SENSOR FUSION AND PID CONTROL

FOR QUADCOPTER HOVERING

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SENSOR FUSION AND PID CONTROL

FOR QUADCOPTER HOVERING

LIM MING JUN

A proposal submitted in partial fulfilment of the

requirements for the award of the degree of

Bachelor of Electronic Systems Engineering (Engineering)

Malaysia-Japan International Institute of Technology

(MJIIT)

Universiti Teknologi Malaysia

8 JANUARY 2023

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ABSTRACT

The purpose of this project is to control the hovering height of a quadcopter by using sensor fusion algorithm with the help of a PID Controller. Sensor Fusion is a method of combining two or more sensors to measure the required data or variable. In the early days,

ABSTRAK

Lorum Ipsum

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LIST OF ABBREVIATIONS

|  |  |  |
| --- | --- | --- |
| UAVs | - | Unmanned Aerial Vehicles |
| Vlog | - | Video Blogging |
| USA | - | United States of America |
| GPS | - | Global Positioning System |
| IMU | - | Inertia Measurement Unit |
| IR | - | Industrial Revolution |
| PID | - | Proportional-Integral-Differential |
| MSHIF | - | Multi-source and heterogeneous information fusion |
| EKF | - | Extended Kalman’s Filter |
| UKF | - | Unscented Kalman’s Filter |
| CNN | - | Convolutional Neural Network |
| FYP | - | Final Year Project |
| MJIIT | - | Malaysia-Japan International Institute of Technology |
| MMA | - | Motor Mixing Algorithm |
| IMM | - | Interacting Motion-Model |
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LIST OF SYMBOLS

|  |  |  |
| --- | --- | --- |
| dof | - | Degree of Freedom |
| D/d | - | Dimensional |
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# INTRODUCTION

## Research Background

With the technology of automation being widely promoted to not only industry, but also commercial use, real time data is becoming the most important part of every piece of devices that wishes to implement automation. From small robots to ‘smart-cities’(Chu & Cetin, 2022), automation is inevitable the life human are living. Studies also found that automation does not cause people to lose their job, but instead increased the opportunity(Manuel, 2020, February 17). From Figure 1.1, it is clear that the estimated growth of market for autonomous vehicle will be growing exponentially. In other words, the reliability towards sensor for its accuracy is crucial especially for maneuvering objects like vehicles, trains, aircrafts, rockets, etc. that requires high demand for safety and low latency.

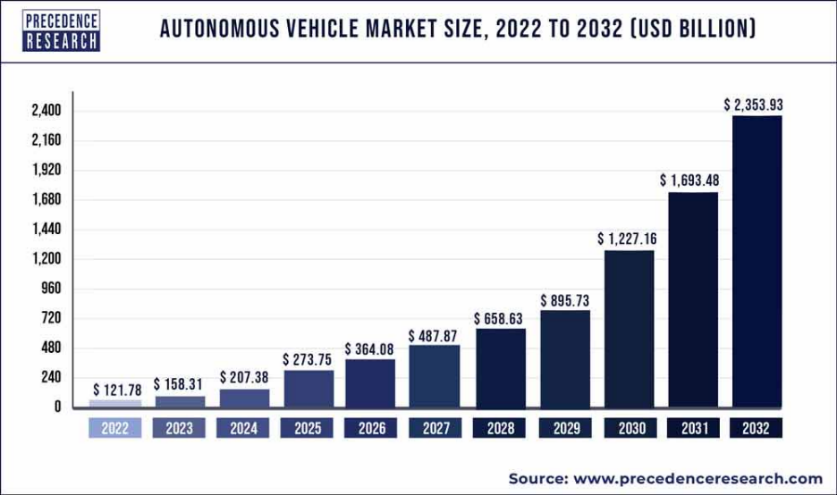


Figure . Autonomous Vehicle Market

(precedenceresearch.com)(Research, 2022)

As mentioned, automations are not just widely used for industrial application, but also for various commercial use like Quadcopter or Drone Technology. In the early days, Unmanned Aerial Vehicles (UAVs) were developed by the United States of America (USA) during the first world war(IWM, n.d). Recently, with the advancement of social media networking and the increasingly population of video blogging (Vlog), Drones are not only being used for military spying purposes, but also used for photography and videography that allows cinematic shots to be taken above in the air where human cannot reach. No matter if it is for military or videography purposes, the UAVs should have sensors integrated in it to improve control and stability.

Ideally, UAVs is expected to have the ability to fly as high as possible and with great agility. However, sensors even until today may not have the ability to cover the desired range of detection of the UAVs or it may be too overly priced. Hence, engineers had come out with a solution called ‘Sensor Fusion’.

### Sensor Fusion

Sensor Fusion is a method of integrating two or more sensors into a hardware used for detecting the parameter of a particular object that can originally be done with only one sensor(Sasiadek, 2002). However, using multiple sensors for detection provides many advantages compared to only using single sensing modality such as:

1. Increasing Quality and Reliability of Measured Data
2. Provides Estimations to Parameters Outside Sensor’s Sensing Ability
3. Increase Coverage Area of Sensor

The sensors used for sensor fusion can be the fusion of the exact same type of sensor placed at different location. An example for this type of sensor is the modern ‘Bird View 360 Surround Parking Sensor’. This type of sensor uses 4 cameras placed at 4 different corners of the car. Each camara is responsible to capturing their surrounding within their coverage area and then all 4 camera combines their data to form a single 2D view around the car. Figure 1.2 shows the processed image from a bird eye view camera.

Sensor Fusion can also be a combination different sensor to measure one single parameter. An example for this is the position sensing for UAVs. Normally, Global Positioning System (GPS) sensor is used for position tracking. However, GPS Sensor has a downside when it comes to accuracy or when the GPS signal is blocked by obstacle. Hence, an Inertia Measurement Unit (IMU) is normally used together with a GPS to overcome the issues mentioned.



Figure . Bird Eye View Sensing

(Source: toyotaofnaperville.com/toyotabirdseye-camera-with-perimeter-scan)

Some other cases of Sensor Fusion are implemented for the sake of overcoming unexpected or unavoidable scenarios that may pose safety issues to the user. An example for this is the pitot tube on an aircraft that is used to measure fluid flow velocity. Most Boeing 737 aircrafts have 5 pitot tubes all around it and are used simultaneously and the data collected are processed for a high accuracy measurement. Sensor Fusion plays an important role when one of the sensors is not functioning especially then the aircraft is at a high cruising altitude and the surrounding temperature is lower than the operating temperature of the sensor.



Figure . Pitot Tube on Aircraft

(Source: Tokyo Aircraft Instrument Co.,LTD.)

### UAVs Positioning an Orientation

A vehicle on land could have 3 degrees of freedom (dof) including forward-back, left-right, and rotation around the z (vertical) axis. This is due to the fact that a land vehicle is designed to only move around in a 2D (not considering going up/down hill) space which is the land. However, for the case of UAVs, they are hovering in mid-air which gives them the ability to move around in a 3D space. The additional dimension allows them to move with 6 dof including 3 translational motion: forward-back, left-right, up-down and 3 rotational motion: pitch, yaw and roll as shown in Figure 1.4.

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| undefined  (a) | undefined  (b) |

Figure . The 6-Dof of an Object in 3D Space

(a: By Horia Ionescu - I (Horia Ionescu) created this work entirely by myself., Public Domain, https://commons.wikimedia.org/w/index.php?curid=10878582 and b: By Yaw\_Axis.svg: Auawisederivative work: Jrvz (talk) - Yaw\_Axis.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9441238)

Pitch is the elevation or depression of the nose of an object. Yaw is the side-by-side movement of the object horizontal with the ground. Roll is the circular motion of the body in the axis of the nose. The angle of all three rotation is described using the right-hand rule.

## Problem Statement

With the promotion of Industrial Revolution (IR) 4.0 and the latest 5G network technology, governance body as well as some corporates are now in the golden era for developing automated technology, in which all machines or devices are able to collect data from the physical world and make its own decision for the best performance. The trend of passing decision-making from human to machines had significantly reduced the workload on human being especially for repetitive work and had proven to be giving less error compared to human operation(Herbert, 2023). As machines such as UAVs which includes quadcopter or drones are given more and more reliability on their decision making, their ability to detect different parameters in the surrounding is becoming crucial especially when it comes to safety.

### Limitation in Single Sensor Model

Simply relying on one single sensor to detect one or many parameter (e.g. like the DHT22 sensor to detect both humidity and temperature sensor) may be a convenient solution for engineers as it is easy to design and reduces the cost of production. However, when it comes to data reliability is taken at the highest priority, single sensor device is definitely not the best solution the taken into consideration. This is due to the fact that all sensors have their limitation in every way including: Detection Coverage, Operating Conditions, Latency, Power Consumption, etc. Some sensors are able to measure a parameter with very high accuracy but is very susceptible to noise and interference. Meanwhile there are other sensor that are less vulnerable to noise but is not as high in accuracy. Furthermore, there are certain conditions where the operating conditions of the machine may cause the sensors to fail. With the single sensor approach, the machine will fail to operate as soon as the sensor fails. This is a cause of a serious hazard if the machine is a UAV that is flying mid-air.

### Limitation of Single Sensor Model on a Quadcopter

Due to the relatively high number of dof, maintaining good stability for quadcopters is a big challenge compared to normal on ground vehicle which only have 3 dof. All 6 dof for a quadcopter including the 3-axis of movement (x, y, z) and the 3-types of rotation (pitch, yaw, roll) are required to have good stability in order for the quadcopter to operate seamlessly. If a single sensor model is applied for the quadcopter, any failure to any parts of the sensor will cause the quadcopter to lose stability and thus causing a serious safety hazard. Besides, in the case of a quadcopter, it is difficult to decide if we wanted a sensor with high accuracy but susceptible to noise or a sensor less susceptible to noise but high latency. This is because, normally quadcopter is expected to have high latency as any slight delay for a quadcopter moving at high speed may cause it to crash into obstacle. However, quadcopters also could not afford to receive noisy signals as the stability of a quadcopter are normally controlled by a (Proportional-Integral-Differential) PID controller, and any small change in signal will be amplified by the P-part of the PID Controller.

## Research Objective

This project aims to implement multiple sensors for the detection and the controlling of the height of the quadcopter. The objectives of the project are:

1. To compare the performance of using single sensor versus using sensor fusion with different sensor combination to measure the hovering height of the quadcopter.
2. To design and assemble a quadcopter using self-made frame, brushless motor, microcontroller chip and different electronic component.
3. To control the height of a quadcopter based on the desired (user) input using a PID Controller.

After this project, a simple quadcopter with 4 propellers will be constructed with multiple sensors integrated in it to measure the height of the quadcopter from ground truth that is controlled with a PID controller programmed from a microcontroller.

## Research Scope and Limitations

This project focuses on the implementation of sensor fusion method to determine the hovering height of a quadcopter. This includes understanding and selecting the types of sensors to be used so that they all could overcome the weaknesses of each other. Besides, it also includes implementing the suitable type of sensor fusion algorithm that works best for both sensor fusion performance and hardware capability. The knowledge of assembling up hardware will also be discussed slightly in this project, which includes the understanding the orientation of propellers, programming the microcontroller into a PID Controller and connecting all components into one piece. It is also to note that only the up-down (height) motion of the quadcopter will be taken into consideration for this project.

Keywords: Sensor Fusion, PID Controller, Quadcopter, Height

## Research Significance

Previously, engineers were required to rely on their experience and do the ‘give and take’ decision to decide which sensor are suitable for their application. With this project, engineers may choose to use both or more sensors based on their needs by using sensor fusion method.

## Proposal Outline

The following parts of this proposal is structured into several chapters. This first chapter, which is this current chapter gives an overview of what the whole proposal is working on. In the second chapter, some relevant literatures and research will be included and the research gap will be determined. Next in the third chapter, the step-by-step process of realizing the project will be discussed. Then in the fourth chapter, some of the preliminary results from computer simulation will be included to visualize the expected outcome before working on the actual hardware. Finally, the fifth chapter will conclude all the proposed idea of this project.

# LITERATURE REVIEW

## Introduction

Many quadcopters or more commonly known as ‘Drones’ that have been used for professional use or even commercial use have various sensors integrated into it for different purposes especially on localization and positioning. Due to the fact that drones are free to move at all directions in the 3D space its stability is the major challenge when designing it. Although drones nowadays have sensors integrated to it, the sensors may be prone to noise and disturbance like the vibration from the drone motors. Hence, engineers had came up with a solution of using multiple sensor fusion technique to ensure a good quality sensor data.

This chapter will show some of the studies done on sensor fusion techniques including the types of sensors that are suitable for different scenarios and the optimum sensor fusion algorithm which is good enough to obtain a good sensor data but not to computational heavy that is too powerful for a basic controller.

### Sensor Types

(Alatise & Hancke, 2020) had made a study on different sensor combination used for autonomous mobile robot sand classified different types of sensors systems based on their functionalities. The class of sensors classified are: Tactile Sensors, Wheel Encoders, Optical Sensors, Heading Sensors, Vision-Based Sensors and Active Ranging Sensors. The summary of description of the different classes of sensors and its relation to our project is shown in Table 2.1. Among the 6 classes, only 3 will be taken into consideration for our project which are tactile sensors, optical sensors and active ranging sensors.

Table 2.1 Sensor Class and Relation to Project

|  |  |  |  |
| --- | --- | --- | --- |
| Class | Description | Example | Relation |
| Tactile Sensor | Determine Exact Position of an object at short distance through direct physical contact. | Contact Switch, Proximity Sensor | Yes (Determine Ground) |
| Wheel Encoder | Measure the distance a wheel had been driven by counting the number of revolutions. | Optical Encoder, Magnetic Encoder | No |
| Optical Sensor | Estimate distance by determining the time required for the emitted light or EM wave to bounce back then return to the sensor. | Infrared, LiDAR | Yes |
| Heading Sensor | Measures angular velocity and orientation. | Gyroscope | No  (Not for Heights) |
| Vision-Based | Receive visual information about the environment for intelligent interaction. | Camera | No (Too Computational Powerful) |
| Active Ranging | Generates highly precise distance measurement similar to optical sensor. | Ultrasonic Sensor | Yes |

(Wang, Wu, & Niu, 2020) had also made some studies different types of sensors used in automated driving and provided some information on the advantage & disadvantage and the normal operating range for the sensors. Besides, the literature also showed some different sensor combination that is suitable for different target and scenarios. According to (Wang et al., 2020), Multi-source and heterogeneous information fusion (MSHIF) technique had shown to give a better result in Figure 2.1 for all scenarios compared to when only using only the sensors individually.

The previous two literatures had given some general ideas various sensor types that is available for determining the range of an object from the sensor which are basically for robots or vehicle. As for the case for a vertical motion like a quadcopter, (Sabatini & Genovese, 2014) had made a study on a loosely coupled filtering approach between an IMU and a Barometer Sensor to estimate the height of an object and its vertical velocity. A later study by (Yang, Qian, Zhang, & Qu, 2020) had also used 4

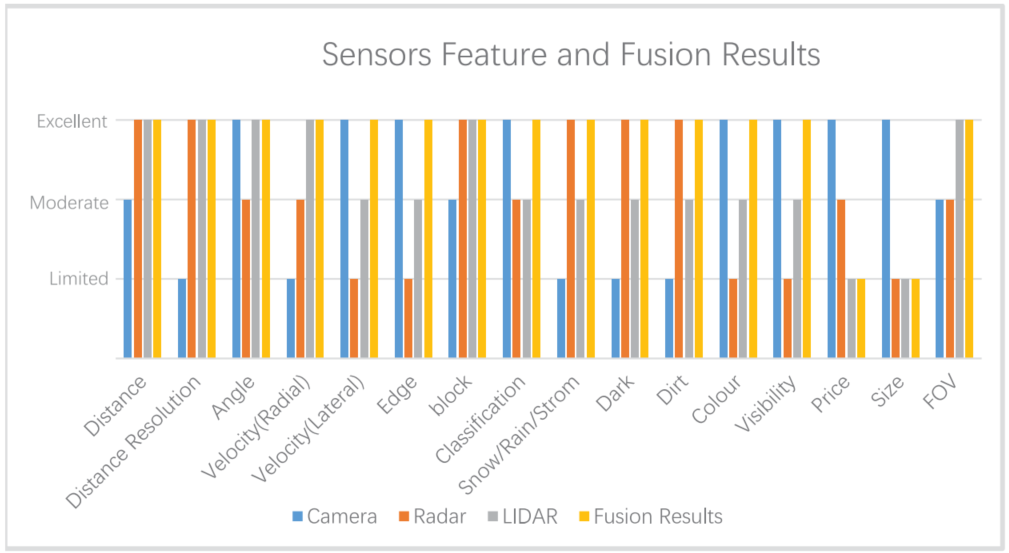


Figure . Sensor Feature and Fusion Results at Different Scenarios

sensors including IMU, GPS, Barometric Altimeter and Radio Altimeter for the measurement of vertical height (except IMU only for acceleration) of a UAV. Figure 2.2 shows the block diagram of a UAV with 4 sensors fused together through a filter.

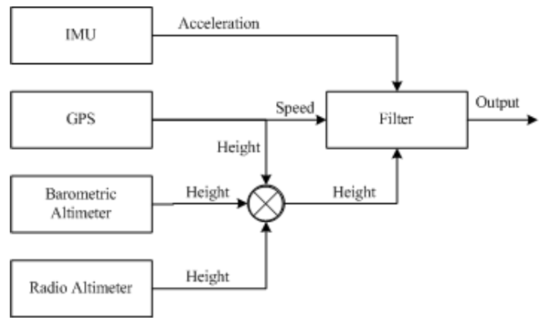


Figure . Block Diagram of 4 Sensors Fused in a UAV system

### Sensor Fusion Algorithm

Sensor Fusion Algorithm is the place where the data received from two or more sensors are being processed through mathematical operations and gives us the higher quality data from the sensors. (Peng Lu, 2022) believes that until this day, there is no sensor that is guaranteed to provide a 100% accurate and reliable data when it is used individually. Therefore multiple sensors with different algorithm are used to attain a more reliable data. (Peng Lu, 2022) had also classified sensor fusion algorithm into 2 classes: Parameter Classification Algorithm and Physical Model Based Classification. Example of techniques classed into Parameter Classification Algorithm are: Weighted Average, Bayesian Estimation, D-S Evidence Theory and Neural Network; whereas example of techniques classed into Physical Model Based Classification are: Kalman Filter. The weighted average technique is known to be the simplest algorithm but still works for many applications.

(Alatise & Hancke, 2020) had made another type of classification for sensor fusion algorithm which are: State Estimation Method and Decision Fusion Method. Table 2.2 shows the description of the two class of algorithms as well as some examples of fusion techniques.

Table 2.2 Classification of Sensor Fusion Algorithm

|  |  |  |
| --- | --- | --- |
| Class | Description | Examples |
| State Estimation | This class involves the uses of current measurement and observation to determine the current state of a system that is continuously changing. | Kalman’s Filter  Particle Filter |
| Decision Fusion | This class combines decision made by many classifiers and make a mutual decision based on the evidence (activity that had happened). | Bayesian Approach  Dempster-Shafer Approach |

(Alatise & Hancke, 2020) also discussed on 2 other filters derived from the Kalman’s Filter which are the: Extended Kalman’s Filter (EKF) and the Unscented Kalman’s Filter (UKF). While Kalman’s Filter typically works only for linear system, EKF is a modified version of Kalman’s filter that is able to work for weakly non-linearised system by linearizing a non-linear system. Whereas UKF is an improved version of the EKF that is able to work on non-linear system with less error compared to EKF but with an increased computational cost. Mentioned in the previous section, (Yang et al., 2020) also used Kalman’s Filter for fusing 4 sensors (IMU, GPS, Barometric Altimeter, Radio Altimeter) and have achieved a greater overall results compared to using single sensor as shown in Figure 2.3.

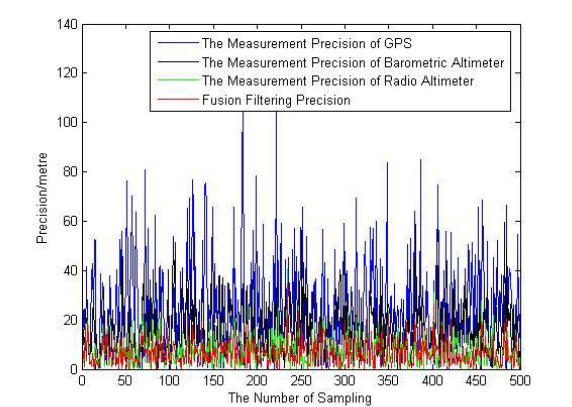


Figure . Accuracy curve of height measurement in different ways.

There are also some studies for much advanced sensor fusion algorithm such as the study by (Kocić, Jovičić, & Drndarević, 2018) had used PointFusion Network which is one of a Convolutional Neural Network (CNN) technique to fuse multiple optical sensor like the Camera, Radar and LiDAR sensor to form a 3D image of the surrounding of a autonomous vehicle. Figure 2.4 shows how sensor fusion is used for occupancy grid mapping for autonomous vehicle. Other CNN algorithm such as YOLO, SSD, VoxelNet were also used in the study by (Yeong, Velasco-Hernandez, Barry, & Walsh, 2021).

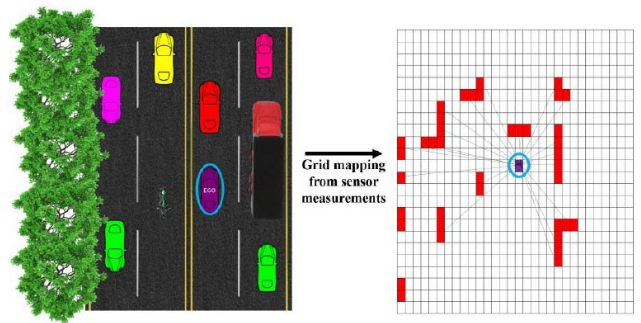


Figure . Occupancy Grid Mapping

### Quadcopter Assembly

The largest challenge when designing and constructing a quadcopter is to ensure its stability during hovering. The two main reason that will cause a quadcopter to lose stability are: All motors will have slightly different speed in rotation despite same voltage is applied to all due to the variation cause during manufacturing and production; and the external factor like winds, imbalanced distribution of the quadcopter that cause one side to be heavier than the other. However, a quick and simple solution to that is to use a PID controller for each motor. A study by (Sumantri, Tamami, Nuraga, & Kurniawan, 2020) had used an STM32 controller as a PID Controller together with MPU6050 to measure the tilt angle and balance the quadcopter. The prototype of the controller circuit is shown in Figure 2.5.

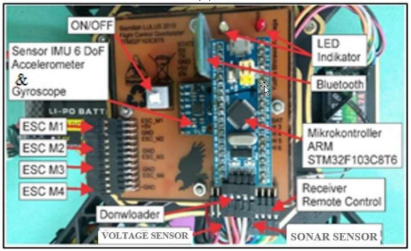


Figure . Prototype of Controller Circuit using STM32

Another study done by (Tagay, Omar, & Ali, 2021) also found to use a similar technique for controlling the quadcopter stability. However instead of using a STM32, it uses an Arduino Uno-R3 as the PID Controller. Figure 2.6 shows the schematic diagram of the circuit.

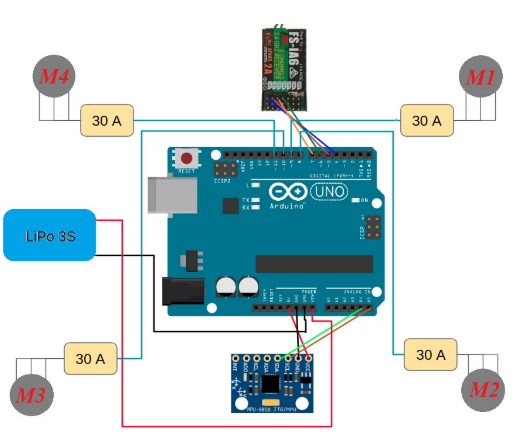


Figure . Schematics of Controller Circuit using Arduino

## Research Gap

There have been a lot of research on various types of sensor configuration, sensor fusion algorithm, and studies on quadcopter assembly. Many researches had done a great job obtaining a positive result from the sensor fusion technique. However, the main limitation from all researches is that none of the research had shown the third advantages of sensor fusion mentioned in Chapter 1 that is “Increase Coverage Area of Sensor”. Most of the literature found had tackled on the first two advantages which are: “Increasing Quality and Reliability of Measured Data” and “Provides Estimations to Parameters Outside Sensor’s Sensing Ability”. Hence for this project, sensors with shorter effective range of measurement will be selected to see if sensor fusion will be able to improve the data quality if the quadcopter is outside the range of measurement of the sensors.

Besides, some sensors mentioned in the literature above are not very common in the market like the Radio Altimeter or is too highly priced like camera. Furthermore, the sensor fusion algorithm used in some literatures are too computational extensive that may not be suitable for a small microcontroller like ATTiny45/48. In this project, we will also look for a cheaper option for sensor configuration as well as suitable sensor fusion algorithm that is optimum for a simple and cheap microcontroller.

## Summary

The literature review for this paper is done with three main scope which are: Sensors, Sensor Fusion Algorithm and Quadcopter Assembly. The literature review on sensor had scoped down the types of sensors suitable for measuring the height of a quadcopter. Meanwhile, the literature review on sensor fusion algorithm had shown many types of sensor fusion algorithm that are very commonly used in UAVs and even autonomous driving. Finally, the literature from Quadcopter Assembly also gives some idea on how to ensure the stability of a quadcopter which is crucial when hovering. Table 2.3 shows the summary of the literatures used in this chapter.

Table 2.3 Summary of Literature Used in Chapter 2

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sensors and Sensor Fusion Algorithm | | | | | | | | |
| Author | Sensor Type | | Algorithm | | Application | Functionality | | Remarks |
| (Alatise & Hancke, 2020) | Tactile,  Encoder,  Optical,  Heading,  Vision-Based,  Active-Ranging | | Kalman,  Particle,  Bayesian Network,  Dempter-Shafer | | Autonomous Mobile Robot | Localization & Navigation | | This literature shows the suitable algorithm for different sensor combination |
| (Kocić et al., 2018) | Camera, Radar, Lidar | | PointFusion Network (CNN) | | Autonomous Vehicles | Localization & Mapping | | This literature uses CNN approach to fuse data and form 3D images |
| (Panem, Gaonkar, Rane, Pandit, & Gad, 2016) | Accelerometer,  Gyroscope | | Kalman’s Filter | | Quadcopter | Basic Sensor Data | | This literature aims to transmit data signal over wireless channels for optimum bandwidth utilization |
| (Sabatini & Genovese, 2014) | IMU, Baro-IMU | | Extended Kalman’s Filter | | Vertical Moving Rigid Body | Vertical Velocity,  height | | This literature studies the vertical movement of a rigid body using IMU and barometer fusion using EKF |
| (Wang et al., 2020) | RADAR, Camera, LiDAR, ultrasonic. GPS, IMU, V2X | | Discernible Unit,  Complementary Features, Target Attributes, Multi-source Decision | | Automated Driving | Object Detection and Recognition | | This literature discussed on various sensor configuration and its results. |
| (Yang et al., 2020) | IMU, GPS, Barometric Altimeter, Radio Altimeter | | Kalman’s Filter | | UAVs | Flight Altitude Data | | This literature uses 4 sensors fused using KF to measure the UAV height and provided some equations, then showed fusion result. |
| (Yeong et al., 2021) | Vision Cameras, LiDAR Sensors, Radar sensors | | Deep Learning (YOLO, SSD, VoxelNet, PointNet) | | Autonomous Vehicle | Surrounding Perception | | This literature shows the use of visual sensors for sensor fusion using deep learning algorithm for surrounding perception |
| Quadcopter Hovering | | | | | | | | |
| Author | | Sensors | | Microcontroller | | | Remark | |
| (Tagay et al., 2021) | | MPU6050 | | Arduino Uno R3 | | | Both studies use the same approach by using PID controller to ensure the stability of the quadcopter during hovering. | |
| (Sumantri et al., 2020) | | MPU6050  HC-SR04 | | STM32F103C8T6 | | |

# RESEARCH METHODOLOGY

## Introduction

In this chapter, the methods that will used for this project will be discussed in detailed. First or all, the project flow will be discussed from the point where the title of this project is decided, to the current state where we’ve focused on the literature, until the future planning where the continue will be continued for in the next semester. For this project titled ‘Sensor Fusion and PID Control for Quadcopter Hovering’, the research methodology will be divided into 3 parts which are: Sensor Fusion, PID Control and Quadcopter (assembly).

## Project Workflow and Gantt Chart

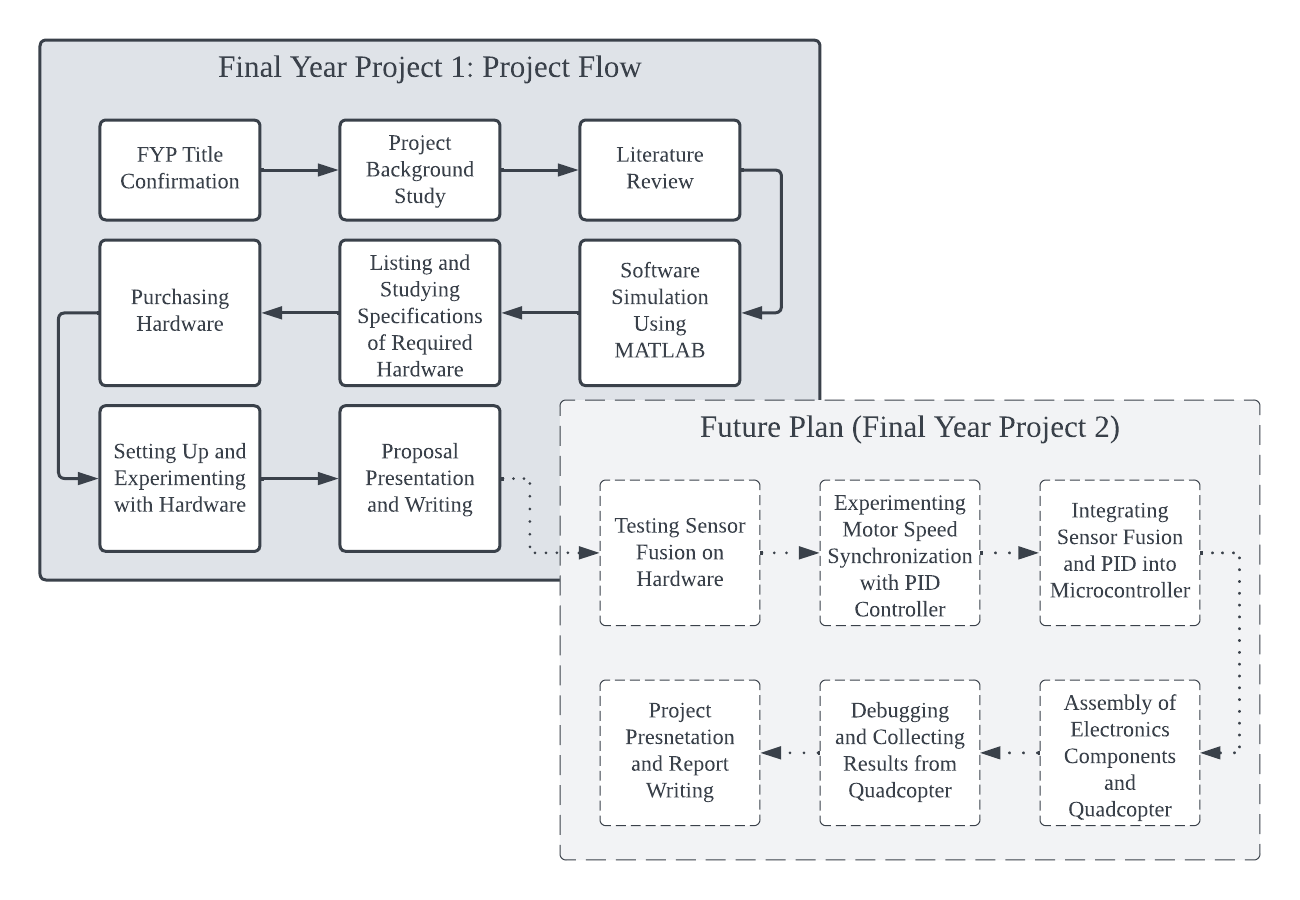


Figure . Project Workflow

Figure 3.1 shows the project flow from the beginning of Final Year Project (FYP) 1 to FYP 2. Multiple titles were provided by the supervisors from (Malaysia-Japan International Institute of Technology) MJIIT. As shown in the cover page, the title selected for the FYP is ‘Sensor Fusion and PID Control for Quadcopter Hovering’ under the supervision of Assoc. Prof. Dr. Shahrum Shah Bin Abdullah. The project first starts with the understanding of the project requirement, and identifying the objectives of the project. Then, multiple literatures were searched on various websites like Google Scholar, IEEE Explore, etc. Literatures are done by searching early studies on related topics and then looking into recent studies to find the research gap as well as referencing some methodologies on the research title. At the meantime, some simulations using software like MATLAB was done to get further understanding on the topic as well as validating the reliability of the other studies. After gaining some ideas from the literatures, the required hardware with their specification was listed down to ease the process of purchasing later. After the hardware had been purchased, the microcontrollers bought were being tested by booting up with their respective IDE and then writing simple programs on the other sensors to ensure they work as expected. Finally for this semester, the proposal was being written and the project idea will be presented to the panels.

Following that, FYP 2 will be mainly focusing on working on building the quadcopter. First of all, the sensor fusion performance will be tested with different sensors configurations and different sensor fusion algorithms. After getting a fairly good result from the sensor fusion part, the process will move on to working on the PID controller for the motors to stays synchronized to ensure the balance of the quadcopter when hovering. With that achieved, both sensor fusion and PID control will be integrated into the same microcontroller to hover at the specified height while maintaining the stability of the quadcopter. Then, the electronics component will be made permanent by either soldering to a stripboard or creating a PCB specific for the project. Finally, the performance and the results from the quadcopter is recorded for the purpose of report writing. During report writing and presentation, the future improvements will be discussed too. Figure 3.2 shows the working Gantt Chart for this project in FYP 1 stage.

Table 3.1 Gantt Chart for FYP 1

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Task | Oct 2023 | | | | Nov 2023 | | | Dec 2023 | | | | Jan 2024 | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Early Work Flow | | | | | | | | | | | | | | | | |
| 1 | Title Selection | ✓ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | Understanding of Project | ✓ | ✓ |  |  |  |  |  |  |  |  |  |  |  |  |
| Research Study and Literature Review | | | | | | | | | | | | | | | | |
| 3 | Sensor Fusion |  |  | ✓ | ✓ | ✓ |  |  |  |  |  |  |  |  |  |
| 4 | PID Controller |  |  |  |  |  | ✓ | ✓ | ✓ |  |  |  |  |  |  |
| 5 | Quadcopter/Drones |  |  |  |  |  |  |  |  | ✓ | ✓ |  |  |  |  |
| 6 | Software Simulation |  |  |  |  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |  |  |  |  |
| 7 | Purchasing Hardware |  |  |  |  |  |  |  |  |  | ✓ |  |  |  |  |
| 8 | Hardware Setup |  |  |  |  |  |  |  |  |  |  | ✓ | ✓ | ✓ | ✓ |
| Report Writing and Presentation | | | | | | | | | | | | | | | | |
| 9 | Logbook Writing |  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 10 | Report Writing |  |  |  |  | ✓ |  |  | ✓ |  | ✓ | ✓ | ✓ | ✓ |  |
| 11 | Panel Presentation |  |  |  |  |  |  |  |  |  |  |  |  |  | ✓ |

## Sensor Fusion

Sensor Fusion is the top focus for this project (including Sensor Fusion, PID Control and Quadcopter Hovering). For our project, the sensor fusion is applied for using multiple sensors in measuring the hovering height of the quadcopter. Figure 3.2 shows the block diagram from where the sensors measures the value of its distance from the ground to the point where the data from each sensor are being processed through sensor fusion algorithm. Finally, the result of the fused data is compared to the performance of each sensor working individually.

Before working on an actual hardware, the performance of sensor fusion is being simulated on MATLAB. For the simulation, an example provided by (MATHWORK, n.d.-a) titled “Pose Estimation From Asynchronous Sensors” is being

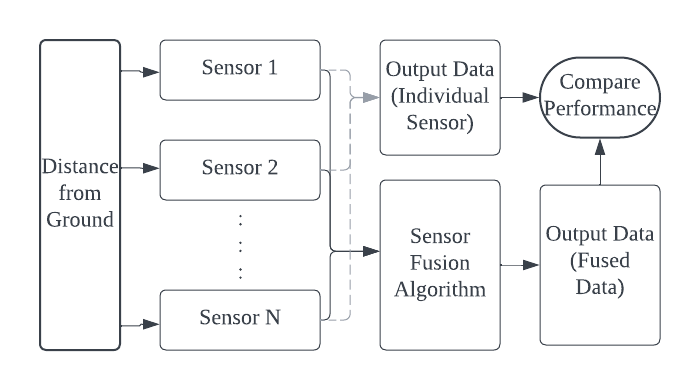


Figure . Sensor Fusion Block Diagram

executed on MATLAB R2021a. In order to run this example, ‘Sensor Fusion and Tracking Toolbox” version 2.1 is required to be installed into MATLAB’s add-ons. Figure 3.3 shows the webpage where the execution code can be copied. This example shows how a system predicts the orientation of an object by using different sensors through EKF algorithm. Options were given on how the fusion of 4 different sensors (accelerometer, gyroscope, magnetometer and GPS) to be done on our own choice, and each sensor’s sample rate can be preset. With this, the visualization of the error between the predicted orientation and the actual orientation of the object can be seen and thus gaining an intuitive view of the power of sensor fusion.

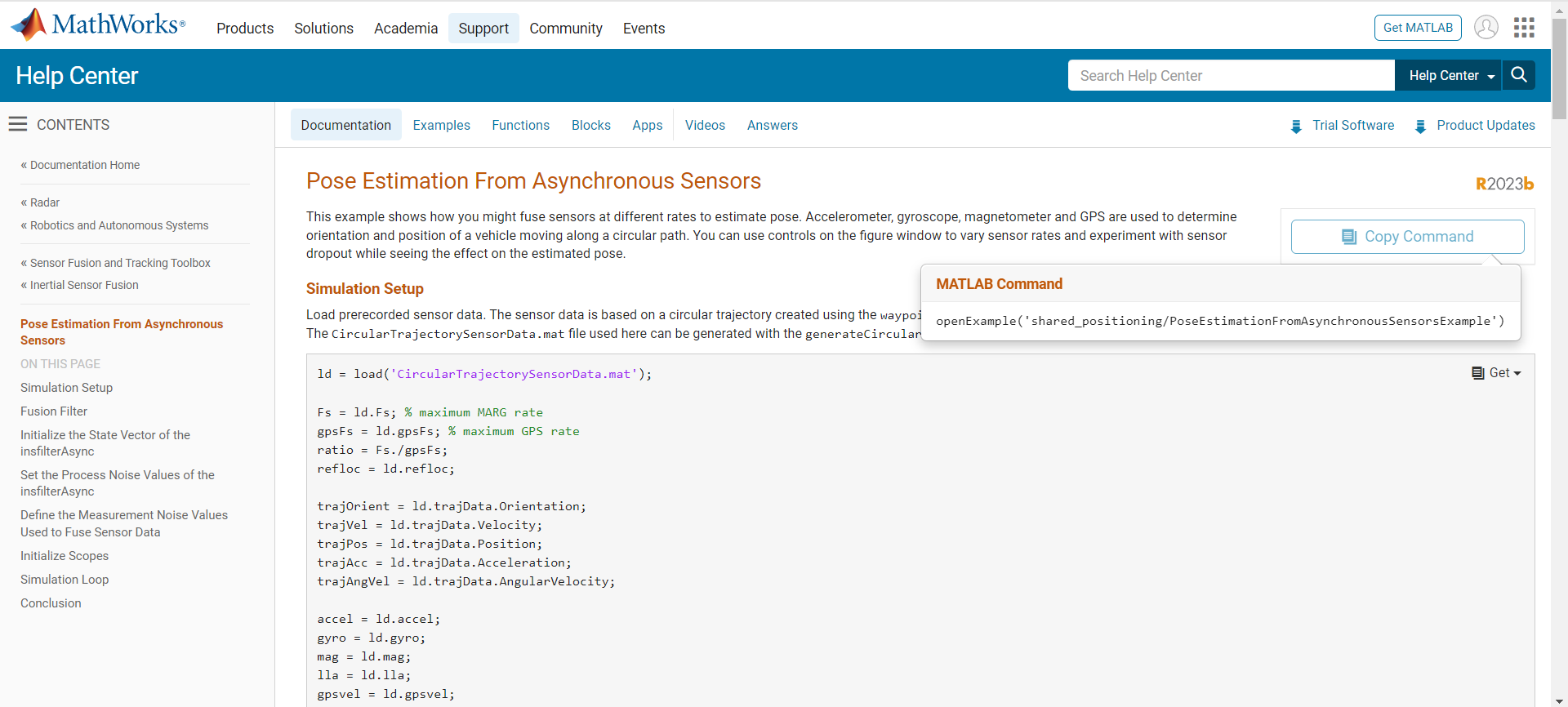


Figure . MATHWORKS Example Website

From Figure 3.2, it can be clearly seen that the types of hardware that will be used are various types of sensors that are able to measure its distance from ground, a microcontroller that will be able to fuse the data received from multiple sensors through the sensor fusion algorithm programmed into it and finally a computer or a display that is able to show and compare the output of the processed signal and the data received by the sensors individually. In Chapter 2, it was mentioned that (Alatise & Hancke, 2020) had made some studies on the types of sensor that are suitable for our use as shown in Table 2.1. At the moment, it is decided that optical sensors will be used for this project. The list and specification of the hardware that is decided to be used at the moment is as shown in Table 3.2.

Table 3.2 List of Proposed Hardware and Specification for Sensor Fusion

|  |  |  |  |
| --- | --- | --- | --- |
| Hardware | Image | Specification | Remarks |
| Sensors | | | |
| Analog Distance Sensor  GP2D120XJ00F |  | Range: 4cm to 30cm  Type: Infrared  Output Type: Analog Voltage  Operating Voltage: 4.5-5.5V | Shorter Range but Higher in Accuracy but susceptible to noise |
| Laser ToF Distance Sensor  VL53LOX |  | Range: 5cm to 120cm  Type: Infrared (Laser)  Interface: I2C  Operating Voltage: 3-5V | Longer Range but Lower in Accuracy but less susceptible to noise |
| Microcontrollers | | | |
| Arduino Uno R3  (ATMEGA-328P) |  | 14 Digital, 6 Analog I/O Pins  Supports I2C via Wire Lib  I/O Voltage: 5V  Clock Speed: 16MHz  SRAM: 2KB  FLASH: 32KB  EEPROM: 1KB | High Performance and easy to program, but Bulky in Size (Too Heavy for Flight) |
| ATTINY45-20PU |  | 6 GPIO  Supports I2C via TinyWire Lib  I/O Voltage: 2.7-5.5V  Clock Speed: 8MHz  SRAM: 256B  FLASH: 4KB  EEPROM: 256B | Light Weight and low power consumption, but limited pins, low processing power |

## PID Controller

The other focus of our project will be the PID Controller Part of the Quadcopter. The PID Controller is crucial to control 2 parameters in this project which are: Tilt and Height. PID controller can be intuitively visualized as:

1. Proportional (P): The proportional part can be imagined as ‘How quickly I want to get to the setpoint’. The larger the value for the P-gain, the quicker it wants to get to the setpoint but have a higher risk of overshooting and vice-versa. ‘P’ is usually thought as the present state of the system.
2. Integral (I): The integral part can be imagined as ‘The longer the time I am away from the setpoint, the quicker I want to get to it’. The larger the value of I-gain and the longer the time the object is away from the setpoint, the stronger the ‘force’ used to set the object to the setpoint. ‘I’ is usually thought as the past memory of the system.
3. Differential (D): The differential part can be imagined as ‘Slow down as I am getting closer to the setpoint’. The larger the value of D-gain, the stronger the damping effect as the object approaches the setpoint. However large D-gain may cause the system to be susceptible to noise. ‘D’ is usually thought as the future prediction of the system.

For simplicity purposes, since only the height of the quadcopter is our region of interest (ROI) only the Proportional and Differential part (I-gain set to 0) will be developed.

As mentioned in Chapter 2, even though the motor from the same manufacturer is being used, there will still be a slight difference in speed of their rotation despite same voltage is applied to it. Therefore, a PID Controller with integrated sensor is required to keep the tilt angle at 0 degree ideally. Besides, the hovering altitude of the quadcopter will also be controller with the PID Controller. Therefore, there will be 2 PID Controllers that’s involved in the system of the quadcopter as shown in Figure 3.4. The PID Controller that controls the tilt angle of the quadcopter receives input from the error between the reference tilt angle and the actual tilt angle; whereas the

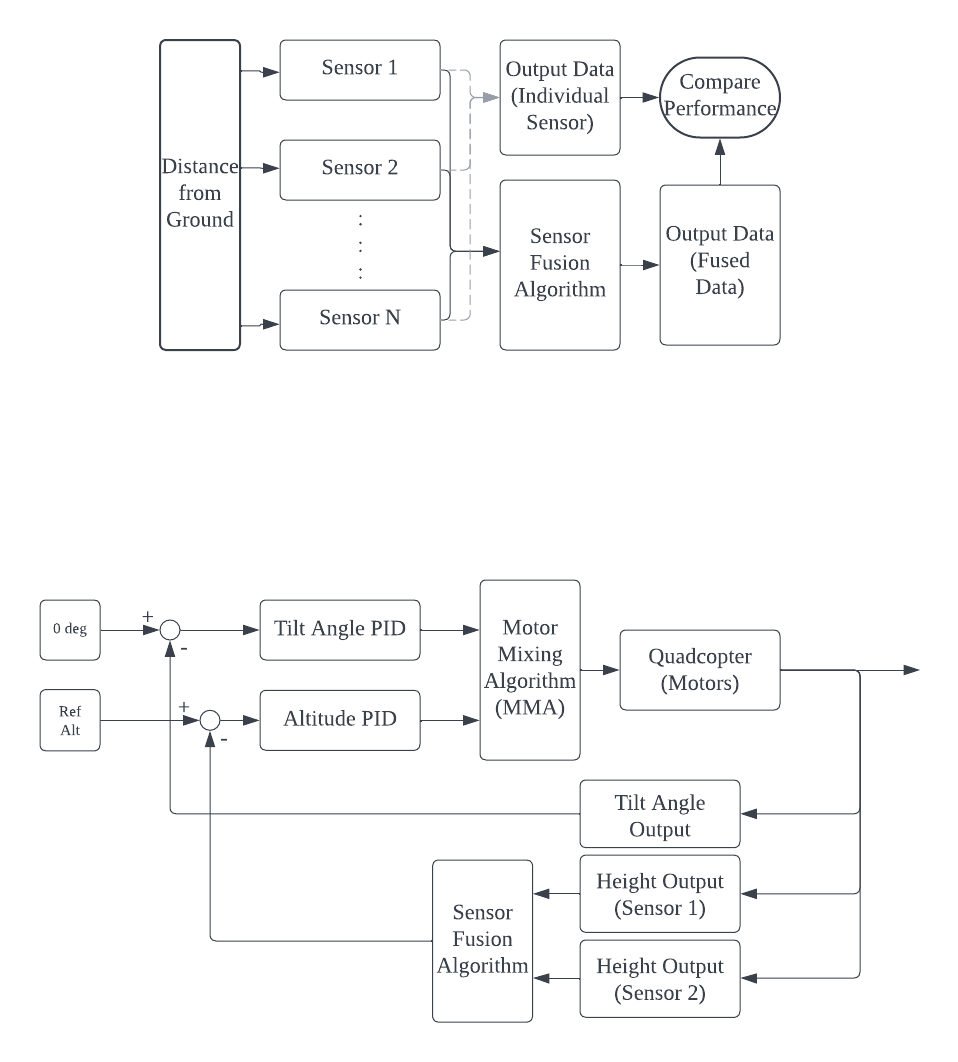


Figure . Block Diagram of Controller for Quadcopter

controller that controls the altitude of the quadcopter receives input from the error between the reference height and the fused sensor data. Then, the output from the 2 PID Controllers is then fed into the Motor Mixing Algorithm (MMA). The MMA is another controller unit that helps to convert human understandable commands like: ‘Increase/Decrease Thrust’ or ‘Roll Left/Right’ etc. to machine understandable instructions like: ‘increase/decrease duty cycle of both motors’ or ‘increase duty cycle of one motor and decrease duty cycle of the other motor’ etc. A simple diagram of a 2-propeller system that is free to translate in the z-axis (up-down) and free to rotate at the y-axis (pitch) together with its MMA is shown in Figure 3.5.

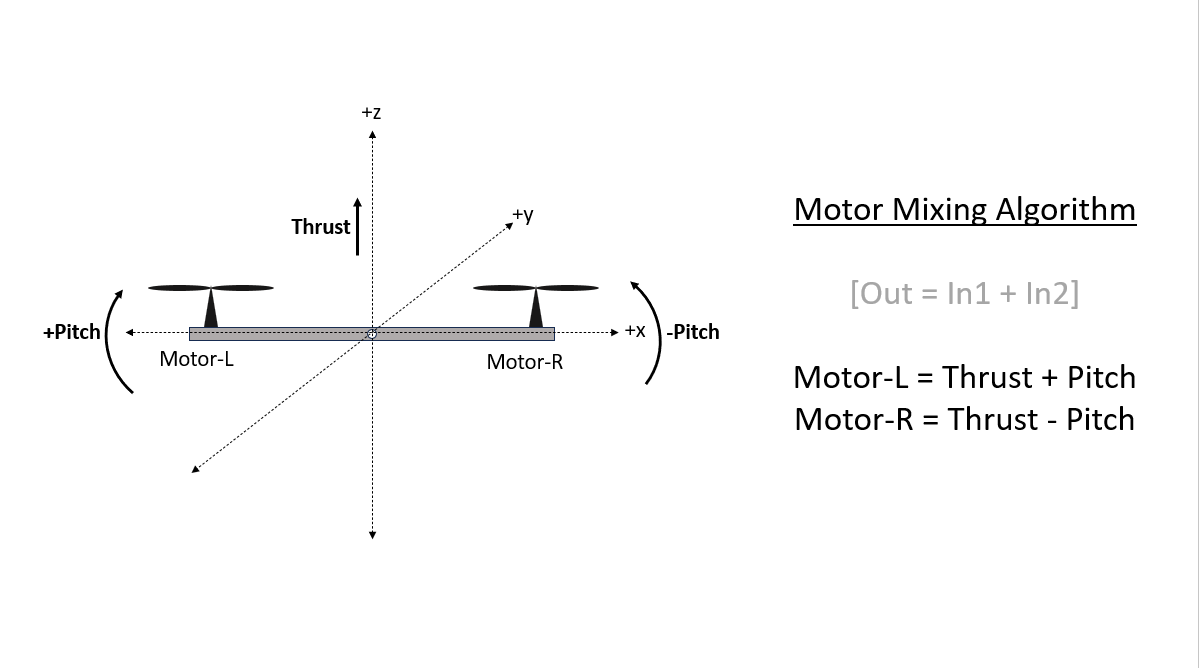
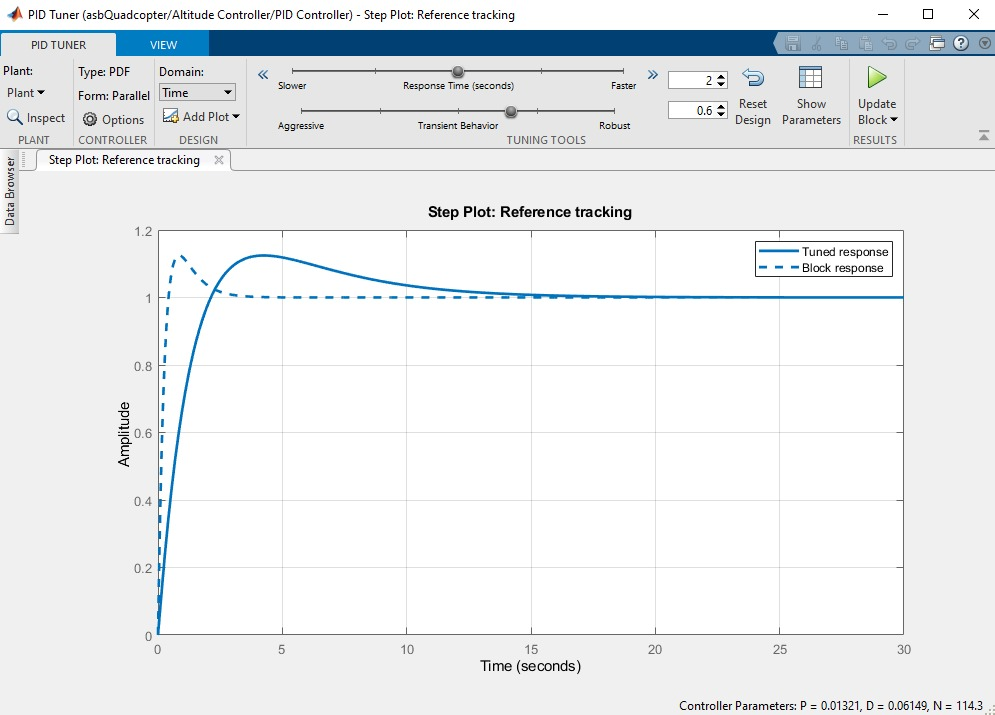


Figure . Motor Mixing Algorithm for 2-Propeller System

On the left of Figure 3.5 shows a 2-Propeller System in which its coordinate frame follows the convention of the right-hand rule; whereas on the right of Figure 3.5 shows the MMA in which how each motor (output speed) reacts to the thrust or pitch command (input voltage). For example, when the user intends to increase the altitude by increasing the thrust (in terms of voltage), both motor-L and motor-R will increase their speed together. On the other hand, when the sensor detects that the pitch angle is not 0 degrees and wants to rotate the system clockwise (positive pitch angle), motor-L will increase in speed; whereas motor-R will decrease in speed. The sensor that will be used to measure the tilt angle of the quadcopter is MPU6050.

Moving back to the PID Controller, determining the gain value of the PID controller is very important for maintaining the stability of the system and also helps to eliminate steady state error to a certain extend. For this project, the gain of the PID Controller will be simulated and tuned using a MATLAB Tool Box called Simulink Control Design Toolbox. This toolbox allows the tuning of a PID Controller gain in Simulink by looking at the system performance at real time. Figure 3.6 shows the interface for PID Tuning in MATLAB where the dotted line shows the current response of the system whereas the solid line shows the tuned response of the system after tunning the response time and transient behavior in the at the top of the interface.



System’s Response

Tuner

Figure . PID Tuner Interface

## Quadcopter Assembly

Finally, the final step of this project is to assemble all the components together into one piece. Since this project will only be focusing on hovering the quadcopter at a certain altitude, the structure of the quadcopter will only be made to allow its movement of vertical translation and pitch rotation. Hence, Yaw and Roll motion for the quadcopter will not be allowed by attaching the quadcopter to a vertical poll. It is also to note that the despite the ‘quadcopter’ is being called here, only 2 propellers will be used since 2 propellers is enough to maintain the altitude and the pitch angle of the so-called ‘quadcopter’ to reduce costing.

There are various electronics component required for the entire setup. The connections between all hardware are shown in Figure 3.7 and the list and specifications of the required hardware is shown in Table 3.3.

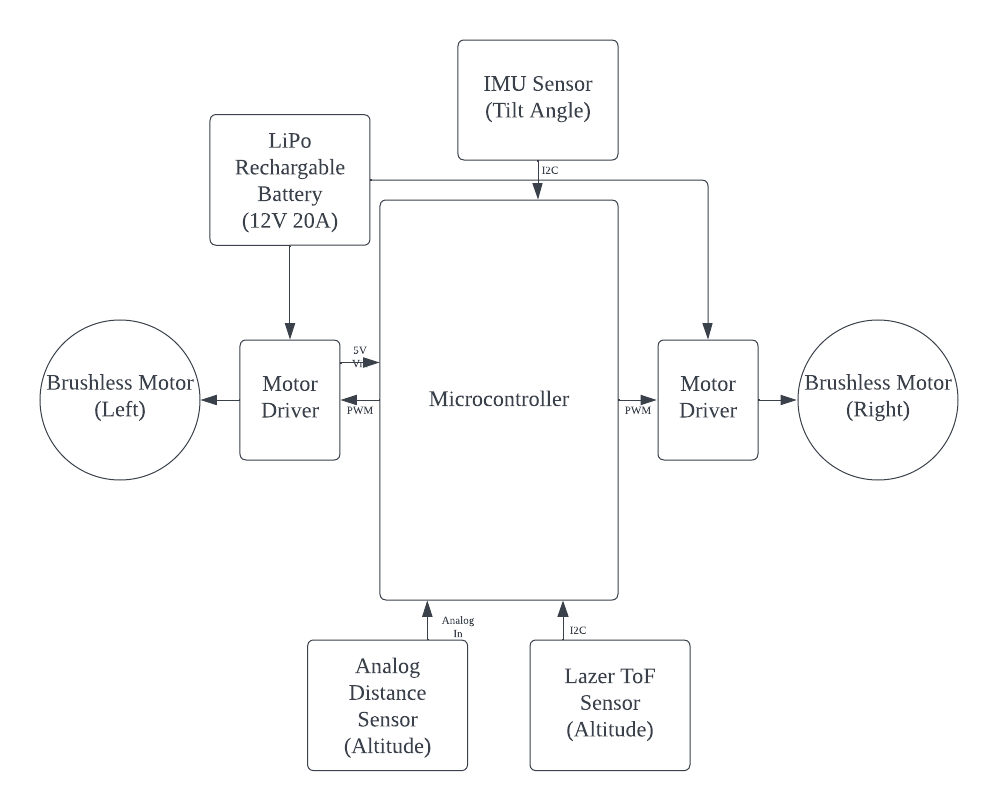


Figure . Circuit Connections between Hardware

Table 3.3 List of Hardware and Specification for Quadcopter Setup

|  |  |  |  |
| --- | --- | --- | --- |
| Hardware | Image | Specification | Remarks |
| Motors | | | |
| Brushless Motor A2212/10T c |  | Operating Voltage: 7-12V Kv Rating: 1400rpm/V Thrust: 900g Propeller Specs: 9” (5” Pitch) | 2 Motors will be needed with their propellers tilted at opposite angle |
| Motor Driver 30A BLDC ESC |  | Input Voltage: 7.4 – 14.8V 3 Phase Output for BLDC 5V, 2A output for Servo Connector | This is required by each motor but two of these can share the same power supply |
| Battery | | | |
| LiPo Battery 11.1V 1300mAH |  | Operating Voltage: 11.1V Capacity 1300mAH | One of this battery may run two motors for approx. 6 minutes |
| Lipo Battery 752025 |  | Operating Voltage: 3.7V Capacity 200mAH | This is a low-capacity battery and will be used to power up microcontrollers |
| Others | | | |
| Breadboard |  | 30 Rows Parallel Connection | PCB/Strip Board might be developed after testing |
| Jumper Wires |  | Male to Male Female to Male Female to Female | N/A |
| Quadcopter Frame | Refer  Figure 3.8 | Dimension: 40cm (L) x 3.6cm (W) x 0.5cm (H) | The quadcopter frame will be 3D Printed |

Besides of the Quadcopter itself, the structure for the quadcopter to be attached to so that it would not wander off during hovering (as the yaw and roll will not be programmed for this project). The diagram of the structure is shown in Figure 3.8 where the quadcopter body will be fixed to a vertical poll.

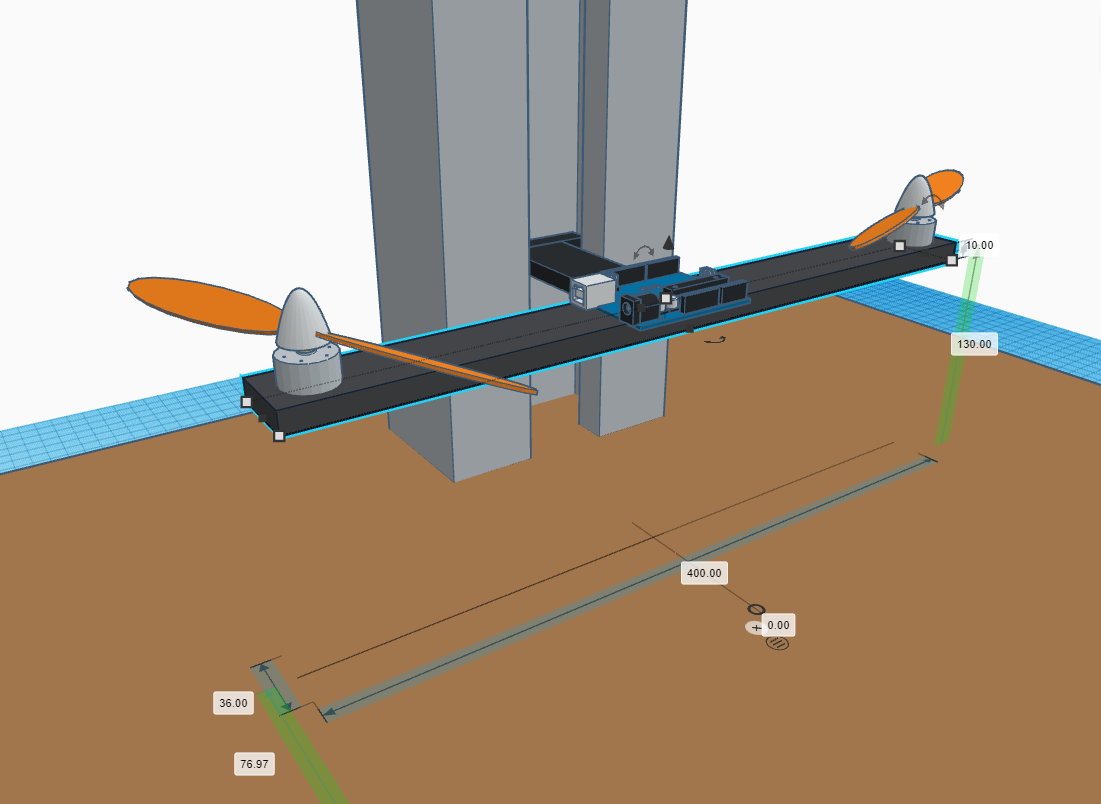


Figure . Structure of Project Setup

## Summary

In summary, this project extends throughout the 4th year of study which is then split into 2 parts: FYP 1 and FYP 2. FYP 1 mainly focuses on understanding of topics, studying literatures & research and planning through how the project will be done; whereas FYP 2 focuses on implementing that things that have been learnt and working towards the objective of this project. At the end of the project, a prototype quadcopter will be created.

The focus of this project is split into 3 parts: Sensor Fusion, PID Control and Quadcopter assembly. In the sensor fusion part, various sensor configuration will be tested with different algorithm to see which is best for estimating height of quadcopter. The PID Control part is basically the software part of this project where the PID will be tuned to ensure a stable hovering altitude and pitch angle. Finally, the electronic components required for this project is being researched and listed out in the Quadcopter assembly part.

# EXPEDTED / PRELIMINARY RESULTS

## Introduction

At this stage, various computer simulation had been done using MATLAB including the performance of Sensor Fusion using the available toolbox developed by people from the internet and also working on the PID Tuning using a model that resembles the actual environment that was also developed by other people. The purpose of doing this simulation is to build understanding on the sensor fusion method and visualize how the quality of the sensor data had been improved compared to using sensors individually. Besides, although tuning the PID Controller using models from other people may not be 100 percent accurate, however it will still give a good initial start when selecting the PID gain and also having a better understanding by visualizing how the gain of for the ‘P’ value and the gain ‘D’ affects the performance of the system without the need to go through a lot of manual calculations.

## Sensor Fusion Performance

Two sensor fusion simulations were done using MATLAB’s example for different applications. The first sensor fusion simulation is done using the ‘Tracking Maneuvering Targets’ by (MATHWORK, n.d.-c) which is used to track the position of an object. This example uses Interacting Motion-Model (IMM) Filtering method.

The second sensor fusion simulation is done using the ‘Pose Estimation From Asynchronous Sensors’ also by (MATHWORK, n.d.-b) which is used to see the how the system predicts its position and orientation using various sensor configuration. This example uses EKF filtering as the sensor fusion algorithm.

### Tracking Maneuvering Targets

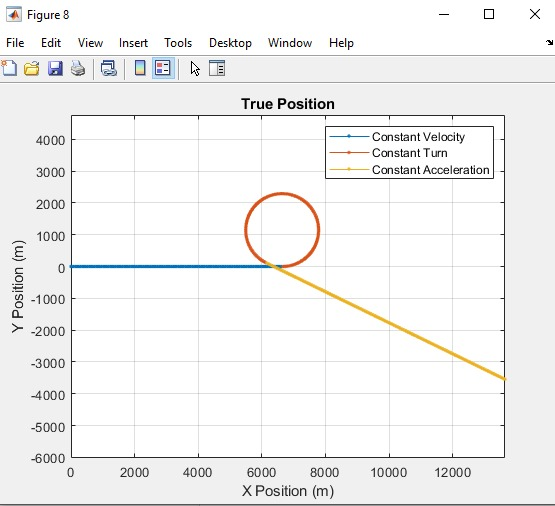


Figure . Motion of Tracked Object

Figure 4.1 shows the actual motion of an object that is going to be tracked by the system’s sensor. The blue line shows the motion where the object is moving at a constant velocity in the positive-x direction. The orange line shows the motion of the object where it is making a turn with a constant angular velocity. The yellow line shows the motion where the object is doing a constant deceleration in the positive-x direction and constant acceleration in the negative-y direction.

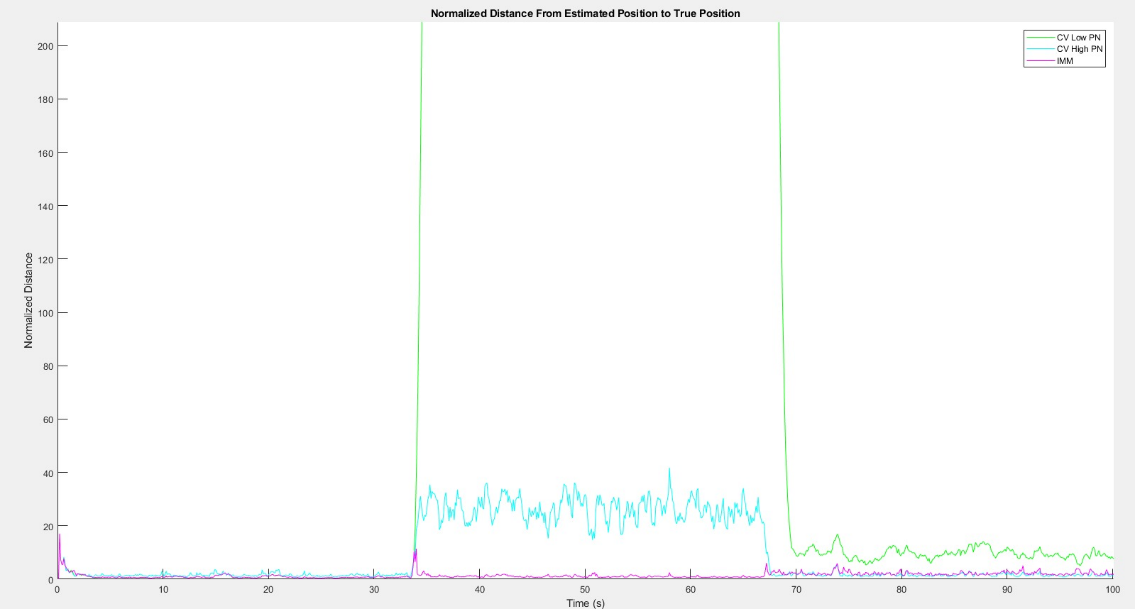


Figure . Normalized Distance from Estimated Position to True Position

Figure 4.2 shows the normalized distance (error) between the estimated position of the object and the actual position of the object. The system has a model which acts as an ‘observer’ which is a sensor to detect the position of an object and another model which acts as an ‘estimator’ which is a prediction system to predict the next state (location) of the object, and the model is very accurate at estimating an object moving at a constant velocity.

In Figure 4.2, the green line shows a model that relies more to the system’s estimator that makes estimations based on the previous data samples. Meanwhile, the blue line shows a model that relies more to the sensor data. At the x-axis of Figure 4.2, we can see that the ‘estimator does a good job measuring constant velocity until time, t <= 35s; whereas there are some noisy signals from the ‘observer’. Next, when the object is making a constant turn from time, 35s < t <= 70s, the error made by ‘estimator’ shoots up to a very large value but the error from ‘observer’ just increased to approximately 30. Finally, when the object is moving at constant acceleration at t > 70s, the ‘estimator’ is still giving off some noise; whereas the ‘observer’ is also doing a great job.

By observation, we can see that the ‘estimator’ produces a smoother signal with less error when an object is moving at a constant velocity. However, it is not very suitable to be used if the object is having a changing velocity. On the other hand, the ‘observer’ is performing quite well to determine the position of the object with just slight error during constant turn, however the signal is quite noisy during constant velocity movement. In contrast, when IMM is applied (purple line), the error produced for all 3 motion significantly dropped. IMM uses an algorithm to determine the confidence level that should be given to the ‘observer’ and the ‘estimator’. It is also observed that the error produced by IMM is even much lower compared when using each model individually.

This simulation shows that a system that is working with multiple model which have their unique performance at different scenarios is a better method than working relying on single model. This is because it does not only choose the model with the lower error, but even produces a result that is better than any of the models.

### Pose Estimation from Asynchronous Sensors

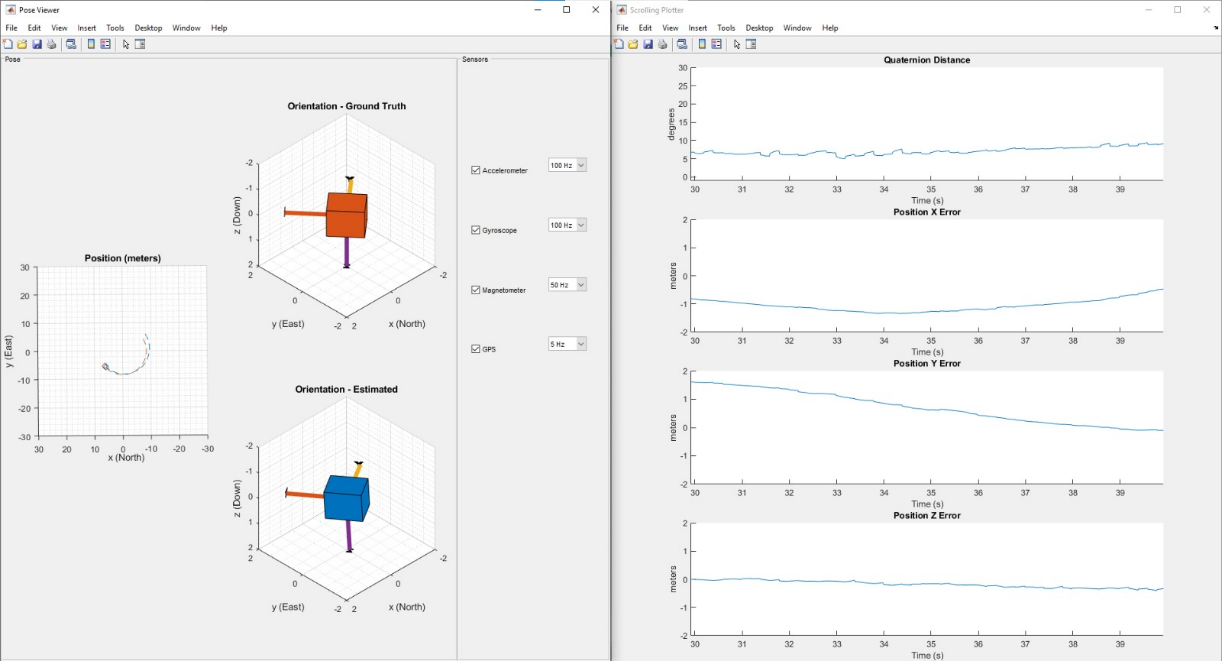


Figure . Pose Estimation using 4 Sensors

Figure 4.3 shows a simulation where 4 sensors are being used to measure the orientation and position of a body that is rotating and revolving at the same time. On the most left, the orange line shows the actual position of an object and the blue line shows the estimated position of an object based on the sensor’s data. Similarly, the orange body shows the actual orientation of an object whereas the blue body shows the estimated orientation of the object.

This simulation allows the user to select the types of sensors to be integrated to the system and varies its sample rate. The 4 sensors used in this system are an accelerometer which is good for measuring the direction of acceleration of a body, a gyroscope which good for measuring the angular rate of a body, a magnetometer which is good for measuring the orientation of a body in a magnetic field, and finally GPS which is good for measuring the position of a body.

Referring to the graph on the right, when all sensors are being selected, the system is performing quite well on determining the position and orientation of the body with very little error.

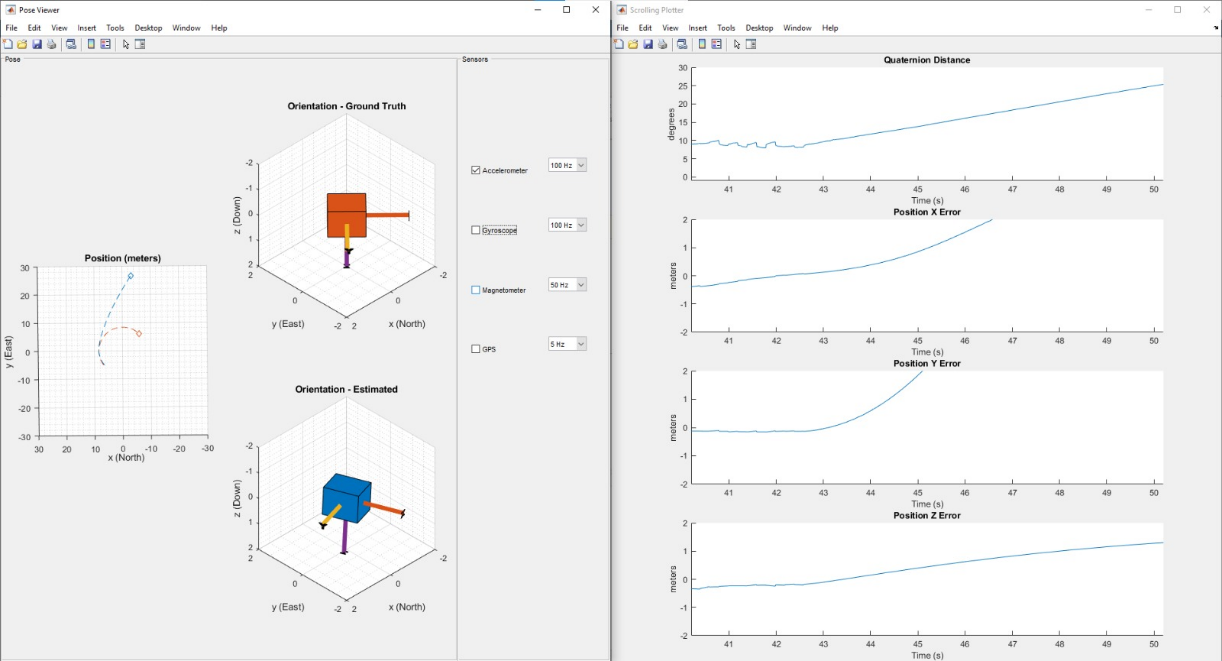


Figure . Pose Estimation with Accelerometer

Figure 4.4 shows when only accelerometer is selected for pose estimation. From the right, the figure shows that as the other sensors are being deselected, the error for all calculations goes up drastically. Due to the fact the accelerometer is only good for measuring the direction of acceleration of the body, hence when other sensors are being turned off, the accelerometer continues to predict that the body is accelerating in one direction and hence it is shown in the most left coordinates that the sensor estimates that the body is moving in a straight line.

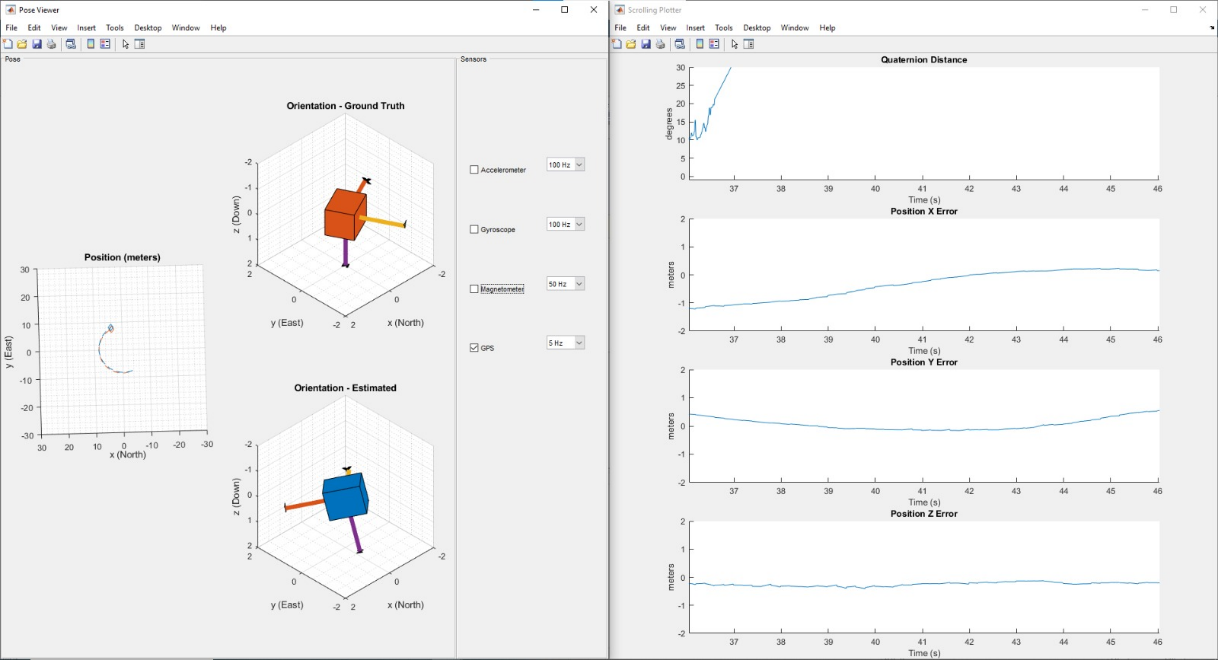


Figure . Pose Estimation with GPS

Figure 4.5 shows when only GPS is selected for pose estimation. From the right, it is shown that as all the other sensors except GPS is being selected, the error for the quaternion distance goes up drastically. It is known that GPS sensor is good for measuring the position of an object, thus it can be seen from the left that sensor does a good job estimating the position of the object but the it did not do a good job estimating the orientation of the object.

This simulation had shown a system can measure and estimate more than one variable like orientation and position by integrating multiple sensors into it.

## PID Tuning

The PID Tuning for this project is done using MATLAB Simulink Control Design toolbox together with a readily model of the quadcopter generated from MATLAB Aerospace Toolbox as shown in Figure 4.6. The model contains the flight-code which is labeled as FCS1 and the rest are the model simulator which contains the airframe of the quadcopter, the environment model etc. However, due to the fact that the environment model does not simulate any disturbance that will affect the pitch angle of the quadcopter, the initial PID gain value will be used directly from flight code and the value will be tuned once the hardware is built.

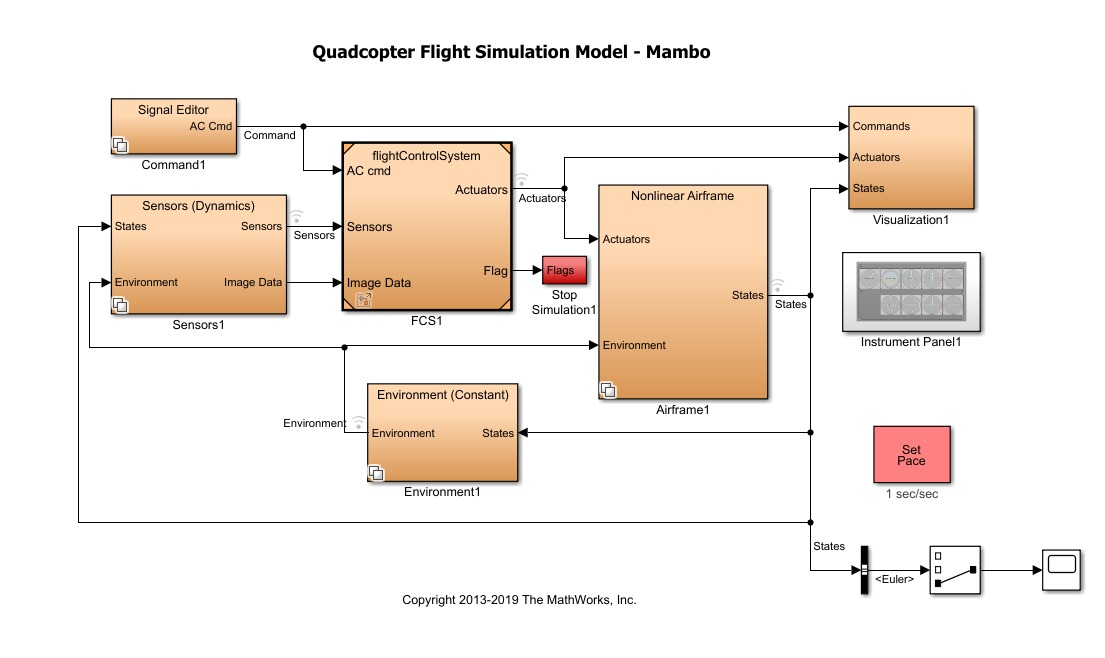


Figure . Quadcopter Flight Simulation Model for Parrot Mambo

On the other hand, since the airframe model contains all the information about the dynamics of the quadcopter such as its mass and inertia, the model can be used to tune the PID gain value for the altitude of the quadcopter. Figure 4.7 shows the model which had been modified specifically for tuning of the PID controller for the quadcopter’s altitude.

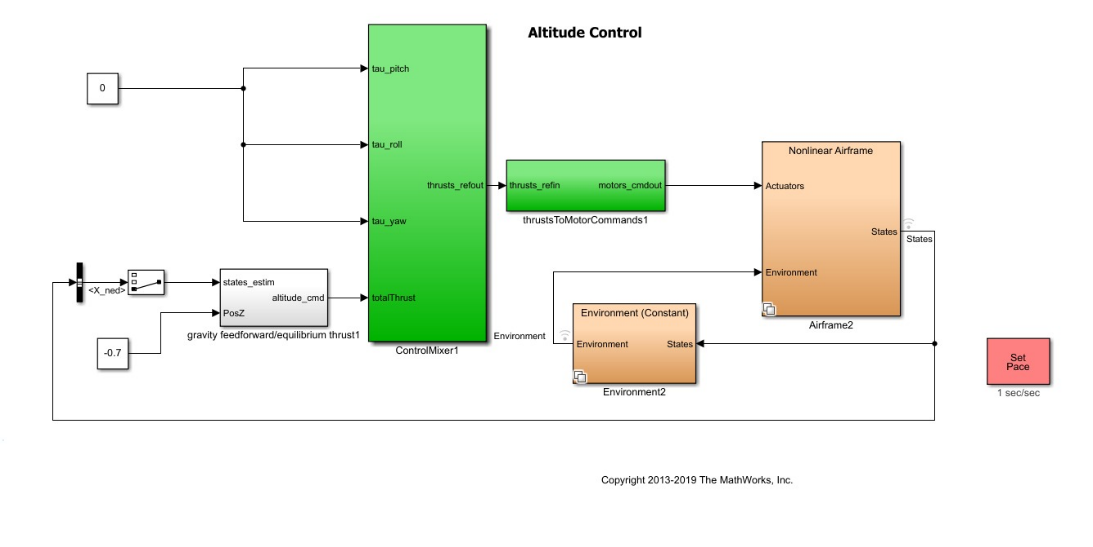


Figure . Modified Model for Altitude PID Tuning

Figure 4.7 shows the model that is modified by extracting the altitude controller block from the FCS1 (Flight Code). From the ColtrolMixer1, it can be seen that besides the roll and yaw roll which is outside our scope of interest, the pitch control is also set to 0 so that when doing the PID tuning for altitude will not be affected from the other motions of the quadcopter. The PID Control for the altitude tuning is placed inside the block of ‘gravity feedforward/equilibrium thrust1’ as shown in Figure 4.8.

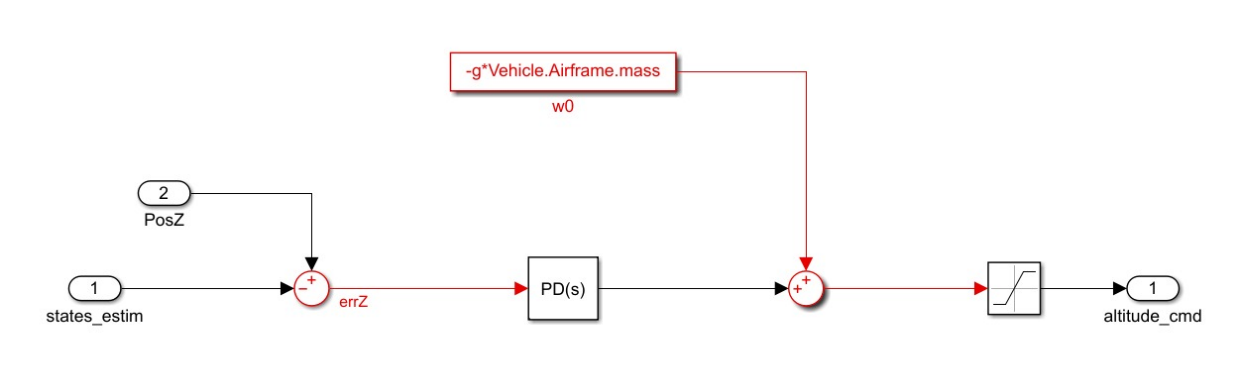


Figure . Block Diagram of PID Control for Altitude Measurement

By using the Simulink Control Design tool box, the response of the system is tuned in the way that the quadcopter will get to the referenced altitude as quickly as possible but does not overshoot too much as shown in the dotted line from Figure 4.9. The solid line is the tuned system where the quadcopter will reach the reference altitude in 1 second with slight overshoot then goes back to the position slowly.

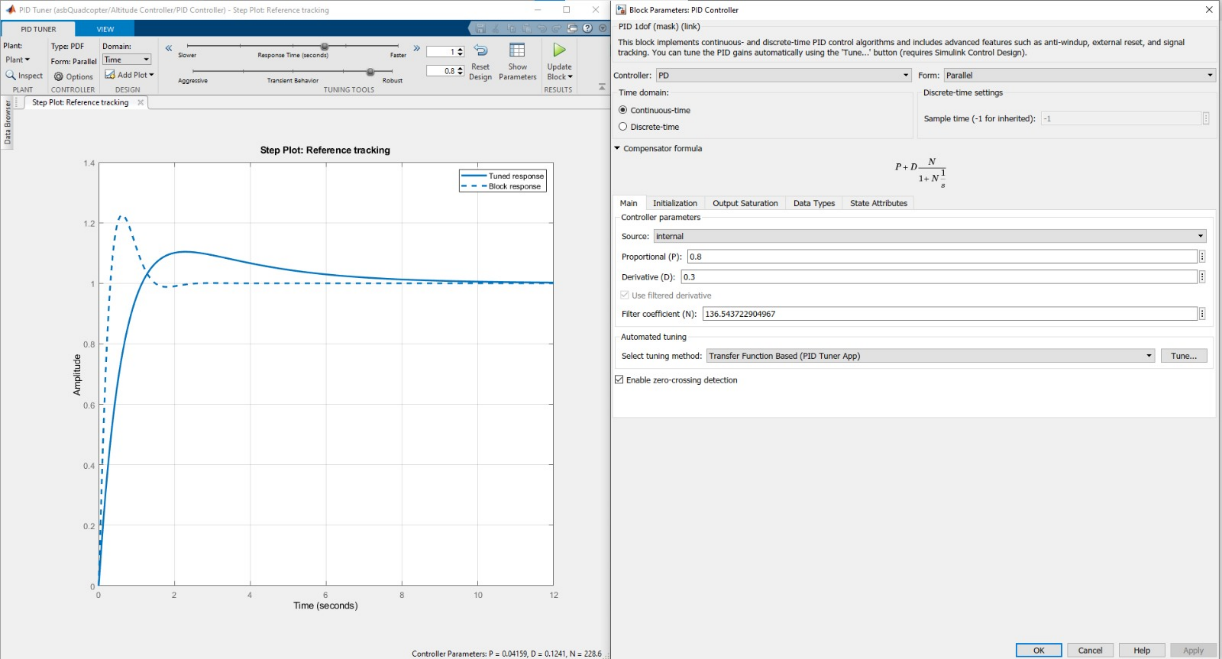


Figure . PID Tuning for Altitude

Table 4.1 shows the initial PID Values that will be used for controlling the quadcopter’s altitude and tilt angle. The values will be used as a starting point especially for the tilt angle as the modal being simulated is not same as what will be built later in this project, thus further tuning is required after the hardware is built.

Table 4.1 Initial PID Values for Quadcopter

|  |  |  |
| --- | --- | --- |
| Parameter | Proportional Gain, Kp | Differential Gain, Kd |
| Altitude | 0.04159 | 0.1241 |
| Tilt Angle (Pitch) | 0.013 | 0.002 |

# CONCLUSION

## Proposal Outcomes

In summary, this paper proposed an idea of building a quadcopter that integrates two sensors onto it through a fusion algorithm to measure its hovering height and maintain its height from the given reference point using a PID Controller. The aim of this project is to see the performance of sensor fusion in an actual hardware and see if sensor fusion improves accuracy of the system to measure distance of object outside the sensor’s range.

After doing some literatures, sensor fusion through simulation using available MATLAB examples had given a good picture on the improved in performance in terms of reducing the error of measurements from the sensors and also improves the functionality of the system by giving it the ability to measure the parameters outside the sensor’s ability individually. Besides, the preliminary tuning for the PID Controller had also been done through a MATLAB simulation using a model designed for simulating quadcopter.

## Continuation of Project

This paper marks the 50 percent milestone of the entire project in which the understanding for this topic is completed to a certain extend with some computer simulations preliminary results. In the next half of this project, the hardware of the quadcopter will be built using actual sensors, motors, microcontrollers, etc. based on the knowledge acquired until now. It is also to note that only a single axis quadcopter, which means 2 motors with a single bar frame will be built and will be attached to a vertical pole. This is because the aim of this project is only to control the hovering and doing so can prolong battery life and reduce costing.

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