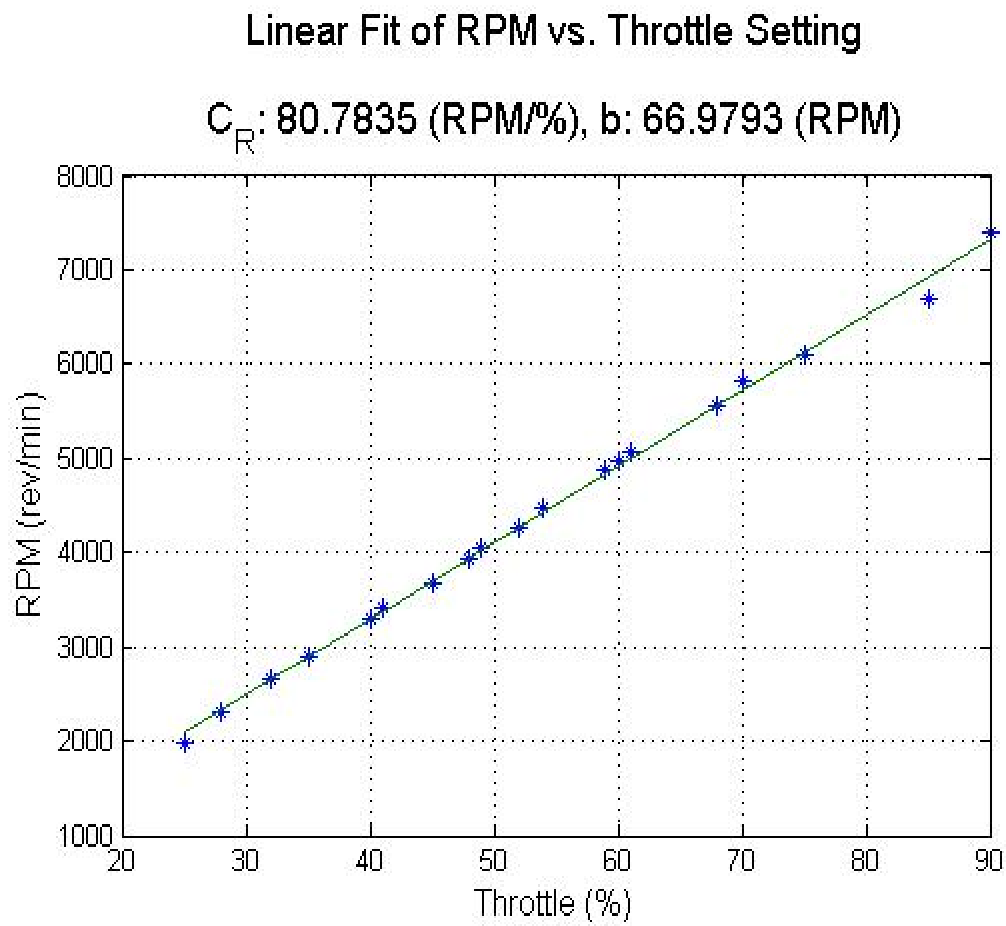


Fig.3.8.6 thrust to rpm relations

2. Rpm vs. throttle and thrust relations

This analysis is actually done to get the constant that relates motor rpm and thrust known as thrust coefficient "K_t or C_T" after inserting the appropriate inputs in the GUI the result that we get is as in figure below. As we can see the graph is not as straight as expected. This is due to the errors in the measurement that we get. The mass of the equipment's of the motor testing setup etc. are the reason for producing this inaccuracy.

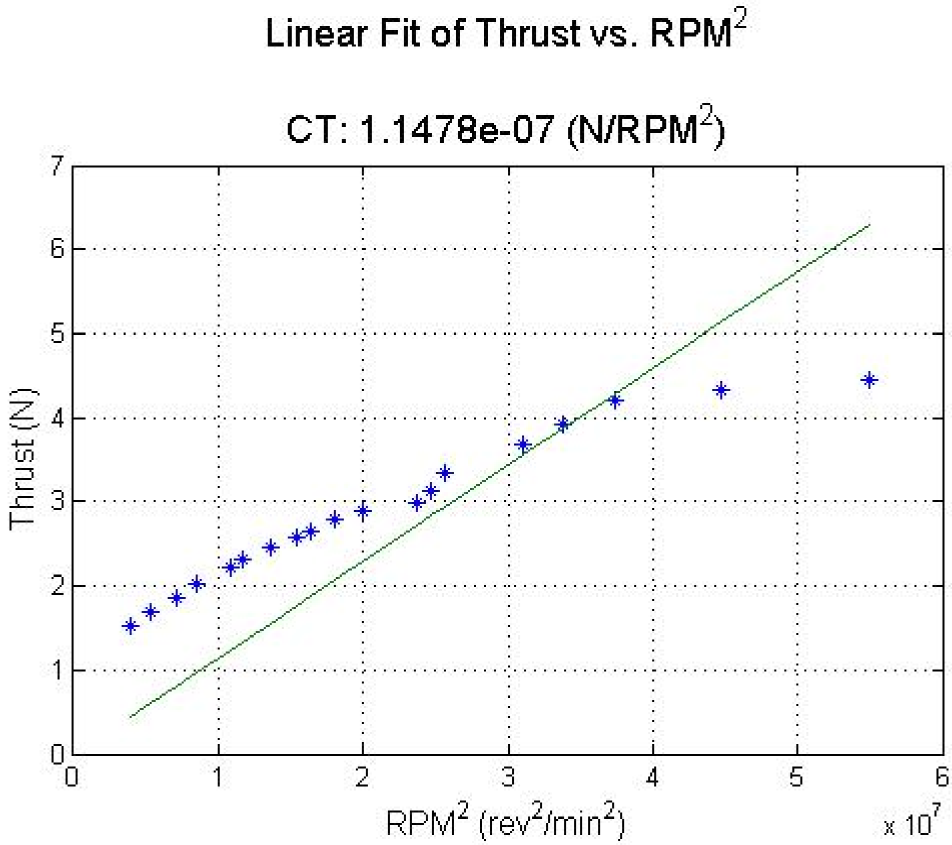


Fig.3.8.7 thrust to RPM² relation

3. Rpm vs. throttle and torque

This analysis is similar to the above in that the variables that we need are the same. Torque measurement involves finding the torque coefficient (C_Q or K_τ) and hence there will be a linear relationship between the torque and the RPM^2.

The graph that we got from data analyzer MATLAB GUI looks like the following graph.

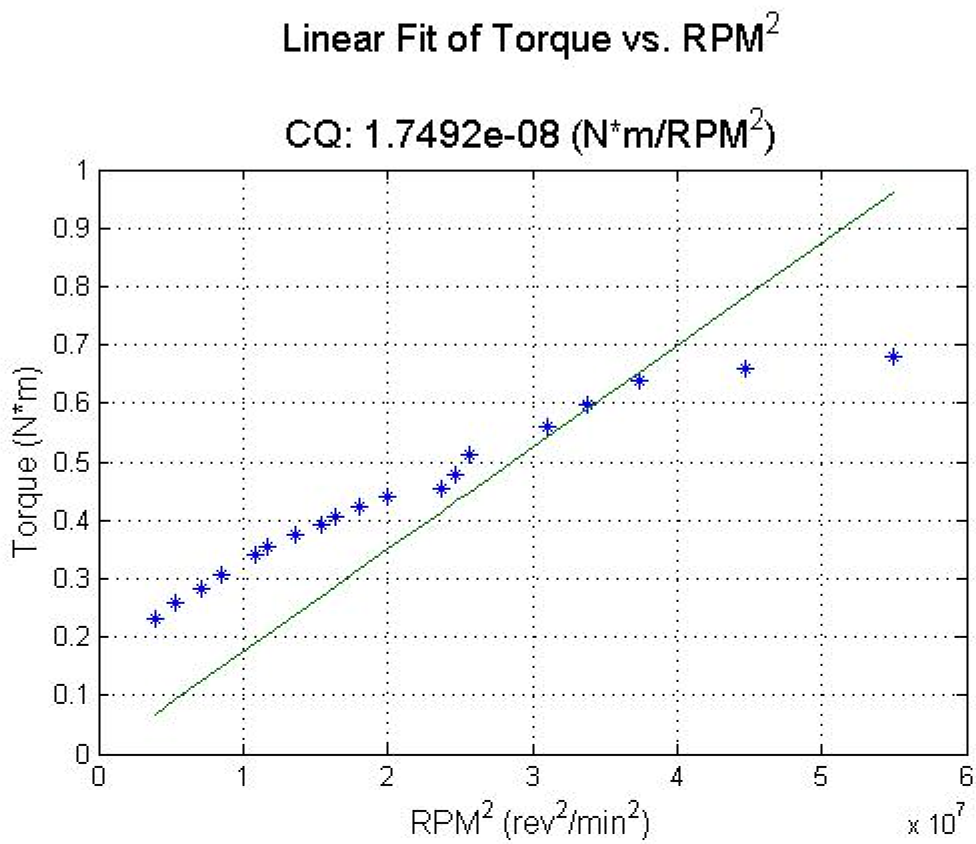


Fig. 3.8.8 torque to RPM^2 relation

3.8.2. MODELING AND LOADING INITIAL CONDITIONS

First the control loop should be drawn in Simulink. Here the first step is to save the model and initial conditions as structures in convenient files. The reason for using the GUI is because it simplifies the modeling and simulation because it is user friendly. The modeling GUI looks like as figure below:

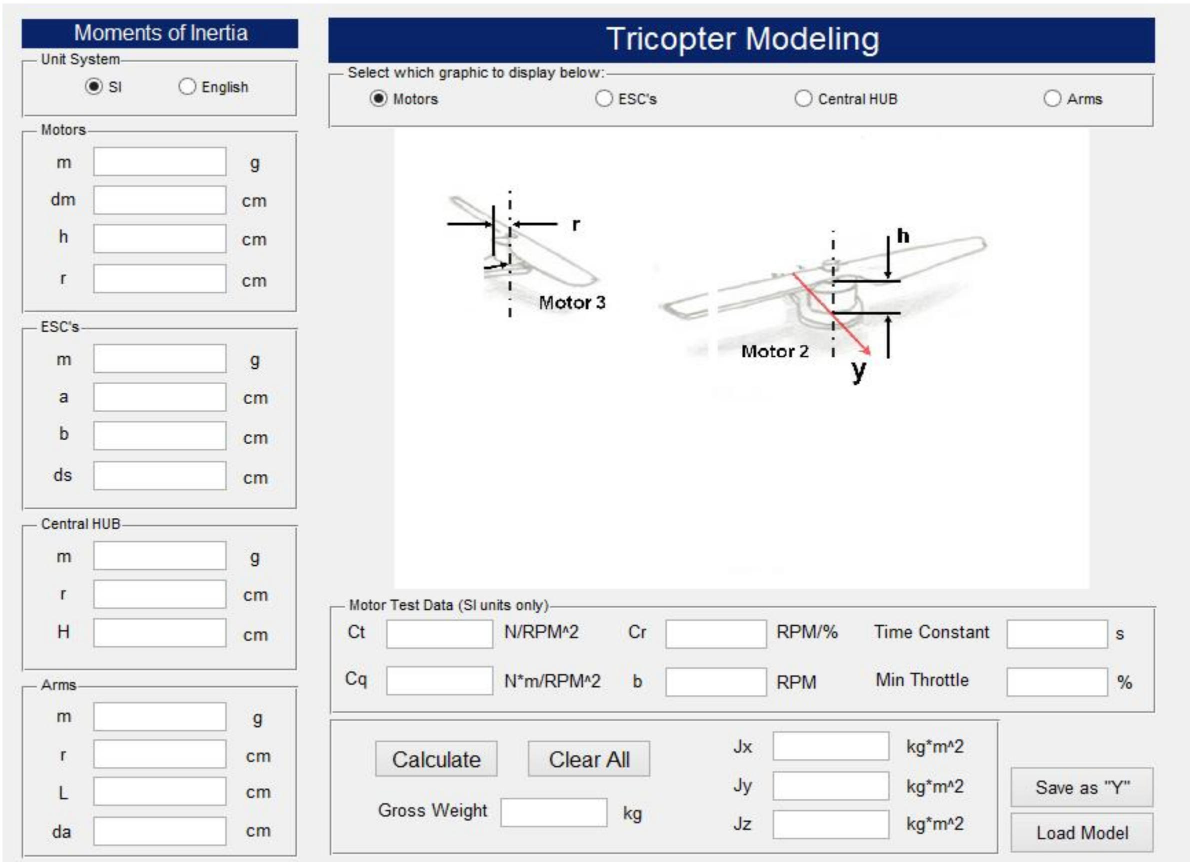


Fig. 3.8.9 Modeling GUI

As it is on the left side of the GUI, the measurements are inserted and by simply pressing the calculate button the inertial matrix is calculated. Then the calculated result is saved in a structure to be used by the Simulink.

Another thing to perform before actually modeling is selecting initial values to each states of the system. For doing this we have also prepared a GUI that is more user friendly and simplifies the way we store the data. We can just press a button to save the data in a convenient structure and then it is eventually loaded to the Simulink model for simulation.

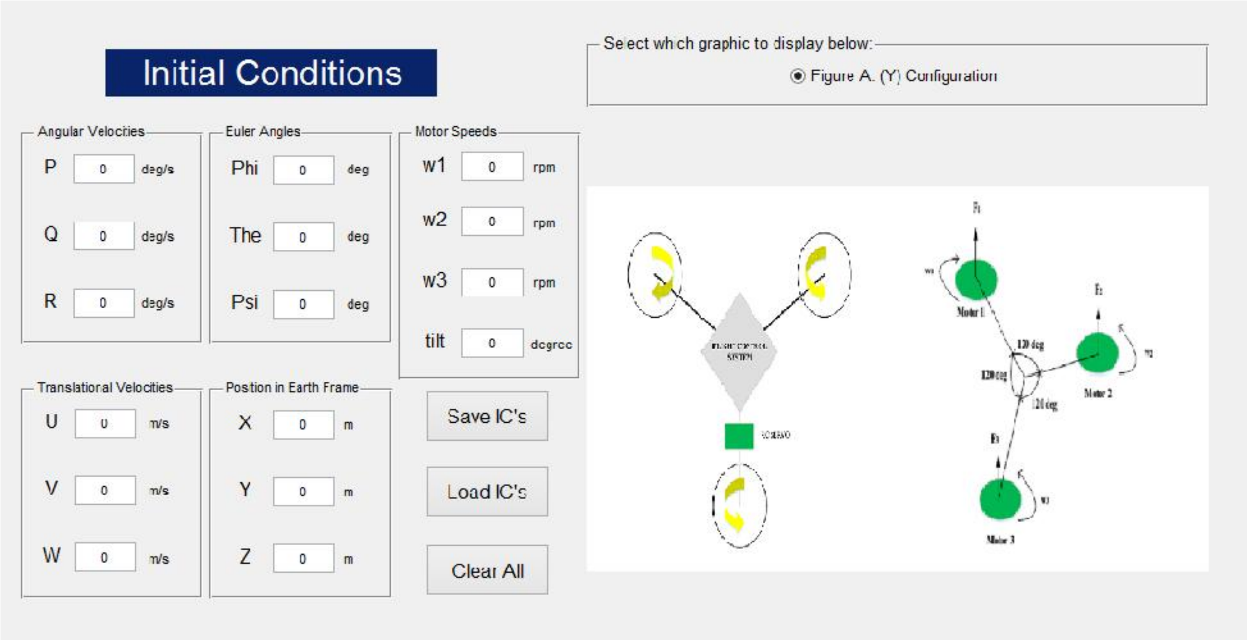


Fig.3.8.10 initial conditions GUI

So by using the above two graphical user interfaces we can save the model as well as the initial conditions of our interest in two separate structures. Hence the
System is now ready to simulate.

8.3.3. SIMULATING IN SIMULINK

In this part the actual model of the tricopter should be loaded with the initial conditions. As can be seen from the control loop of the system the blocks are actually buttons and subsystems. The buttons are the once which are not connected and are independent.

The controller that we are using is called attitude controller and it is a PID (Proportional Integral and Derivative). This is an attitude-command-only model. In other words, there is no control system to track position. Instead the controller only tries to track attitude (roll, yaw and pitch) and altitude (Z) commands using a PID controller. The attitude of the tricopter depends on the Euler angles (roll, yaw and pitch) and the altitude. The controller just controls these four system variables. This controller has tunable PID constants which are selected according the desired performance of the system. The reason for going to the PID is that we want to improve both the steady state as well as the transient response.

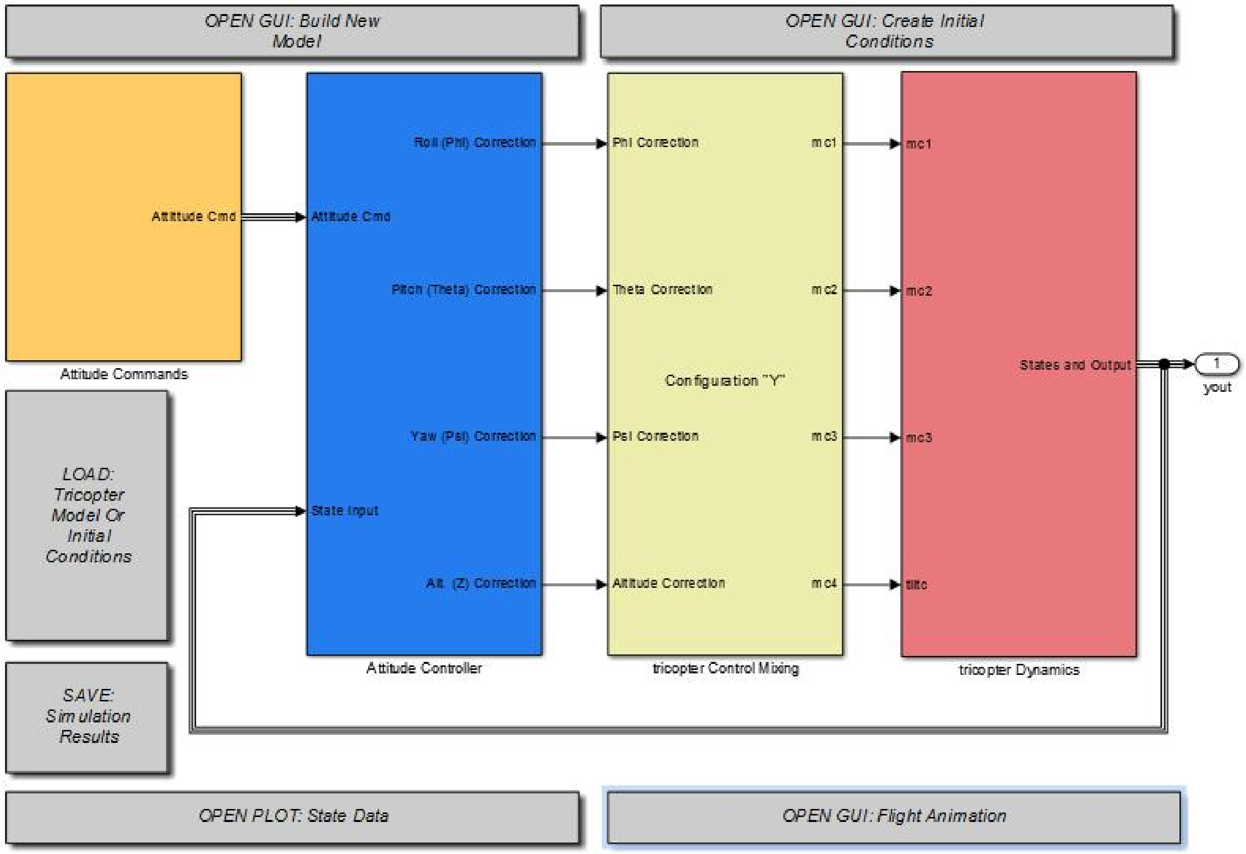


Fig.3.8.11 Simulink modeling

Each box consists of sub systems which are available after clicking on the boxes.
Let's check out what really is inside each block.

Open the Attitude Commands block and look at the signal source blocks. These can be changed to any source you want, and what we've provided is just an example. Note that, the simulation uses radians for angles and meters for distance except otherwise it is noted.

Next check out the Attitude Controller block, looking in here you'll see the following

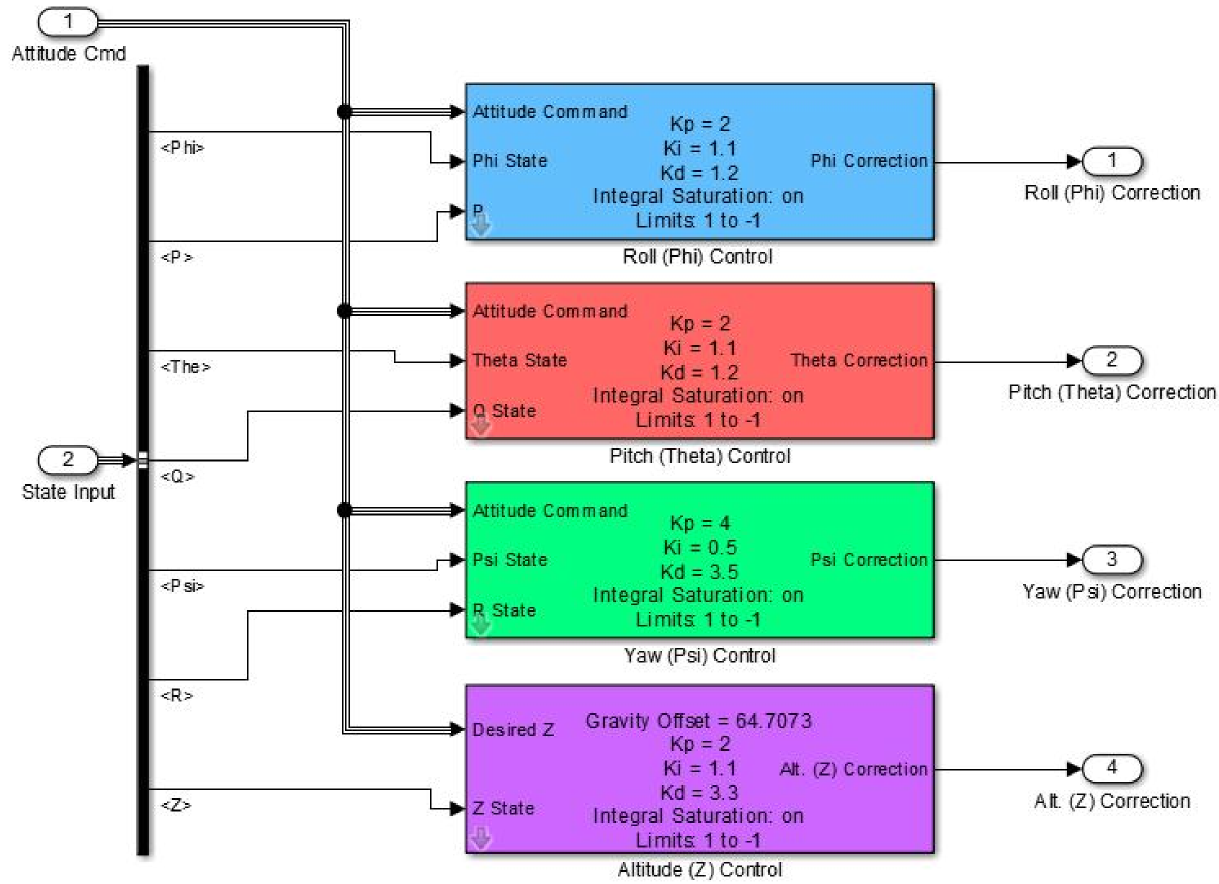


Fig. 3.8.12 attitude controller

Exploring the attitude controller also leads to a masked Simulink models underneath. These are the PID blocks and can be tuned by just clicking the blocks and changing the constants. For example, the roll controller looks like as figure below

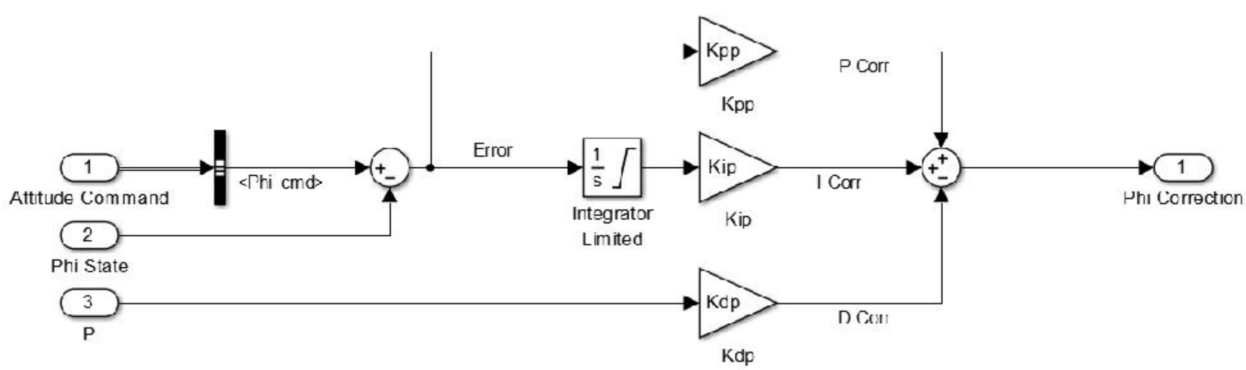


Fig. 3.8.13 roll PID controller

When you've explored that, back out and look inside the next block entitled "Tricopter Control Mixing". This block takes the correction commands for the Phi, Theta, Psi and Z and "mixes" them by letting each correction be sent to the correct motor.

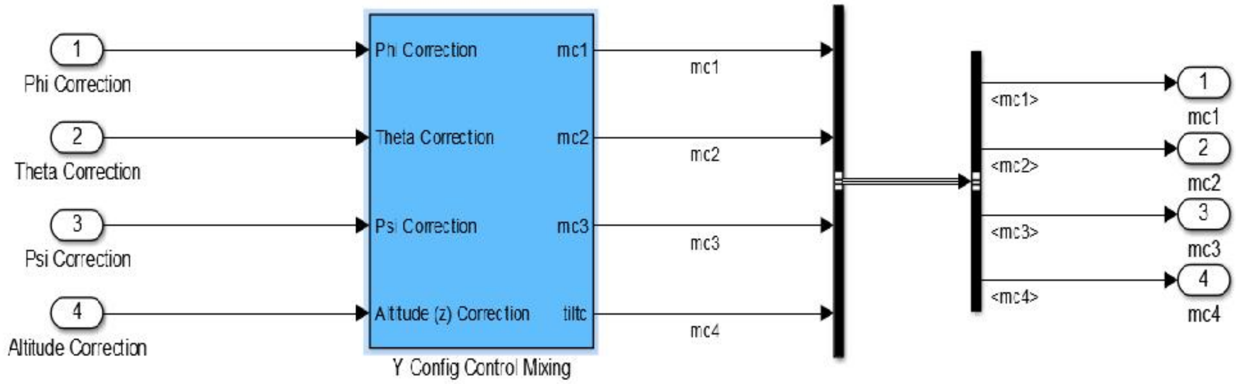


Fig.3.8.14 control mixing

It should be mentioned that these output signals are in terms of percent throttle.

Next we'll check out the tricopter Dynamics block. Inside you'll see the diagram shown in the next figure

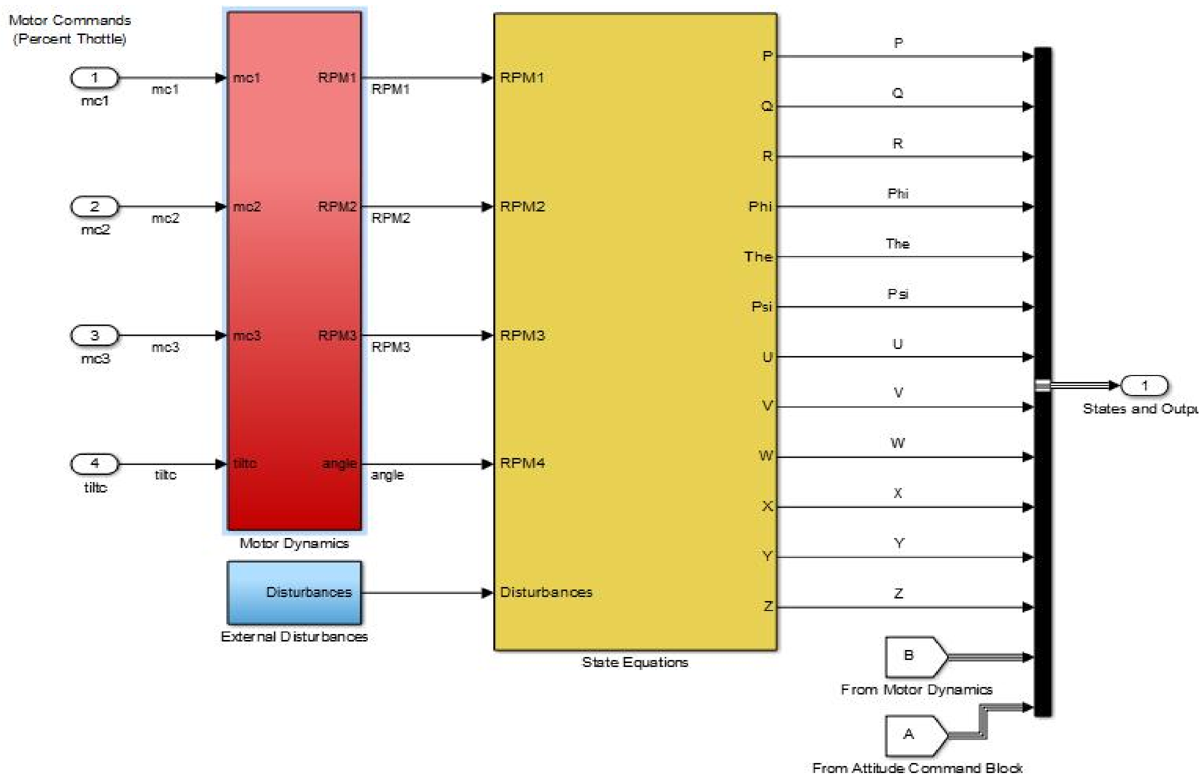


Fig. 3.8.15 Tricopter dynamics

The motor dynamics block restricts input commands to between 0% and 100%throttle (which is obviously the maximum possible range of throttle command signals), simulates the motor cutoff behavior at very low throttle, and most importantly applies the linear relation to the percent throttle signal. The output of the block is the RPM for each motor at any given moment in time. The disturbance block adds the step disturbances as in the form of torque and force.

Finally we have the heart of the simulation. The State Equations block executes a level 2 S-Function written in the MATLAB language. This is where we simulate the state equations describing the dynamic behavior of the vehicle.

After simulating the model for a specified time, we have provided the results in two ways. First one is graphical view of the 12 state variables as well as the motor RPMs as shown below.

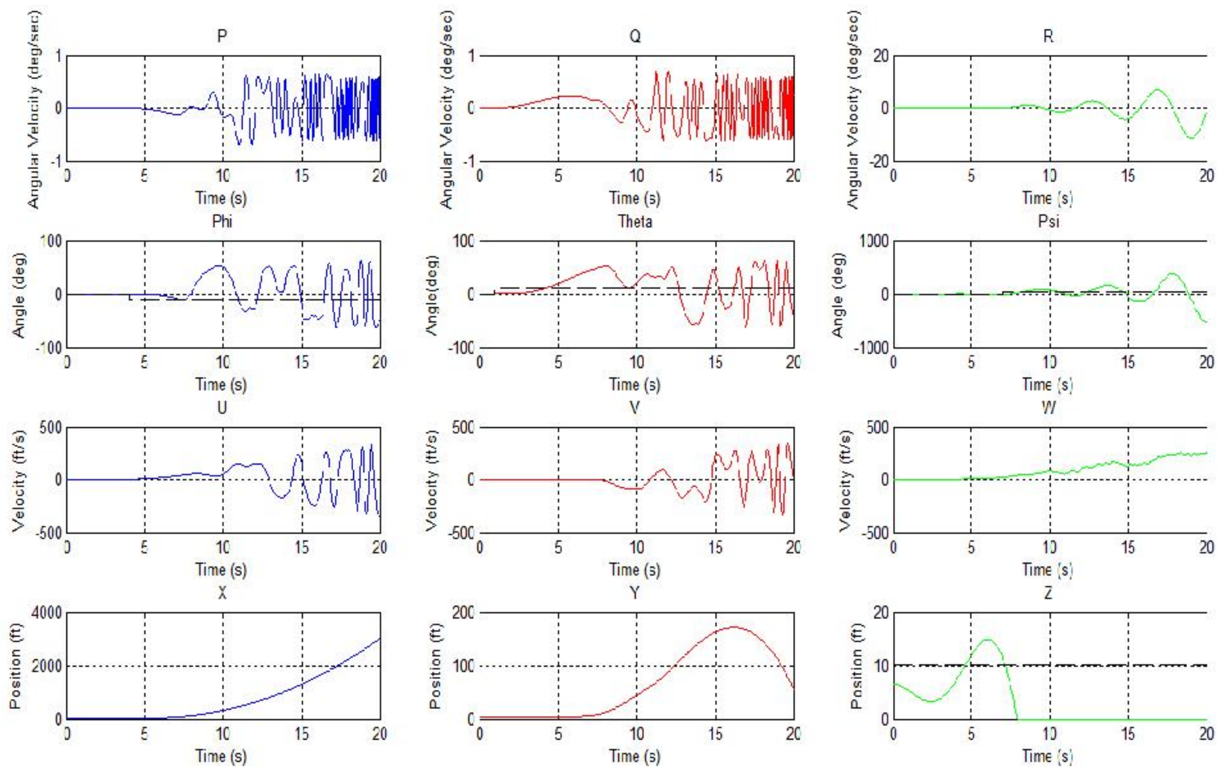


Fig. 3.8.16 state plot

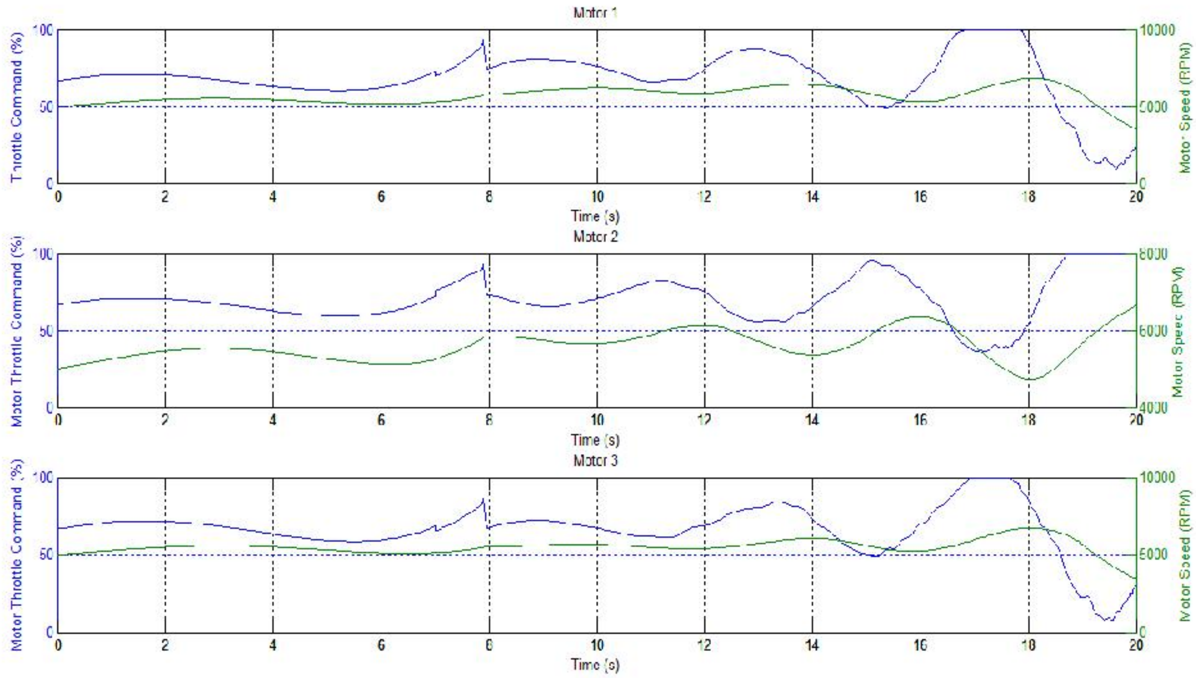


Fig. 3.8.17 RPM and %throttle plots

Actually interpreting and analyzing this many graphs may seem difficult. We can also view whatever plots of variable that we have used in the system by just saving the simulation by using the save simulation button in the model of the Simulink.

The second type of output is the animation output which is created in the MATLAB GUI. This output gives the animated view of the geometry of the tricopter. This form of output is actually more intuitive and easy. The animation taken for arbitrary inputs and initial conditions looks like as shown in fig. 3.8.17

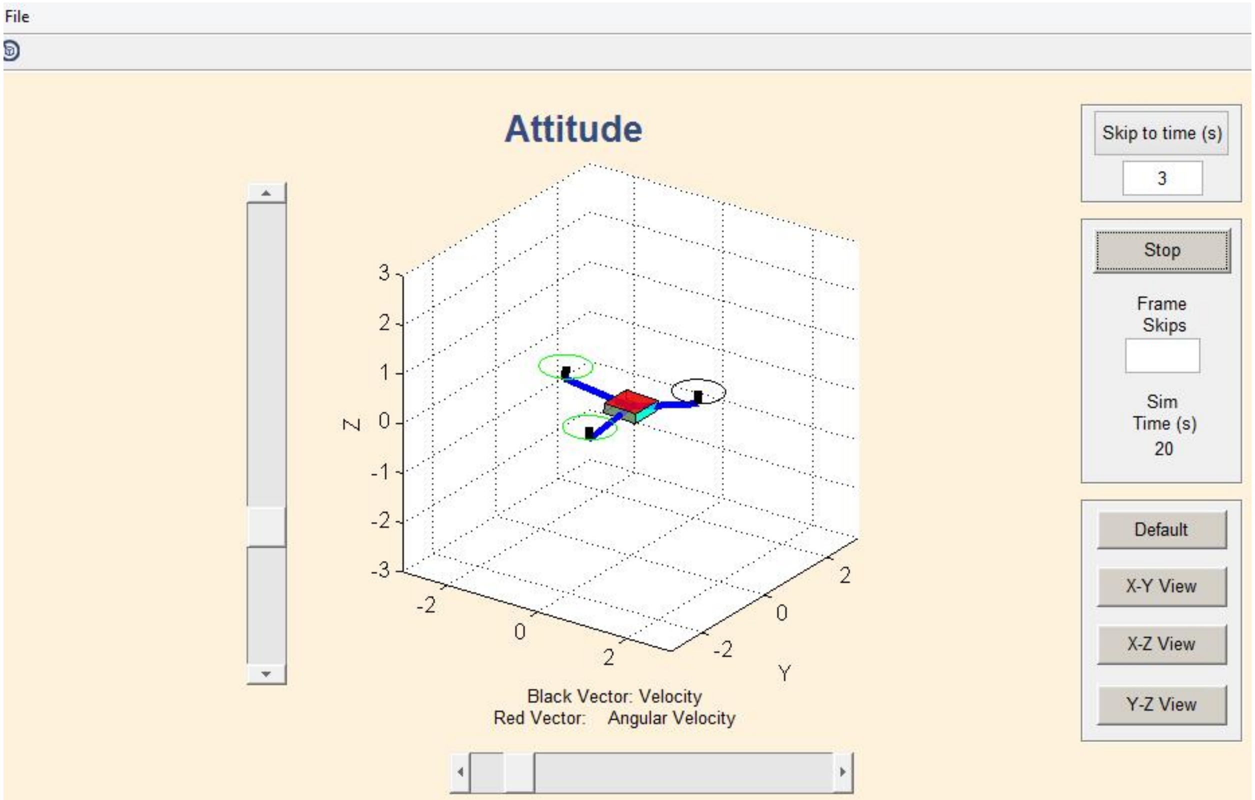


Fig. 3.8.18 animated view of tricopter

CHAPTER – 4

CONCLUSION AND FUTURE ENHANCEMENT

4.1 CONCLUSION

Over all the design of the Tricopter was a success. After coming back from a number of field flying tests we can say that the programmed code in the four microcontroller shows a synchronized results both from the gyro and accelerometer interconnecting with the human pilot commands shows stable results. However for Tricopters, finding the suitable gains on the PID values can be a frustrating experience .The tricopter flew smoothly and was stable. It had sufficient power to perform its required task at a full throttle speed of 50mph for around 7 minutes.
Surveillance footage was captured using the built in wireless camera mounted on the tricopter and saved in the laptop.

All structure components such as the rotor arms, center plate, and motor fairings were bolted in place. At every intersection site that each component met a rubber washer was used to help further dampening the transmission of the vibration throughout the frame. The tuning of the PID controller is subjective and a trial and error effort. More research would be needed to identify ideal flight characteristics based on the tricopters ability and operators preference.

With the advancements in LiPo technology high power density cells in the near future would enable longer endurance times in flight, expanding the possibilities of its Capabilities and applications. Designs of tricopters, or any multicopter, based on both pilot and autonomous Engineering principles and proper use will ensure the safe evolution and application of this new and expanding field.

4.2 FUTURE ENHANCEMENT

There are still ample opportunities for the development of this test bed,
These include but are not limited to:

- Develop the PID control to produce accurate stabilization and fully autonomous flight.
- Implement more sensors onto the platform such as GPS and altitude sensors.
- Further develop the inertial navigation system to produce accurate position data.
- Several Tricopter working autonomously for search and rescue, incorporating thermo graphic cameras.
- Security and border patrol
- War head operation drones
- Autonomous flight
- Transportation of goods and Medicine to and from rural area(high payload carrying capacity)
- Long range country surveillance with satellite receiver

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